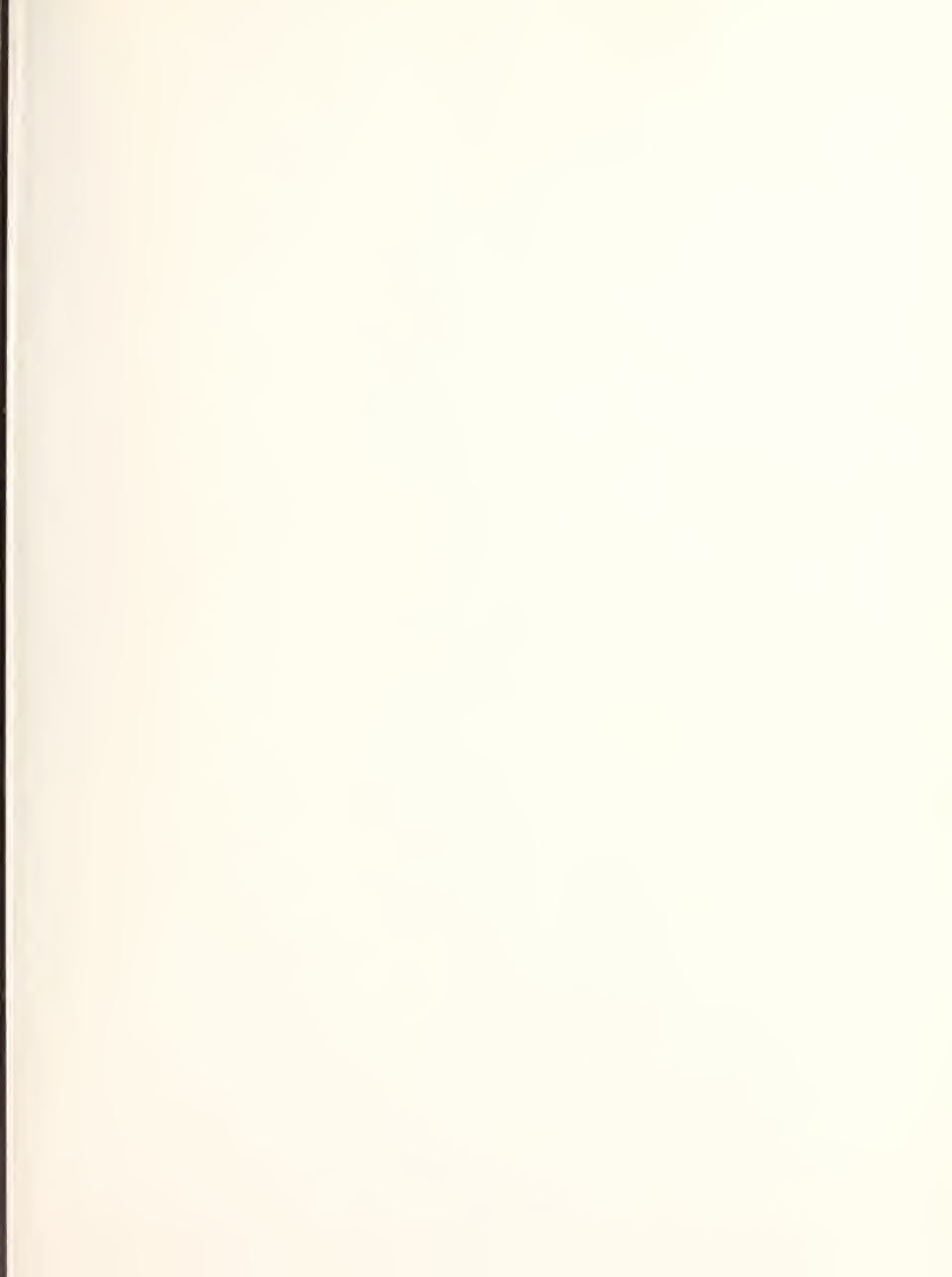DEPARTMENT
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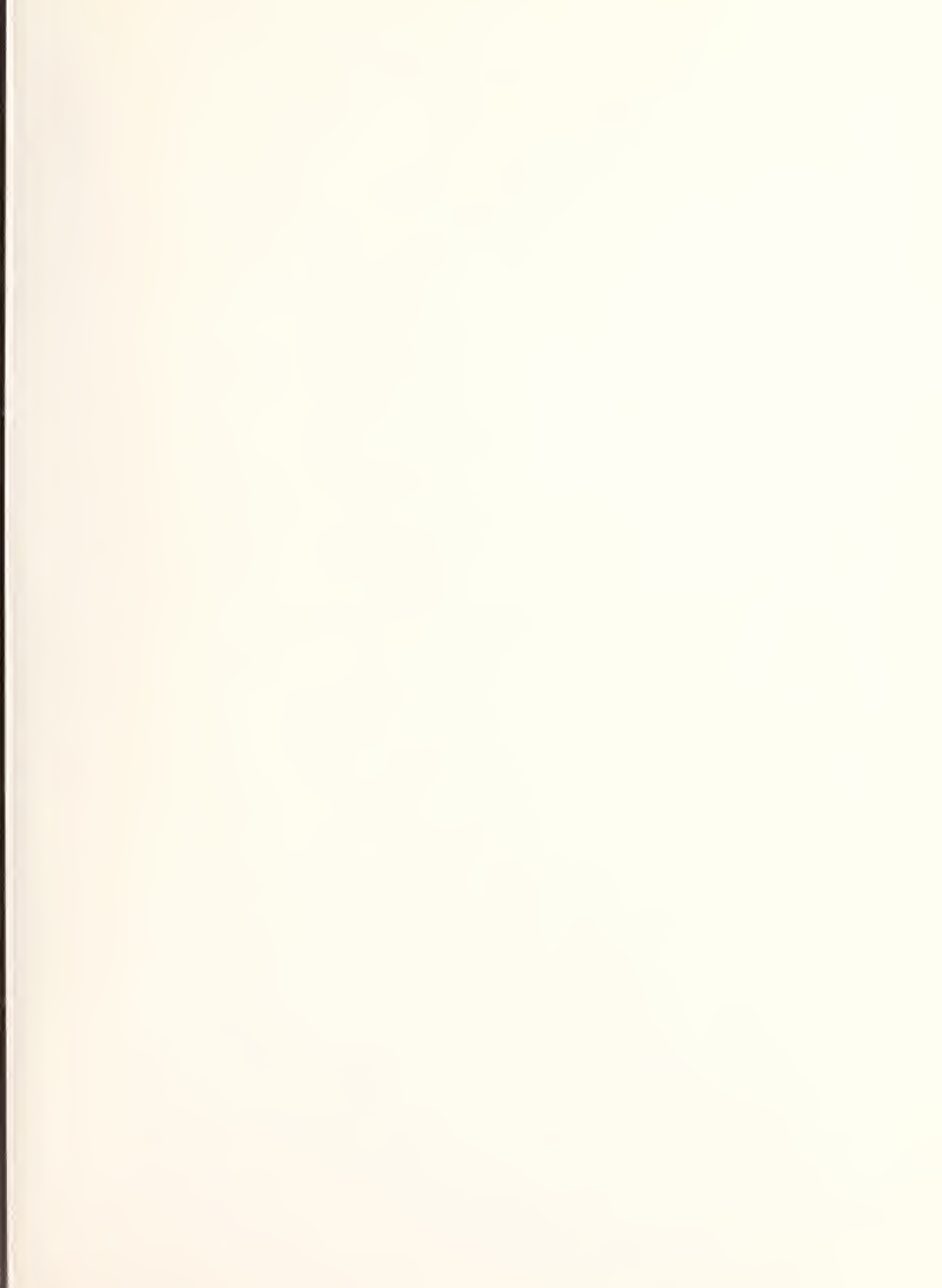NATIONAL
BUREAU
OF
STANDARDS

NOS. 265, 267 - 270

Dimensional Metrology

Subject-Classified With Abstracts

Through 1964

Including linear, angular, and geometrical measurement and in-process control of size and form, but generally not including gages, gaging, and inspection as to limits of size.

Compiled by

Irvin H. Fullmer

Abstract

This bibliography covers two of the three principal divisions of dimensional metrology, namely (1) linear, angular, and geometrical measurements of solid bodies, and (2) in-process control of sizes. The remaining division is gages, gaging, and inspection as to specified limits of size. There are about 3,600 references classified under main subject headings in 12 sections, which are further subdivided into 102 subsections covering 100 subjects. The 12 main subjects are (1) general metrology, physical and dimensional; (2) length and diameter measurements by interferometry; (3) length and diameter measurements by mechanical methods; (4) calibration of line standards of length, including tapes; (5) dimensional measuring instrument design features; (6) angle measurement; (7) measurements of deviations from geometrical regularity; (8) measurement of profile; (9) measurement of screw threads; (10) measurement of gears; (11) measurement of thickness of thin films; and (12) measurement and production techniques for accurate in-process control of size and form. The references in each subsection are arranged chronologically and a brief abstract of each is given with few exceptions. The bibliography is an attempt to organize and make more readily available the extensive existing knowledge in the field covered.

Foreword

In the manufacture of modern machines and instruments, an indispensable requirement is the control of the dimensions of parts to within specified tolerances. Such control makes possible the interchangeability of parts produced in different localities; it also is essential to the proper functioning and reliability of the final assembly.

Various methods are used to achieve dimensional control. They include (1) control by the production machine or process; (2) application of statistical methods of quality control, which involve measurement of samples of parts taken at intervals; and (3) the gaging of in-process or finished parts by means of fixed or indicating gages. All such methods of control require that measurements of the gages or product be made. Thus the underlying basis of such control is the selection and application of measuring techniques whose accuracy is compatible with the gage or product tolerances.

This bibliography has been compiled to facilitate the application of existing knowledge regarding measuring methods and equipment. In particular, it is designed to further the development of a series of American Standards by Sectional Commitee B89 on Dimensional Metrology, organized under the procedure of the American Standards Association and sponsored by The American Society of Mechanical Engineers. Although the literature of dimensional metrology is extensive in the areas of gaging methods and gages, the present publication, consisting of about 3,600 references, is mostly limited to dimensional measurement that yields numerical results.

A. V. Astin, *Director.*

Preface

The arrangement of this bibliography was determined by the nature of the subject matter treated. A strictly chronological arrangement of all entries would have required an extensive subject index, which was considered economically impracticable for such a broad subject. Instead, the entries are grouped into sections according to the principal subject treated in each case, and a brief abstract of each entry is given.

There are 12 major sections, which are further subdivided into 102 subsections covering 100 subjects. Within each subsection, the references are arranged chronologically, so that a reading of the successive abstracts will yield a fairly comprehensive picture of the historical development of each subject. There is some, but not extensive, cross-referencing.

The order of the sections has only slight relation to their importance. The first section is general and therefore introductory. The section on interferometry is placed next because the international standard of length is now a wavelength of light from a krypton 86 lamp. From the point of view of historical development, section 4 might have been the second section, followed by section 3.

The compiler has not indicated in detail the sources of the abstracts, of which he prepared about 25 percent. He gratefully offers the following acknowledgments with respect to assistance and sources:

To the Engineering Index, Inc., New York, for about 50 percent of the references and abstracts which were copied, by permission, directly from the numerous volumes of the Engineering Index.

To Physics Abstracts, London, as the source of about 25 percent of the abstracts.

To Dr. Lewis V. Judson, Physicist, NBS (now retired), who had compiled lists of early references which are embodied in section 4 and subsection 6.4.

To Dr. Werner F. Vogel, Engineering Advisor, NBS (Professor Emeritus of Engineering Mechanics, Wayne State University, Detroit), for suggestions relative to arrangement and content, particularly with reference to sections 9 and 10.

To Dr. Erwin G. Loewen, Bausch and Lomb, Inc., who furnished a list of references not otherwise available to the compiler.

To the secretarial staff of the Engineering Metrology Section, NBS, who over many years prepared an extensive card file on this and other subjects of interest to the Section, and for typing and duplicating services.

How To Use This Book

If you are looking for references on a particular topic: First consult the table of contents and find the subsection that covers your topic. (If the topic is a broad one or is not well defined, it may take more than one subsection to cover it adequately.) Then turn to the page number indicated, where you will find the references of that subsection listed in the order of their dates of publication.

If you are looking for publications by a particular author: First consult the author index at the back of the book, where all publications included in this bibliography are listed under the author's name, by subsection number and year of publication. You can then find the references you need by consulting the page numbers given.

If there are a great many publications by a single author, you may be able to select those most likely to interest you on the basis of their subsection numbers (which indicate the topics) and years of publication.

A considerable number (a minority) of the papers listed herein are in a file at the Engineering Meteorology Section, NBS, which is keyed to this publication. When articles are not otherwise available to the reader this file may be consulted. Advance arrangement to do so is desirable. Also, authors are invited to send reprints for inclusion in this file.

Further hints on the use of the book may be obtained by reading the preface. Also, note the list of abbreviations that follows.

Bibliographic Abbreviations

AAAS_____ American Association for the Advance-
ment of Science
Abh_____ Abhandlung(en)
Acad_____ academie, academy
AGMA_____ American Gear Manufacturers Associ-
ation.
Agric_____ agricultural
AIEE_____ American Institute of Electrical
Engineers
Akad_____ Akademie, akademii
Am_____ American
An_____ anales
Analyt_____ analytical
Angew_____ angewandte
Ann_____ annales
Annu_____ annuaire
AOA_____ American Ordnance Association
App_____ applied
Arch_____ architectural
ASA_____ American Standards Association
ASHRAE_____ American Society of Heating, Refriger-
ating, and Air Conditioning Engineers
ASME_____ The American Society of Mechanical En-
gineers
Assn_____ association
ASTM_____ American Society for Testing and
Materials
ASTME_____ American Society of Tool and Manufac-
turing Engineers
Astron_____ astronomical, astronomische
Astrophys_____ astrophysical, astrophysics
Austral_____ Australian
Automat_____ automation
Ber_____ Berichte
BIPM_____ International Bureau of Weights and
Measures
Bldg_____ building
Brit_____ British
Bros_____ brothers
BS_____ British Standard
Bul_____ bulletin
Bur_____ bureau
Can_____ Canadian
Cer_____ ceramic
Chem_____ chemical, chemistry
Chim_____ Chimie, chimique
Cir_____ circular
Civ_____ civil
Co_____ company
Conf_____ conference
Constr_____ constructional
Corp_____ corporation
CP_____ circular pitch
CR_____ comptes rendus
Dept_____ department
DIN_____ German Engineering Standard
Div_____ division
Dokl_____ doklady
DP_____ diametral pitch
Ed_____ edition
Elec_____ electric, electrical
Elecn_____ electrician
Eng_____ engineering (British Periodical)
Engr(s)_____ engineer(s) (British Periodical)
Exper_____ experimental
Fiz_____ fizika, fiziki

FoKoMa_____ Fertigungstechnisches Forschungs- und
Konstruktions-Kolloquium Werkzeug-
Maschinen und Betriebswissenschaft
Fortschr_____ Fortschritte
Found_____ foundation
Gaz_____ gazette
GB_____ Great Britain
Gen_____ general, generale
Geol_____ geological
Geophys_____ geophysics, geophysical
Ges_____ Gesellschaft
GOST_____ Russian All-Union State Standard
Gov_____ government
Handb_____ handbook
Handl_____ Handlungen
Högsk_____ högskolans
IEEE_____ Institute of Electrical and Electronic
Engineers
Illum_____ illuminating
IMS_____ Industrial Mathematics Society
Inc_____ incorporated
Indus_____ industrial, industrielle, industries
Ing_____ Ingenieur
Inst(s)_____ institut, institute(s)
Instn_____ institution
Instrum(s)_____ instrument(s)
InstrumKde____ Instrumentenkunde
Int_____ international
IRE_____ Institute of Radio Engineers
ISA_____ Instrument Society of America
ISO_____ International Organization for Stand-
ardization
Izmer Tekh_____ izmeritel'naya tekhnika
Izv_____ izvestiya
J_____ journal
K_____ kungliga
Lab(s)_____ laboratory(ies)
Ltd_____ limited
Mach_____ machinist
Machy_____ machinery
Mag_____ magazine
Mar _____ marine
Math_____ mathematical
Matl(s)_____ material(s)
Meas_____ measurement
Mech_____ mechanical
Mem_____ memoirs, mémoires
Memo_____ memorandum
Met_____ metallurgical, metallurgy
Mfg_____ manufacturing
Mfr(s) _____ manufacturer(s)
Mgmt_____ management
Mil_____ military
Min_____ mining
Misc_____ miscellaneous
Mitt_____ Mitteilungen
Mod_____ modern
Monogr_____ monograph
Mun_____ municipal
Nachr_____ Nachrichten
NASA_____ National Aeronautics and Space Admin-
istration
Nat_____ national
Naut_____ nautical
NBS_____ National Bureau of Standards
NPL_____ National Physical Laboratory, Great
Britain

CONTENTS

*One or more additional references relating to this subject are given in the Addendum at the end of the section.

Section 1. General Metrology, Physical and Dimensional

CONTENTS

1.1. General Physical Metrology

The Progress of Science as Exemplified in the Art of Weighing and Measuring, PROF. Wm. HARKNESS, U.S. Naval Observatory. Presidential address before the Philosophical Society of Washington, 1887. Smithsonian Report, 1888, or Bul of the Phil Soc of Washington v10 1887 p 39–86 67 refs. Historical paper dealing partly with length standards.

The Theory of Measurement, A deF. PALMER. McGraw-Hill Book Co. 1912 248 p. Chapters 1–7 deal with the general principles that underlie all measurements, nature and distribution of errors, and most probable result; 8–12, precision of measurements; 13, methods of physical research.

The Theory of Measurements, L. TUTTLE. Jefferson Laboratory of Physics, Philadelphia. 1916 303 p. Some chapter heading are: Angles and circular functions, significant figures, coordinates in three dimensions, accuracy, the principle of coincidence, measurements and errors, indirect measurements, systematic and constant errors. Republished in expanded form, 1925, Tuttle and Satterly.

Mensuration for Marine and Mechanical Engineers, J. W. ANGLES. Longmans, Green and Co. London 1919 162 p. Collection of formulas and tables; elements of trigonometry; lengths, taper, speed; areas of rectilinear figures; areas of circle and ellipse; surfaces, volumes, weights; surface and volume of cylinder, displacement; the cone and sphere; similar figures, Simpson's rule; weights of machinery.

Metrology in the Industries, Proc Phys Soc of London Meeting of Mar 28, 1919 29 p 3 figs. A general discussion initiated by Sir R. T. Glazebrook.

The International Bureau of Weights and Measures, J. BOYER. Sci Am Monthly v3 n2 Feb 1921 p 105–9 7 illus. An interview with Charles Edouard Guillaume, director.

Bibliography for Measuring Instruments, with Special Reference to Instruments and Methods of Metrology used in Mechanical Engineering, F. J. SCHLINK. J Opt Soc Am and Rev Sci Instrum v9 Sept 1924 p 309–21. Bibliog-

raphy classified under the following heads: 1. General material, theoretical or basic, on physical and mechanical instruments. 2. Measurement and production of small linear and angular displacements and distances. 3. Theory and measurement of vibration; measurement of speeds and time intervals. 4. Frictional and other types of hysteresis and their relation to instrument design and testing; accuracy, sensitivity and variance. 5. Dynamometers, measurement of force (except weighing scales), torque, and accellerations. 6. Measurement and control of temperature and humidity. 7. Weighing scales. 8. Pressure gages, manometers, and aneroid barometers. 9. Engine indicators. 10. Properties and design of springs. 11. Miscellaneous instruments.

History of the Standard Weights and Measures of the United States, L. A. FISCHER. NBS Misc Publ n64 1925 34 p. Paper contains a series of photographs of important standards, both ancient and modern.

Metorology, W. BLOCK. Eng Progr, v6 Sept 1925 p 283–5 4 figs. Its definition, significance, and fields of application.

Precision Measurements, G. BERNDT. Eng Progr v6 Sept 1925 p 289–91 4 figs. Their significance and utility in engineering; examples taken from machine construction and instrument making, illustrating great savings achieved by applying precision measuring.

Measurement and Calculation, N. R. CAMPBELL. Longmans, Green and Co., Ltd. 1928 293 p. Chapter headings are: the laws of measurement, number, numerical laws, derived measurement, classification of magnitudes, standards and factors, errors of measurement, errors of numerical laws, calculation, and argument from dimensions.

Experimental Mechanical Engineering, 1, Engineering Instruments, H. DIEDERICHS AND W. C. ANDRAE. 1930 John Wiley & Sons, Inc. 1082 p. illus. diagrs., charts, tables. Rewritten text based upon Carpenter and Diederich's "Experimental Engineering," for students and practicing engineers; construction, calibration, and use of instruments for measuring length, etc.; methods in use

described, theory explained and commercial forms of instruments presented. Eng. Soc. Library, N.Y.

ATM Archiv für Technisches Messen, R. OLDENBOURG Lieferungen 4–12 Nov–June 1932 Munich and Berlin, 222 p. illus. diagrs. charts tables. Compendium of measuring instruments and methods intending to cover, in 5 vols., whole field of technical measurements; parts are issued monthly, but may be bought singly; each contains concise 2 to 4-page reviews of dozen instruments or methods, accompanied by references to sources from which account was compiled. Eng. Soc. Library, N.Y.

Introduction à l'Étude de la Metrologie Industrielle, P. NICOLAU. Mécanique v20 n269 Nov–Dec 1936 p 235–45. Introduction to study of industrial measurements; biographical report and cross-sectional view of technique employed in mechanical engineering.

Pruefen und Messen als Voraussetzung technischer Fortschritts, C. RAMSAUER. VDI Zeit v80 n48 Nov 28 1936 p 1429–32. Testing and measurements as prerequisites of technique in engineering progress; author points to role which precision measurements play in modern engineering, and discusses various fields of application in mechanical engineering, aviation, welding, electrical engineering and in factories.

Limits of Measurability. W. GERLACH. VDI Zeit v81 Jan 2 1937 p 2–7. The author presents a general review of the importance of precision in measurement and outlines the methods by which the limits of measurability have been extended. Examples are given of the application of physical laws to this end, e.g., the application of the theory of interference colours to the determination of thickness. Atomic physics and the quantum theory have extended the attainable limits. The reaction of the measured quantity on the measuring device often imposes a limit on direct measurements. The influence of the Brownian movement is discussed and illustrated in relation to the measurement of very small amounts of energy; and the measurement of atomic magnitudes is discussed.

Tolerances and Their Effect on Physical Measurements, C. DARWIN. Light and Lighting v37 n6 June 1944 p 86; Engrs' Digest (Am Ed) v1 n11 Oct 1944 p 616–8. Author emphasizes that tolerances has become respectable part, not only of engineering practice, but also of fundamental science; among examples cited are manufacture of machine for weighing bullets, theory of sound, and optical measurements; Uncertainty Principle as limitation to tolerances in nature. From address before Illuminating Engineering Soc.

Effect of Tolerances on Measurements, C. DARWIN. Metal Progr v47 n5 May 1945 p 941–6. Discussion of examples showing allowable tolerances, limitations and physical measurements, including importance of subject of errors and tolerances in relation to foundations of physics.

Metrologie Générale (Grandeurs et Unités), M. DENIS-PAPIN, J. VALLOT. Dunod, Paris, 1946 428 p plates I–XLVI tables diagrs. charts. Discussion of measurement in general, international system of weights and measures, and symbols and equations of fundamental systems of measurement; methods of measurement and units described for fields of geometry, geography, mechanics, angular measure, stresses, electricity and magnetism, heat and radiant energy, optics and time as well as for everyday use. Eng. Soc. Library, N.Y.

A Discussion of Units and Standards, Staff of NPL. Proc. Royal Soc A v186 21 Mar 1946 p 149–217 6 figs refs. A discussion of 10 types of physical standards.

Symposium on Metrology, J. C. EVANS, Eng v161 n4189 Apr 26 1946 p 401–2; Nature (London) v157 n3991 Apr 27

1946 p 538–40. Review of symposium held at Royal Society, of short papers dealing with principal units and standards of scientific measurement, read by Director, D. Darwin, and members of staff of National Physical Laboratory.

Training In Inspection and Gaging In Mechanical Engineering, R. L. GEER. Instrum v19 n12 Dec 1946 p 726–8. Need in mechanical engineering curriculum of study of precision measuring techniques; origin and development of course in measuring instruments for Sibley School of Mechanical Engineering, Cornell Univ. is discussed; program of lesson topics of course is outlined in detail.

Fundamental Concepts of the Technique of Measurement. J. HARTMANN, Rev Sci Paris v85 Apr 1 1947 p 323–4 in French. The idea of measurement as a production, analogous to an industrial production, of which the product is an image in figures of the property measured, is developed. The terms, uncertainty (incertitude), error (faute). tolerance, in relation to the production, and indeterminacy, falsification, in relation to the product, are clearly defined. The relationships between these are explained and illustrated by examples. It is shown that the uncertainty of production is manifested by the indeterminacy of the product, i.e. by oscillatory deviations from a mean value, whereas the error of production is manifested by the falsification of the product, i.e. by a unilateral deviation.

Limit of Sensitivity, J. L. VAN SOEST, J. L. BORDEWIJK. Tijdschrift van het Nederlandsch Radiogenootschap v12 May 1947 p 113–23 in Dutch. A general discussion of sensitivity of measurement and restrictions on the accuracy of measuring instruments and scale readings.

Metrologie, son Origine, son Évolution, A. C. PRULIERE. Microtecnic v1 n3 June 1947 p 126–32 (English translation in separate section p 54–7). Origin and development of metrology; data on metric system and length standards; review of work done in field of metrology in United States, England, France, Germany and Switzerland. Bibliography.

Precision Measurement Methods and Formulas, J. JOHNSON. Pitman Publ Corp, New York and London, 1948 181 p diagrs tables, Bridging gap between "school" mathematics and practical application theory, book presents actual problems and their solutions; overall theory behind solution is shown; solutions are for greater part based on setups requiring simplest of instruments; no special ability other than knowing how to use trigonometric tables is necessary. Eng. Soc. Library, N.Y.

Some Applications of Electronics in Metrology, E. J. B. WILLEY. Sci Progr v36 Jan 1948 p 55–65 4 figs 18 refs. A short review article. Electrical gages, surface meters, vibration and acceleration meters, strain gages and ultrasonic thickness meters and flaw detectors are touched on.

Instruments, Physics, and Physicists, G. F. GARDNER. Gen Elec Rev v51 n10 Oct 1948 p 11–3. Good measuring instrument is essentially conveniently arranged physics experiment that can be repeated at will within specified accuracy limits; historical examples of instrument development or invention are given.

Messung und Darstellung physikalisch-technischer Groessen, W. SPAETH. VDI Zeit v91 n18 Sept 15 1949 p 471–5. Measurement and presentation of physical-technical quantities; relation between two coordinates; practical examples include time and reciprocal of time, hardness and softness, stability limit of rivets, frictional phenomena, coefficient of expansion and melting point, and applications in Bessemer converter. Bibliography.

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Coup d'Oeil sur la Situation de la Métrologie Industrielle dans le Monde, M. CHALVET. Rev. Gen de Mécanique v34 n13 Jan 1950 p 18–25. Outline of world status of industrial metrology; historical background; types of measuring apparatus; gages, comparators, interferometers, etc; illustrations.

Neue optische Messgeraete fuer Werkstueck- und Werkstoffpruefungen, A. METZ. VDI Zeit v92 n13 May 1 1950 p. 323–31. New optical measuring instruments for testing of workpieces and materials; different types of microscopes.

Atomic Definition of Primary Standards, R. D. HUNTOON, U. FANO. Nature (London) v166 n4213 July 29 1950 p 167–8. In view of limits to accuracy with which one can compare any physical quantity with primary standards, possibility of selecting other quantities to serve in place of present primary standards, such as immutable properties of atoms or molecules with which other physical quantities can be readily and accurately compared, is considered; set of working definitions consistent with latest values of atomic constants are atomic meter, second, ampere, Newton, Coloumb, and kilogram.

Handbook of Measurement and Control, M. F. BEHAR, editor. The Instrum Publ Co. Pittsburgh 1951 291 p. Classisification; measurables, effects and methods; static measuring properties; the response; the prime relay.

Changes of State Caused by the Process of Measurement, G. LUDERS. Ann Phys Leipzig. v8 n5–8 1951 p 322–9 in German. A treatment by v. Neumann (Mathematische Grundlagen der Quantenmechanik, 1932) is critically discussed and an alternative treatment introduced, which permits of a fuller discussion of the concept of the compatibility of measurements.

Units and Standards of Measurement Employed at the National Physical Laboratory. I. Length, Mass, Time; Volume, Density and Specific Gravity, Force and Pressure, Dep of Sci and Indus Res. London, H.M. Stationery Office 1951 12 p. This pamphlet describes the standards of the three fundamental units of measurement, and definitions of them are given in the international Metric and British Imperial Systems. The derived units are also described, and the values of the standards and bases of measurement employed in work involving these units are given. The absolute value of the acceleration due to gravity at the Laboratory is included.

Recent Developments and Techniques in the Maintenance of Standards, London, H. M. Stationery Office 1952 100 p. Proceedings of a symposium held at the N P L on 21st and 22nd May 1951. Reported in Nature (London) v168 Oct 6 1951 p 594–7.

Fluctuation Theory in Physical Measurements, C. W. McCOMBIE. Rep Progr Phys v16 1953 p 266–320. An attempt is made to give a coherent, elementary account of the ways in which fluctuation theory has been applied to some of the simpler types of physical measurement. Uncertainties in measurements involving suspended systems are discussed on the basis of simple correlation function arguments, and consideration is given to the methods of measurement appropriate when there are various practical limitations on the parameters of the suspended system. There follows an elementary development of the mathematical and physical considerations usually employed in treating fluctuations in linear measuring instruments; remarks on the status of the random force method as applied to equilibrium systems are included. The circumstances under which there is an absolute limit to the attainable accuracy are discussed. It is shown that, in the case of measurements with a suspended system, feedback may enable these limits to be attained with a convenient measurement procedure. An account is given

of various approaches to the calculation of the limits of accuracy in measurements with radiation detectors. Finally some elementary results are established concerning the optimum characteristics of an instrument used to follow a varying signal in the presence of noise. 78 refs.

Instrument Engineering. v2: Methods for Associating Mathematical Solutions with Common Forms, C. S. DRAPER, W. McKAY, S. LEES. McGraw-Hill Book Co., New York, 1st ed. 1953. 827 p. Continuing presentation of generalized method of attack on problems of measurement and control, volume reviews mathematical background and illustrates procedures by actual derivation of quantitative results. Eng. Soc. Library, N.Y.

Metrology and the Classification of Measuring Apparatus, A. MOLES. Ann Telecomm v8 July 1953 p 250–3 In French. The precise function of measuring apparatus as transducers of information is recalled and discussed. The distinction between recording and measuring is emphasized, and the information obtained by Fourier and similar analyses of records is briefly discussed. It is shown that the field of measuring apparatus is limited and in the physical domain is defined by three factors, the scales of frequency f_{max}/f_{min}, amplitude A_{max}/A_{min}, and precision ϖ. By means of a three-dimensional diagram [diagramme d'equarissage] with coordinates $\log A$, $\log f$, and ϖ the various instruments are classified according to their particular technical field and usefulness.

Pratical Calibration Adjustments for Apparatus Which Obeys a Theoretical Law Imperfectly, J. W. HEAD, Electronics Eng v25 Dec 1953 p 499–501. Various empirical methods of adjustment are considered. The nature of the adjustment achieved is fully explained. The object throughout has been to obtain easily a calibration curve which is sufficiently smooth and sufficiently near the observed values to satisfy practical requirements, rather than to find the unique curve which satisfies a least-squares or other mathematical criterion of goodness of fit.

Concepts in Measurement, D. J. MONTGOMERY. J ISA v1 n11 Nov 1954 p 51–3. Analysis of some of concepts in physical measurement illustrating modern work in philosophy of science and its applicability to problems in instrumentation; example of measurement of temperature by means of mercury thermometer, and of measurement of average cross-section area of non-uniform filament by means of vibroscope.

The Language of Instrument Calibration and Performance, K. M. GREENLAND. J Sci Instrum v33 n7 July 1956 p 249–54. A critical discussion is presented of the terms used in describing the establishment of instrument scales and the performance of measuring instruments. Examination of a number of vocabularies and of unrecorded usage shows that many of the important terms have more than one meaning. Arguments are put forward in support of certain unique definitions consistent, wherever possible, with the original sense of the words. The discussion takes as a basis the new definitive glossary compiled by the British Standards Institution (B.S. 2643: 1955).

Some Principles of Measurement and Control, J. F. COALES. J Sci Instrum v33 n12 Dec 1956 p 457–64. Measurements can be divided into two broad classes: those which only have to be observed and recorded and those which are used to control sources of power in order to change some quantity such as position, speed, temperature or pressure. In both cases the principles are the same: there are certain limitations from which all measuring instruments suffer, e.g. they all disturb the physical system on which the measurements are being made and they all have inertia and damping to some degree. Also, no measuring instrument is completely stable and all exhibit unwanted fluctuations if the sensitivity is increased to the limit of usefulness. These limitations are

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discussed together with the principles underlying the design of measuring systems to reduce their effect to a minimum. The simple theory of linear control systems is developed, and it is shown that the only real difference between measuring systems and control systems lies in the magnitude of the power required at the output. Negative feedback in a closed-loop system is shown to be the equivalent of the restoring force in an open-loop system.

Precise Measurements of the Density of Mercury at 20° C. I. Absolute Displacement Method, A. H. COOK, N. W. B. STONE. Phil Trans A v250 Nov 28 1957 p 279–323. The densities of four samples of mercury at 20° C were measured by finding the mass of mercury displaced by an accurately formed cube of known volume that just sinks in mercury. The cube is of tungsten carbide and was lapped to such an accurate form and good surface finish that the standard deviation of the volume of mercury displaced, as calculated from optical interference measurements of the dimensions of the cube, is 0.15 parts per million. The weight of mercury displaced had an uncertainty of 0.28 ppm but the uncertainty of the density at 20° C is increased by errors of temperature measurement and the effects of residual grease films on the cube to up to 1 ppm. The mean density at 20° C and 1 atm pressure of four samples of mercury from different sources is 13.545 892 g/cm^3, the range of the four values being 1.1 ppm. The corresponding value at 0° C is 13.595 086 g/cm^3. The purification, chemical analysis and determination of the isotopic constitution of the samples are carefully discussed.

Optics in Metrology, P. MOLLET. Pergamon Press 1960 436 p. Colloquia of the Int. Commission for Optics, 6–9 May 1958. A compendium of 59 papers in three languages.

Bases of Measurement, H. BARRELL. Instn Prod Engrs J v37 n1 Jan 1958 p 3–18 (discussion) 19–35; Mass Prod v33 n12 Dec 1957 p 59–65, 120. How standards are compared; comparing end standards by contact measurement in measuring machines; comparison of primary standards of mass; defining standard of time or frequency; 1,200-ton compression machine being used for calibrating 135-ton load standard by buildup from three 50-ton standards.

Classification and Nomenclature for Standards of Measurement, A. G. McNISH, NBS. IRE Trans on Instrumentation v7 n3 and 4 Dec 1958 p 371–8. Definitions of units and standards, classification of standards, orders in the prototype category, orders in other categories, nomenclature for other laboratories.

Measurement: Definitions and Theories, C. W. CHURCHMAN, P. RATOOSH. John Wiley & Sons, Inc. 274 p. New York. 1959. I. Some meanings of Measurement. II. Some theories of Measurement. III. Some problems in the physical sciences. IV. Some problems in the social sciences.

Length and Time in the Problem Range of the Physikalisch-Technischen Bundesanstalt (PTB), U. STILLE. Z angew Phys v11 n8 Aug 1959 p 316–23 in German. A review in which the units, standards and methods of measurement of length and time, with particular reference to the practice at the PTB, are briefly surveyed. Some 150 references.

Algebra of Microscopic Measurement, J. SCHWINGER. Nat Acad Sci Proc v45 n10 Oct 1959 p 1542–53. Fundamental mathematical structure of quantum mechanics is considered from viewpoint of natural evolvement as symbolic expression of physical laws governing microscopic realm; measurement theory based on concept of interaction between system of interest and measurement apparatus that can be made arbitrarily small, so that measurement disturbs no property of system; representation of physical quantities by numbers identifies properties with nondisturbing measurement results; calculation methods.

Precision Measurement and Calibration. NBS Handb 77 Supt. of Documents, Government Printing Office, Washington, D.C. 1961. A compilation by SHERMAN F. BOOTH, of 150 selected papers previously published by the staff of NBS. Issued in three volumes:
I. Electricity and Electronics, 840 p.
II. Heat and Mechanics, 965 p.
III. Optics, Metrology, and Radiation, 1036 p.

Special Report on Measurement Standards. ISA J v8 n2 Feb 1961 p 38–74. Measurement Gap, O. L. LINEBRINK, 38: Why Are Better Standards Needed, T. K. GLENNAN, A. T. WATERMAN, A. B. KINZEL, H. F. YORK, H. W. RUSSELL, A. V. ASTIN, 39–41; Measurement Standards in Science and Industry, G. A. HALL Jr, 42–4; NBS—Source of American Standards, W. A. WILDHACK, 45–50; Traceability—Instrument Pedigree; S. C. RICHARDSON, 51–3; Evaluating Measurement Standards, B. AXMAN, 54–7; Recommended Environments for Standards Labs, ISA Measurement Standards Task Force 58–62; Refining Measurements by Capacitance Techniques, F. K. HARRIS, R. D. CUTKOSKY, 63–6; Education for Metrology, G. A. HALL JR, 67–8; Role of ISA in Measurement Standards, O. L. LINEBRINK, 69–70; Bibliography on Measurement Standards, 71–4.

Prise Automatique de l'Information, J. GOUZIL. Automatisme v6 n11, 12 Nov 1961 p 437–44, Dec p 495–9, v7 n6, 7–8 June 1962 p 219–27, July–Aug p 275–82. Automatic obtaining of information; automatic measuring instruments and measuring principles; continuous or analog indicating devices for measuring instruments; applications to teletypes and facsimile, weighing etc.

Main Trends in the Development of Measurement Techniques, V. O. ARUTYUNOV. Meas Techns 1961 n5 Dec 1961 p 241–5. Translated from Izmer Tekh n5 p 1–5 May 1961. Discusses problems of diversity, accuracy, measuring range, dynamic measurements, special conditions, operational inspection in production, and reliability.

Sleeping Giant of Sciences Awakens. Indus Quality Control v18 n6 Dec 1961 p 15–7. Efforts made to overcome serious shortcomings in attaining extreme accuracies with respect to measurements, standards or calibrations; program of U.S. Bureau of Standards to meet situation by enlarging and strengthening its own calibration services program, by encouraging industry and developing greater cooperation between government and industry; efforts made by military branches; work done by Center for Measurement Science, operated by School of Engineering, George Washington Univ. Washington, DC.

Instrumentation for Engineering Measurement, R. H. CERNI, L. E. FOSTER, John Wiley & Sons, Inc. New York, 1962 456 p. Contents: Measurements of physical systems; transducers and primary sensors; amplifiers and signal conditioning; data indication and recording; telemetry and data transmission; data handling and processing; data instrumentation system.

Experimentation: an Introduction to Measurement Theory and Experiment Design, D. C. BAIRD. Prentice-Hall, Inc. 1962 198p 20 refs. Contents: The nature of measurement; the propagation of uncertainties; the nature of experimenting; experiment planning; experiment evaluation; the scientific report; laboratory practice; appendix.

Experimentation and Measurement, W. J. YOUDEN, NBS. Nat Sci Teachers Assn, Washington, 1962 127 p. Introduction, the plan of the book; why we need measurements; measurements in experimentation; typical collections of measurements; mathematics of measurement; instruments for making measurements; experiment with weighing machines; selection of items for measurement; measurement of thread strength.

United States Air Force Calibration Program, W. L. HORTON, ISA Trans v1 n1 Jan 1962 p 81–94 7 figs 4 tables 7 refs. Outlines in detail USAF calibration program, including its mission assignment, organizational location in the Air Force, concept of operation, calibration procedures, location of laboratories, activities supported, facilities and environments personnel and training, measurement areas and accuracies, program monitoring, determination of requirements, future objectives, and general discussion of calibration philosophy.

Making Meaningful Measurements, P. K. WINTER. Gen Motors Eng J v9 n2 Second Quarter 1962 p 20–5. Nature of process called measurement, and means whereby working hypotheses are tested and retested, and on basis of which next step in investigation is planned; various examples relating to chemical analysis are given; evaluation of measurement results; precision and accuracy defined.

Fundamentals of Measuring Practice, DIN 1319 Jan 1962 15 p. Deutscher Normenausschusses, Berlin. States basic principles governing the use of measuring instruments and fundamentals of errors arising in measuring practice.

High Speed Instrument for Quantitative Mapping, D. R. GREEN. Rev Sci Instrum v33 n10 Oct 1962 p 1079–81. Instrument for mapping magnitude of variables, such as temperature, vibrational amplitude, radiation, height, etc. at different positions on surface is described; values of variable are recorded as broken line segments on 2-dimensional map; visible density of map is greater within regions of greater line length so the qualitative picture is obtained at glance; instrument was designed for application to heat transfer testing of nuclear fuel elements; method may have many other applications.

Appraisal of Current Measurement Personnel and Effect upon Quality of Measurement, C. D. FERRIS. ISA Proc Preprint 44.4.62 for meeting Oct 15–18 1962 6 p. Appraisal of competencies and deficiencies of personnel and resultant effect upon measurement quality as revealed by regular course work and special programs presented at Center for Measurement Science; particular areas of concern are lack of realization of physical limitations of equipment and technology, statistical treatment of data, and setting of confidence limits.

How We'll Measure Tomorrow, Steel Dec 31 1962. What's ahead in measurements? New combinations of present techniques. For example, ultrasonics and eddy currents in one tool enable operators to determine case depth, hardness, tensile strength, micro-structure, and density of parts in process without stopping the line. (The technique is expected to become a real help to those looking for ways to automatically control a process with a computer.) Finer, closer, more reliable dimensional measurements. The newest machine parts within millionths of an inch on a production instead of a laboratory basis. (It was formerly considered a laboratory technique.) Significance: More accurate and reliable parts than ever before. New rays—neutrons, electrons, and lasers—offer new ways to tell how good structures are inside, improving the reliability with which inspectors can evaluate the quality of the parts.

Defining the Concept of Measurement, G. I. KAVALEROV, I. Ya. KAVERKIN, S. S. SOKOLOV, N. A. SHOST'IN. Meas Techns 1962 n8 Feb 1963 p 621–5 13 refs. Translated from Izmer Tekh n8 p 1–3 Aug 1962. Compares several definitions of the concept of measurement and concludes with the following definition of measurement: Measurement is an operation consisting of comparing experimentally a given quantity with a certain value of that quantity adopted as a unit of comparison, performing the required logical and computing operations and presenting the result in a numerical form with an indication of its accuracy.

Measurement-Agreement Audits—Method for Increasing Confidence in Measurements. P. M. RIVOT, IEEE Int Convention Rec v 11 pt 5 (Aerospace & Navigational Electronics, etc) 1963 p 264–9. Causes for measurement incompatibility and some measurement-agreement-audit techniques for increasing confidence in compatibility of measurements; measurement agreement audit can be considered system for checking and having necessary adjustments made in accuracy of calibrations, measurements, and tests by submitting appropriate samples or measurement devices for calibration, measurement, or test.

Fundamentals of Measurement, A. G. McNISH. Electro-Technology v71 n5 May 1963 p 112–28. Historical development of measurement systems and standards; conceptual basis of measurement; techniques of measurement, including aspects of precision and accuracy, are described; basic quantities of mass, time and temperature, and other physical quantities, including electrical quantities are examined, and impact of contemporary technology on measurement concepts and techniques. 6 refs.

Mechanical Measurements—Basic Tool of Precision Engineering, C. L. SAPPET, E. D. KNAB. Bell Laboratories Rec v44 n5 May 1963 p 187–91. Requirements and methods for precision measurements in Bell Laboratories Mechanical Testing Laboratory at Whippany, N.J.; metrological techniques for testing physical properties of materials, accuracy of gears and bearings, strains and stresses in structures, effects of irradiation, and other precision measurements.

Reproduction of Rapid Processes by Means of Linear Recording Systems, V. G. VASIL'EV. Meas Techns 1963 n1 Aug 1963 p 7–13 5 figs. Translated from Izmer Tekh n1 p 6–9 Jan 1963. Develops a method of deciphering oscillograms to find the real nature of a phenomenon when solving problems of measurement and automatic control technology.

Proceedings of the 1962 Standards Labortory Conference. NBS Misc Publ 248 Aug 16 1963 254 p. Contains 31 papers and panel discussions presented at sessions dealing with National Bureau of Standards service to industry, error analysis of measurement systems, National Conference of Standards Laboratories business and information, corporate measurement standards programs, measurement agreement comparisons among standardizing laboratories, training of measurement personnel, calibration recycle analysis and work load control, NCSL relations to and cooperation with technical societies, and recommended practice for standards laboratories.

Principles of Measurement, L. FINKELSTEIN. Soc Instrum Techn Trans v15 n3 Sept 1963 p 181–9. Underlying philosophy of measurement is surviving from point of view of instrument and control technology; definition of measurement, its relation to qualitative concepts, classical and modern views of processes, and scales of measurement are discussed; uses of measurement analyzed; nature of measuring instruments is examined.

Les Étalons de Mesures Physiques, J. TERRIEN. Soc des Ingenieurs Civils de France—Mem v116 n11 Nov 1963 p 17–32. (Standards of Physical Measurement.) Particular aspects of standards for measuring physical quantities are reviewed; modern standards of length, mass, time, force, pressure, temperature, as well as standard measurements for photometric and ionizing radiations are discussed.

Quantity of Information for a Uniformly Distributed Measured Variable and Error, V. I. RABINOVICH, M. P. TSAPENKO. Meas Techn 1963 n6 Nov 1963 p 455–60 3 figs 4 refs. Translated from Izmer Tekh n6 p 1–5 June

1963. Describes a technique which may be applied for comparing measuring instruments as well as in certain cases for determining the quality of measuring processes.

International System of Units—Resolution n12, NASA— Tech Translation F—200 Feb 1964 3 p. Resolution 12 of Eleventh General Conference on Weights and Measures adopted standards based on 6 basic units called International System of Units (SI); units established are meter for length, kilogram for mass, second for time, ampere for electric current, degree Kelvin for thermodynamic temperature, and candle for light intensity; nomenclature and abbreviations are established, and derived units included. Translation from C. R. des Séances de la Conférence Générale des Poids et Mesures, Paris, Oct 11–20 1960.

Metrology, H. BARREL, Encyclopedia Britannica, 1965 Ed. v15 p 310–4. Outlines the scope and organization of

metrology, defines units and standards of measurement and their functions in the process of measurement; discusses random and systematic errors of measurement; provides a table of the accuracies currently attainable in some of the more basic operations of metrology; and gives detailed descriptions of the standards of length and mass and how they are maintained.

Scientific Metrology on the International Plane and the Bureau International des Poids et Mesures, J. TERRIEN. Metrologia v1 n1 Jan 1965 p 15–26. Subjects discussed are: Convention du Mètre and related organizations; past activities of the Bureau; length measurement; mass measurement; temperature measurement; electrical measurements; photometric measurements; time and frequency measurement; ionizing radiation measurement; the SI, International System of Units; and Conclusion.

1.2. General Dimensional Metrology

1.2.1. General

Miscellaneous Papers on Mechanical Subjects, J. WHITWORTH. Longman, Brown, Green, Longmans, and Roberts, London. 1858 183 p. Contains the following papers: On Plane Metallic Surfaces or True Planes, p 2–19, read at the meeting of the British Association in Glasgow 1840; On a Uniform System of Screw Threads, p 23–36, read at the Institution of Civil Engineers in 1841; Presidential Address delivered to the Institution of Mechanical Engineers, Glasgow, 1856 p 41–53; On Standard Decimal Measures of Length, p 57–69, read at the meeting of the Institution of Mechanical Engineers, Manchester, 1857; Rifled Fire-Arms, p. 73–84 5 figs; New York Industrial Exhibition in 1853, special rept p 87–177.

Laboratory Physics, D. C. MILLER. Ginn & Co. Boston 1903 403 p. Contains descriptions of exercises in making length and angle measurements, including the following: Length with the calipers; length and radius of curvature with the spherometer; constant of a micrometer microscope; length with the (line) comparator; length with the dividing engine; (graduation of) circular arc with the dividing engine; errors of a graduated scale by Gay-Lussac's method; errors of a graduated scale by precision methods; length with the optical micrometer; constants of a level with the level trier; areas with the planimeter; angular distance with the sextant; small lengths with the interferometer; plane and plane-parallel surfaces by optical methods; angle of a crystal by the reflecting goniometer; and angle of a prism with the spectrometer.

Measurements of Length and Area, including Thermal Expansion. NBS Cir n2 4th ed May 1 1912. A general description of the tests made by the Bureau involving the precise measurement of length and area.

Length Standards and Measurements, L. A. FISCHER, NBS. J Washington Acad Sci v5 n5 Mar 4 1915 p. 145–59. Presidential address before the Phil Soc of Washington on Jan 16, 1915. Reviews history of various length standards and discusses accuracies of measurement.

Stretched Wire Apparatus for Measuring Thermal Expansions, A. W. GRAY. Chem and Met Eng v21 n13 Nov 26–Dec 3 1919 7 p 6 figs refs. Discusses difficulties in making reliable measurements, stretched wire method for measuring linear displacements, accuracy and range of the method, detailed description of simple stretched wire dilatometer, preparation of specimens for testing, sources of error, concrete illustration of an expansive determination, variations of the instrument.

A Dictionary of Applied Physics Edited by Sir R. GLAZEBROOK. MacMillan & Co. London in 5 vols. v3 1923

Meteorology, Metrology, and Measuring Apparatus. Contains articles on surveying tapes and wires; design of scientific instruments; comparators; line standards of length; gages; metrology, micrometers, and many others.

Gage Inspection Methods F. R. DANIELS. Machy (NY) v28 May 1923 p 702–5 8 figs. Discusses wear of inspection standards, uses of measuring machines, use of lead measuring machine, inspection of taper plug gages, application of the sine bar fixture, bench centers with dividing head.

Precision Measuring Instruments Used in Gage Inspection, G. K. BURGESS, Army Ordnance, v4 May–June 1924 p 375–80 8 figs. Deals with such apparatus as is applied in measurement of dimensions of gages and tools used in manufacture of machine parts, artillery ammunition, etc.

Fine Measurement, J. E. SEARS. Machy (London) v24 May 15, 29 and June 5 1924 p 209–12, 266–71, and 299–303 22 figs. Deals with precision measurement in its relation to mechanical work; methods by which control of standard gages is effected in laboratory; recent development in methods of precision measurement. See also: Präzisions-Längenmessungen (Precision Length Measurements), J. E. SEARS. Zeits für Feinmechanik und Präzision v33 n19 1925 p 209–13, n20 p 222–5, n21 p 235–8 11 figs in German.

Optics as Applied to Measuring, O. EPPENSTEIN. Eng Progr v6 Sept 1925 p 293–301 23 figs. Applications in construction of apparatus and machines; notes on magnifying glass; optical dividing head; measuring microscope; projection apparatus; thread-measuring comparator; micrometer; optimeter; measuring machine; measuring by light interference.

Precision Machines and Instruments for the Measurement of Length, G. K. BURGESS, NBS. Paper No. 335, Proc. World Engineering Congress, Tokio, 1928 v5 58 illus. For abstract see p 39.

Gauges and Fine Measurements, F. H. ROLT. Edited by R. T. GLAZEBROOK. 2v London, MacMillan. 1929 723 p. Reviewed in Times Trade and Eng Supp v25 n597 Dec 14 1929 p 311. Book is directed specially to measurements of length of which practical use is made in engineering manufacture and tests, and two volumes deal respectively with standards of length, measuring machines and comparators, and with limit gages, measuring instruments, and general methods of measurement.

Measurement of Length, W. BLOCK. Instrum v3 Aug 1929 p 50.–10 7 figs. Continuation of Chapter 6 on measurement of length; measuring screws and their practical application; test indicators; dial gages; special measuring apparatus.

Messgeraete und Verfahren fuer den Austauschbau, G. BERNDT. VDI Zeit v76 Mar 5 1932 p 241–7. Measuring instruments and methods for production of interchangeable parts; gages, mechanical and optical feelers, micrometers, measuring machines and comparators, measuring of angles and degree of tapering, dividing heads, etc.; screw-thread measuring equipment; measurement of gear teeth.

Archiv fuer Technisches Messen, R. OLDENBOURG. Lieferungen 15–18 Sept–Dec 1932. Berlin and Munich. Illus diagrs charts tables. Archiv fuer Technisches Messen is encyclopedia of technical measuring instruments and methods being published serially in loose-leaf form; articles are well-illustrated practical descriptions, usually with bibliographies and are signed; all classes of measurements included. Eng Soc Library, N.Y.

Fundamentals of Mechanical Dimensional Control, I. H. FULLMER. Mech Eng v57 n12 Dec 1935 p 772–80. Correlation of fundamental principles of mechanical precision, tolerances, precision in production of parts, gaging and measuring physical dimensions. Bibliography.

Application of Optics to Engineering Measurements, F. H. ROLT. Eng v144 n3734 Aug 6 1937 p 162–6. Few of more important types of optical instruments now on market described and illustrated, including measuring microscopes, projection machines, optical levers, angle measuring instruments, and autocollimators for testing straightness. Lecture delivered at Conference of Optical Devices in Research and Industry held by Inst. of Physics.

Engineering Measurements, H. W. BOWEN. Junior Instn Engrs J v49 pt2 Nov 1938 p 61–79. Standard of measurement; interferometry; measurement of flatness, industrial standards; measuring machines; screw gage and thread measurements.

Die praktische Bedeutung einer zuverlaessigen Messung, H. TOERNEBOHM. Schweizer Archiv v5 n11 Nov 1939 p 309–25. Practical significance of reliable measurement, with special regard to errors in design of workpieces and their influence on measurement results; inspection of macrogeometric design errors by means of measuring instruments; discussion of fits and tolerances and their measurement, thread and linear measurements, gages, etc.

Der Abbesche Grundsatz fuer Laengenmessungen, R. LEHMANN. Werkstattstechnik und Werksleiter v34 n5 Mar 1 1940 p 73–5. Application of fundamental rule of Abbé to longitudinal measurement; use of rule in workshop practice is shown on basis of examples.

Using Checking Gauges. Can Machy v51 n12 Dec 1940 p 125–9. New standards of accuracy highlight importance of proper use and controlled accuracy of thousands of measuring and master instruments; data on standards of length, wavelengths of different colors of light; stand gages, comparing end standards, and comparators. Based on a lecture given by PROF. H. GRAYSON, Univ of Toronto.

Begriffe und Benennungen in der Messtechnik, G. BERNDT. Werkzeugmaschine v45 n9 Mar 6 1941 p 227–32. Conceptions and terminology of measurement technique; dimension measurement, gages, sorting, gaging, comparing, difference between measurement and testing.

Messen in der Werkstatt (Measurement in the Workshop), K. KRESS. Carl Hanser Verlag, Munich 1942 96 p 118 figs. Contents: Concepts of measuring and testing; problems and build-up of work-room; influence of workpiece errors on tolerances and fits; influence production accuracy and workmanship; influence of work-piece errors on measurement results and their measurement; measuring force and deformations; influence of temperature differences; end standards; properties of measuring equipment and methods.

Fine Workmanship Fine Weapons, F. L. STEVENS. Can Machy v54 n12 Dec 1943 p 426, 428–9. Discussion of instruments being used in Britain to secure greater accuracy; autocollimator, section projector, vertical measuring machine, balloon theodolites, interferometer, and lenses of improved design are discussed.

Dispositif Automatique de Mesure et de Controle, Pratique des Industries Mécaniques v28 n1 Apr 1945 p 9–12. Automatic measuring and controlling apparatus for various purposes described and illustrated; discussion of mechanical and electrical transmission of measurements; application of special devices, such as bolometer which works by means of photoelectric cell for checking diameter of drill holes, and of device applicable only for measurement of cylindrical bodies. Bibliography.

Essentials of Metrology, C. H. KLAWE. Prenco Aircraft Manuals, T.D. Bul n2 May 1945 39 p 48 figs 23 refs. General remarks, standards room, accuracy of measurement, units and standards of measurement, precision blocks, optical instruments for absolute measurements, measuring machines, comparators and indicators, micrometers, vernier calipers, measurement of angles, measuring screw threads, measurement of surface rectitude, small tools for measuring purposes.

German Measuring Instruments Reflect High Degree of Precision. Am Mach v89 n18 Aug 30 1945 p 99, 102. Flexibility in German tooling provided through application of high quality gage blocks, vernier calipers, quality control in operating department instead of relying on specialized jigs and fixtures or transfer of working tolerances to snap, plug and ring gages; design and operation of variety of German precision measuring instruments discussed.

Sir Joseph Whitworth, A Pioneer of Mechanical Engineering, F. C. LEA. Longmans, Green and Co., London, 1946 31 p 16 figs. A brief account of some of the work of SIR JOSEPH WHITWORTH (1803–87). Among the subjects discussed are: the true metal plane surface; importance of precise measurement, and the measuring machine; standard gauges; and screw threads.

Quelques Applications de l'Optique à la Métrologie des Longueurs (Some Applications of Optics to the Metrology of Length), A. MOTTU. Microtecnic v1 n1 2 Feb 1947 p 27–31, Apr p 71–6 (English translation in separate sections p 8–10 and 28–30). Some applications of optics to metrology; historical background and development of standards of length; Fizeau's method for comparing end standards with line standard; line standards and their comparison; characteristics of measuring machines; design and operation of jig borer cited as example of importance of optics in precision measurement.

Engineering Metrology, K. J. HUME. MacDonald and Co. Ltd. London 1950 293 p. Contents: Basic principles; standards of measurement; standardisation; manufacture of gauges; optical projectors and microscopes; linear measurement; angular measurement; circular division; straightness, flatness and squareness; alignment testing; screw threads; screw thread measurement; surface finish; gauge and instrument design; miscellaneous measurements.

Messwerkzeuge Werkstattmessungen (Measuring equipment, workshop measurements), H. KÖRWIEN. Fachbuchverlag Gmbh, Leipzig. A. Ziemsen Verlag, Wittenberg. 1950(?) 248 p 335 figs. The study of this book places the plant specialist in the position safely to decide which kind of measurement is best and most economical in the production of single work pieces. After a theoretical introduction in the fundamentals of measurement and economical production (measuring system, standards,

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fits, tolerances, ISO system, etc.) there are set forth systematically the construction, operation, and management of the variety of measuring instruments and machines. All occurring cases of measurement (length, angle, threads, gears, surface texture, etc.) are treated, from the simplest to most precise.

National Research Laboratories—Gauge and Associated Measurements, Work of Metrology Section, R. H. FIELD. Can Machy v62 n1, 2 Jan 1951 p 69–74, Feb p 101–4 119. Jan: Present situation in Canada regarding standards of length and mass; length standards for shop use, and instruments used for gage measurements; angle measurement. Feb: Equipment for measurement of plugs and tapers; optical projectors used for measurement, thread gage measurement, devices for measuring hobs and surface plates; measurement of surface finish studied; photographs.

Kontrolle im Austauschbau, Lehre oder anzeigendes Gerät (Control in interchangeable manufacture, gages or indicating instruments). G. BERNDT. Wiss Zeit der Techn Hochschule Dresden v2 n4/5 1952–3 p 639–50 16 figs 8 refs.

Precision Measurement In Metal Working Industry. Prepared by Dept. of Education of International Business Machines Corp. Syracuse Univ Press, Syracuse, N.Y. revised 1952 365 p. Manual for use in Factory Training Program of IBM Corp; deals with instruments and gages among which are; plug, ring and snap gages, micrometers and verniers, angle-measuring instruments, comparators, optical instruments, hardness testers, and nondestructive testing methods. Eng Soc Library N.Y. Previous edition published in 1944.

Métrologie D'Atelier (Workshop Metrology), L. COMPAIN. Éditions Eyrolles, Paris, 1952 261 p 91 figs bibliography. Chapter headings are: generalities, units, standards, direct measuring instruments; comparators; interchangeability and the use of limit gages; verification of screw threads; verification of gears; applications of geometric verification to parts and assemblies.

Development of Engineering Metrology, F. H. ROLT. Engr v193 n5018–5019 Mar 28 1952 p 448–50, Apr 4 p 480–3; Machy Market n2701–2702 Aug 22 1952 p 25–7, Aug 29 p 27–8. Development of tools and instruments for measurement; gages and measuring instruments in Great Britain in 1900; measurement of standard gages by optical interference methods; early machines for measuring screw gages; comparators; work at National Physical Laboratory; developments by Zeiss and Société Genevoise d'Instruments de Physique; testing flatness and straightness; metrology and machine tools; measurement of surface finish and gears; illustrations.

Niektore Radzieckie Narzedria Miernicz do Warsztatowych Pomiarow Dlugosci i Katox, A. TOMASZEWSKI. Przelad Mechaniczny v11 n10 Oct 1952 p 389–91. Soviet instruments for measuring angles and lengths in machine shops and principles of interference meter of Uverski, design measuring projector of Safronov and Moskalev and angle plates of Kushnikov; diagrams.

Pomiary Na Optimetrze Poziomym Produkcji Radzieckiej, L. LOWCZYNSKI. Mechanik v25 n11 Nov 1952 p 492–5. Measurements by means of horizontal optical meter manufactured in Soviet Union; instrument used for precise measurements in metal industry; principle of measuring; structural elements of instruments; external and internal measurements; accuracy of measurements; diagrams.

The Science of Precision Measurement. The DoAll Co., Des Plaines, Ill., revised 1953 258 p. History and development; on clearances and tolerances; gage blocks; the micro-step gaging system; angle measurement by the use of sine bars and sine plates; measurement with light waves;

measurement with electrical and mechanical comparators; thread and gear inspection by the wire method; mobile inspection; statistical systems of dimensional quality control.

Taschenbuch der Längenmesstechnik für Konstruction, Werkstatt, Messraum, und Kontrolle (Handbook of length measurement technique for construction, workshop, measurement room, and control), P. LEINWEBER in cooperation with G. BERNDT and O. KIENZLE. Springer-Verlag, Berlin 1954 806 p 790 figs 39 tables. An exceptionally comprehensive review of measuring means and methods under the following general headings: Fundamentals; standards and measuring equipment for general purposes; gages; treatment, care, and surveillance; simple measuring problems; composite measuring problems; special work areas; organization of measuring systems; and tables.

Engineering Inspection, Measurement and Testing, H. C. TOWN, R. COLEBOURNE. Odhams Press Ltd. London 1956. Contents: The function of the inspection department; standardization; principles of precision measurement; standards of length, linear measurement; comparators and measuring machines; multidimension inspection machines; measurement during machining—automatic sizing; workshop inspection methods and calculations; angular measurements; testing straightness and flatness; screw thread measurement; surface finish measurement.

Practical Metrology, vI–IV, K. J. HUME, G. H. SHARP. McDonald and Co. Ltd., London, 1956–1962. Presents 43 experiments in measurement of gages, etc.

Les Appareils d'Optomécanique, M. PAUL. Rev Gen Mécanique v39 n82 Oct 1955 p 343–50, v40 n85 Jan 1956 p 29–34. Application of optical instruments to industrial measurement and control. Oct 1955: Optical control of alignment; comparators; profile projectors. Jan 1956: Application for control of machines.

Modern Measurement Methods, V. W. STANLEY. Mass Prod v32 n2 Feb 1956 p 88–94, 98. Method for producing three-dimensional airfoil models using relatively simple equipment; use of autocollimator for measurement of small changes of rotation or angle; straightness or flatness measurement, circular and bore measurement; applications of pneumatic or air gaging; interferometry for length standards; optical technique using plane transmission diffraction gratings.

Messkniffe und Messhilfen (Measuring Artifices and Auxiliaries), R. LEHMAN. Feingerätetechnik v5 n10 Oct 1956 p 463–70 18 figs 8 refs. Contents: (1) general principles of measurement; (2) small scales and the measuring microscope; (3) simple dividing head; (4) coordinate measurement of hole locations; (5) measurement of small parts with hand measuring tools. Discusses use of available measuring means when special measuring equipment is not available.

Engineering Precision Measurements, A. W. JUDGE. Chapman and Hall, Ltd., London, (3d ed) 1957 447 p 445 figs refs. Contents: Linear measurement, instruments and indicators; micrometers, verniers and measuring machines; engineering fits, gauges and methods; slip gauges and their uses; screw thread measurements; internal measurements; measurement of angles; comparators: other optical measurement methods; measurement of straightness, flatness and alignment; interferometry methods; miscellaneous m e t h o d s and appliances; surface finish; automatic gauging and worksizing; appendices.

Precision Instruments for Engineering, E. R. ALLAN. Design v29 June 1957 6 p 14 figs. Describes British precision equipment used in engineering industry. Dis-

cusses desirable improvements in design standards and styling.

The Measurement of Thickness, G. KEINATH. NBS Cir n585 1958 79 p. Methods for measurement of thickness are treated in seven groups (mechanical, chemical, electrical, magnetic, optical, x-ray and radioactive) according to physical operating principles. Ranges, accuracies, advantages and limitations are discussed. A bibliography of references, a list of suppliers and an index of gauges, methods, applications and trade names covered are appended. 220 refs.

The Transfer of Basic Length Standards into Industry, E. G. LOEWEN. Presented at Section M AAAS Annual Meeting, Dec 30 1958. Discusses screws, scales, electrical scales, gage blocks, direct measuring interferometers.

Some Fundamentals of Modern Dimensional Metrology, I. H. FULLMER. ASTME v60 n240 1960 13 p 11 figs 17 refs. Discusses recent developments in attaining extremely high precision and accuracy in the measurements of lengths and the dimensions of master gages.

Precision Measurement and Gaging Techniques, W. GROHE. Chem Publ. Co., N.Y. 1960 222 p. 116 figs 21 refs. Among 15 chapters contains chapters on comparators, gage blocks, interferometric measurements.

Metrology and Gauging, S. A. J. PARSONS. MacDonald and Evans, Ltd. London 1960 2d ed 27 chapters 286 p 209 figs. The following subjects are treated: Fundamental length standards; light waves as length standards; working standards; principles of interchangeability; design of gages, gaging screw threads; manufacture of gages; testing limit gages; measuring equipment and mechanical measuring devices; optical principles and measuring devices; electrical devices; pneumatic measuring devices; circular division; screw thread measurement; measurement of gears; measurement of surface texture; straightness, flatness, and alignment testing; miscellany; appendices.

Métrologie Industrielle (Industrial Metrology), E. BODART, R. MOSSOUX, Univ of Liege 1961. Contents: Introduction; dimensional control; gages; instruments and accessories for measurement; control of gages; measurement of angles; screw threads; surface state; verification of gears; exercises.

Cours de Métrologie (Course in Metrology), E. BODART, Univ of Liège, 1961 247 p. Contents: Introduction; definition and realization of units; precision amplification, accuracy; length standards; interference measurements; measuring techniques and instruments; gages, dimensioning, and tolerances; measurement of angles; measurement of inaccessible elements; screw threads; gears; surface state.

Gomz (State optico-mechanical plant) Instruments for linear and angle measurements, N. F. DELYUNOV, E. I. ROZENBERG. Meas Techn 1961 n4 Nov 1961 p 264–9 8 figs 4 refs. Translated from Izmer Tekh. n4 p 5–9 Apr 1961. Describes universal measuring microscopes, optimeters and comparators, cathetometers. Also, in recent years several instruments for special application have been made, such as the MIV–1 and MIV–2 machines for measuring the parameters of guide screws 2000 mm long, optical contactless micrometers type OBM–2 for measuring thickness up to 50 mm by a countless method, an instrument type PGVK for checking shaft screws, and a number of other precision measuring instruments.

Engineering Dimensional Metrology, L. MILLER. Edward Arnold Publ Ltd Lond 1962 290 p 184 figs refs. Contents: The true plane; definition and measurement of surface texture; instruments for measuring surface finish and roundness; standards of length; the calibration of working standards by interferometry; same by direct comparison in series; development of limit systems; metrology of angles; metrology of screw threads; metrology of gear teeth; measuring machines.

Opportunities Presented to British Industry by Recent Developments in Engineering Dimensional Metrology, J. LOXHAM. Machy (London) v100 n2581 May 2 1962 p 1015–22. Handmade vs mass-produced products; existing manufacturing arrangements; conditions necessary for ideal arrangement; economics of high precision manufacture; why present period is very suitable for introducing "ideal arrangement"; management requirements.

Measuring in Millionths. C. W. KENNEDY. Machy (N.Y.) v68 n10, 12 June 1962 p 128–37, Aug. p 118–27, v69 n3 Nov p 131–9. Recommendations of ways and means to improve and modernize daily routines. June. Gaging equipment; effects of environment; errors due to vibration; combating dirt, metallurgical effects; phenomenon of penetration; gaging pressure; deflection. Aug. Study of inspection problems such as looseness, wear, and improper manipulation; gaging errors introduced by deceptive geometry of lobing. Nov. Effective procedures for calibrating master gage blocks; interferometry, and use of laboratory and modern compact types of interferometers.

Die Weiterentwicklung der Präzisionslängenmesstechnik, ihre Anwendung in Fertigung, Kontrolle und Messraum, im Blickwinkel der Automatisierungsbestrebungen und der Kaderfrage (The further development of the precision length measuring technique; its application in finishing, control, and measuring room, in the angle of view of the automation endeavor and the framework question), G. MEISTER. Feingerätetechnik v12 n5 1963 p 212–24 19 figs 74 refs. A comprehensive review of the state of the art of applying the micron, the arc second, and electronics to the control of machines and automatic measurement. Also presents a look toward the future.

Length and Mass Calibration at National Bureau of Standards, T. R. YOUNG NBS Misc Publ 248 1963 p 9–13. Survey is presented of present length and mass measurement capability, developments underway, and plans for future work; particular reference is made to present and future accuracy capabilities and requirements.

Case Histories of Methods to Achieve Cost Reduction Through Optical Tooling. A. W. YOUNG. ASTME Creative Mfg Seminars-Tech Paper SP63–120 Feb 1963 7 p. Eleven examples are described dealing with alignment of machine tools, checking out rotational error of rotary tables, transfer of angular measurement in shops, use of telescope and clinometer mounted in one fixture, etc.

Checked Your Gage Blocks Lately, H. EASTMAN. Am Mach/Metalworking Mfg v107 n5 Mar 4 1963 p 56–8. Recommendations on how to conform with government contracts which require adequate gage surveillance programs, with special emphasis on "pedigree" of measurement standards; calibration laboratories; importance of measuring technique and what should be done to minimize uncertainties; preparing blocks; checking flatness; temperature stabilization; light contact pressure of comparator recommended; blocks of different materials; equipment maintenance.

Differential Measuring Mechanisms, A. 1. SOLOV'EV. Meas Techn 1962 n12 July 1963 p 1007–11 3 figs 3 refs. Translated from Izmer Tekh n12 p 19–22 Dec 1962. Article demonstrates the measuring facilities provided by kinematic double-contact measuring (differential) mechanisms, their structural and kinematic unity, and their degeneration into parallelogram devices which constitute a double tangential mechanism. The reason for the elimination of the effect of the component's run-out on the measurement results in differential mechanisms

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has been demonstrated analytically. Formulas have been suggested for determining the displacement of the indicator stem in terms of the depth of machining and the geometrical parameters of the mechanisms.

Geometrical and Physical Limitations in Metrology, J. C. MOODY. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 567–73. Published by ASME. Refinements in metrology are explored from point of view of engineers in metal working industry; measurement of flatness, parallelism, straightness, roundness, and surface finish; measurement of elastic and permanent compression, deflection, and surface deformation; problems arising from effects of temperature and of heat transfer on objects being measured, and on measuring machines or references.

Machine Tool Optics, K. RAENTSCH. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 625–33. Published by ASME. Review of all current possibilities of applying linear optical measuring devices to machine tools, principles of which apply to measuring instruments as well; special stress is placed on adherence to Abbe Comparator principle, with methods outlined of how to simulate adherence with special optical techniques, in order to achieve more compact designs.

Geometrical and Physical Limitations in Metrology, J. C. MOODY. Tool and Mfg Eng Oct 1963 p 69–74. Fundamental concepts, geometrical features, physical properties, temperature and heat.

Why, When, Where, How and What of Measurements, D. E. WENDELN. ASME–Paper 63–WA–256 for meeting Nov 17–22 1963 5 p. Proper time and place to measure are emphasized to gain maximum benefit from measurements taken; small part with 0.040+0.001 diam hole is used as example and engineering approach to four different methods of inspections are explained; current measurement problems are discussed and areas requiring research and development work are pointed out.

Metrology, P. MARTIN. Bul n1314 1964 of the Soc Genevoise d'Instruments de Physique, 22 figs. Reviews history of metric and yard systems. Discusses contemporary industrial metrology and describes role played by SIP in the progress of metrology.

Fundamentals of Dimensional Metrology, Wilkie Brothers Foundation, T. BUSCH. Delmar Publ, Inc. New York 1964 428 p. A text about technique. Discusses reasons for, language of, and systems of measurement; measuring instruments, standards, and comparators; reference planes; and angle measurement.

DIG, a Long-Travel Ultraprecise Absolute Reading Digital Linear Measuring Instrument. Bausch and Lomb, Rochester, N.Y. 1964 8 p 4 figs. DIG, produced by General Measurements Research Inc., is a long-travel (40 in. single scale) digital measuring instrument giving absolute measurements in microns, ten-thousandths in. or 50 micro-inches. Three basic elements are: a precisely calibrated glass scale, an optical/electronic reading head, and an electronic readout console. The reading head and scale may be attached to any set of guided machine elements whose relative position is to be measured or controlled. Measurements are made by digitally interpolating intervals between reflective scale graduations, spaced one mm or 0.050 in. apart. A unique coarse encoder identifies the scale graduations by scanning an adjacent decimal-coded track.

Automatisierung in der Längenmesstechnik (Automation in Length Metrology), W. ECKERKUNST. Veb Verlag Technik, Berlin 1964 320p 311 figs 82 refs. Deals with indicating gages and pickups in mechanized and automated testing and sorting equipment; mechanized testing and sorting equipment for testing stationary workpieces; automatic testing and sorting, including (1) supply line, meter-

ing arrangements, measuring arrangments, data accumulators, and derivation systems, and (2) executed constructions of automated testing and sorting; problems of testing moving workpieces including (1) determination of form deviations and (2) examples of mechanized and automated testing equipment for out-of-roundness and form; testing in the machine and realized constructions; automation of the evaluation pickup for statistical quality control; profitableness of mechanized and automated testing equipment.

Precision Length Measuring Instruments of Japan '63, T. NAKADA, President, Editorial Committee. The 30th Anniversary Issue of the Japan Society of Precision Engineering, Tokyo, Apr 1964 137 p. Part I on precision measuring instruments for length includes abstracts from Japanese Industrial Standards and catalog displays of gage blocks, vernier calipers, micrometers, interference comparators, measuring machines, and gages. Part II on precision measuring instruments for angle and applied system includes abstracts from Japanese Industrial Standards and catalog displays of precision flats, levels, dividing heads, toolmaker's microscope, projectors, autocollimators, gear measuring instruments, interferometers, air gages, electronic comparators, auto sizers and sorters, etc.

1.2.2. Units of Length and Angle

Standard Decimal Measures of Length, J. WHITWORTH. Publ. in Miscellaneous Papers on Mechanical Subjects, J. WHITWORTH. Longman, Brown, Green, Longmans, and Roberts, London, 1858. Paper read at meeting of the Institution of Mechanical Engineers, Manchester 1857 p 57–69. Advocates use of decimal system of measures, replacing fractions such as eighths, sixteenths, and thirty-seconds of an inch.

Weights and Measures of the United States, T. C. MENDENHALL. Tech Q Dec 1892 p 312–19; Eng News Nov 9 1893 p 378. Gives history of the yard and pound, and the growth and adoption of the metric system as the international system of weights and measures.

Industrial Length Measures (La Loi des Longueurs Industrielles), F. BAYLE. Tech Mod v15 Mar 1, 15 and Apr 1 1923 p 129–34, 165–9, and 209–11 7 figs. Necessity for standardization; principles of standardization; units of length; national and international law for length measure; advantages of a universal length measure.

A Fundamental Basis for Measurements of Length, H. W. BEARCE. NBS Sci Papers n535 Sept 22 1926 p 395–408. Relations between yards and meters, inches and millimeters; definition of meter in terms of light waves; acceptance of simple relation; points out that official action by United States defining yard and meter in terms of light waves, and adopting relation 1 in.=25.4 mm as exact, would not only give official sanction to simple and convenient relation already widely used in United States and Great Britain, but would tend to bring about its universal adoption; change would never be felt except in cases of extreme accuracy such as manufacture and testing of precision end standards and graduated linear scales.

La Conversion des Unites Anglaises de Mesures Combinées et de Temperatures en Unites Metriques (Conversion of British units into metric), E. KLAPPER. Genie Civ v94 n19 May 11 1929 p 459–61; English abstract in Engineering v128 n3327 Oct 18 1929 p 490. Synopsis of principal combined units which writer has been able to compile from study of British and American as well as continental publications; symbols used in table are those which have been standardized for scientific purposes in different countries.

The Conversion of Combined Metric units into British units. Eng v129 Jan 23 1930 p 20. Reference is made to

article by E. KLAPPER published in Oct 18 1929 issue of this journal, covering table of factors for converting quantities expressed in British or American units; as table contained a number of errors it is reprinted in full with certain additions; every care has been taken in checking this table as it now appears, and it is believed to be entirely reliable.

Definition of Inch, H. W. BEARCE. Mech Eng v54 n10 Oct 1932 p 689–91. Recent proposals for defining inch; present basis of United States inch; relation of United States to British inch; proposal to establish value, 1 inch equals 25.4 mm, as standard industrial practice.

Standard Inch-Millimeter Conversion Factor for Industrial Use, C. E. JOHANSSON. Indus Standardization v4 n1 Jan 1933 p 1–4. Practical significance in industrial practice of use of standard conversion ratio 25.4.

Angle Converters and Meter. H. MAURER. Zeit fuer Instrumkde v55 Nov 1935 p 448–56. Disadvantages of various systems of angular measurements, e.g., in terms of radians, degrees, minutes, seconds, etc., are briefly referred to, the application of such systems in military and naval science being, interalia referred to. The advantages of a system in which 2π radians divided into 6,000 units are pointed out. The term "set" (derived from sechs and tausend) is suggested for the new unit. Devices for interconversion of the various scales are described and their use exemplified.

Why Metric System?, A. BLACK. Aero Digest v54 n1 Jan 1947 p. 151, 207. It is stated that arguments in favor of metric system are old and fallacious and that switch to metric dimensions would cause chaos; author suggests discarding foot, yard and mile and substituting multiples of inch; prefixes of metric system could be used; thus, 1000 inches would become "kiloinch" and 1,000,000 inches would become "meginch."

Les Bases Fundamentales de Nos Unites de Mesure, A. PICCORD. Microtecnic v1 n1 Feb 1947 p 14–9. (English translation in separate section p 1–4). Fundamental bases of our units of measurement; historical review of theory and development of centimeter, gram and second as measurements of length, mass and time and standards from which they are reproduced.

Fundamental Considerations Regarding Use of Relative Magnitudes, J. W. HORTON. IRE Proc v40 n4 Apr 1952 p 440–4. Advantages of expressing quantities as relative magnitudes, as demonstrated by convenience of decibel; with relative magnitudes, changes in quantities may be expressed as ratios, which combine by multiplication; there are two number systems, conforming concurrently to decimal system by which relative magnitudes may be evaluated; use of "logit" ($10^{0.1}$) as basic number relating these systems.

On the Dimensions of Angles, O. REEB. Optik v11 n2 1954 p 75–94 in German. The author suggests that in addition to the basic units of mass, length and time, angle should be considered as fundamental. Tables are given showing the dimensions of properties used in photometry and rotational dynamics, in terms of the system based on four fundamental units.

Measurements and Calculations in Physics. Fundamentals of the Introduction of Physical Quantities and the Definition of Units (Messen und Rechnen in der Physik. Grundlagen der Grösseneinführung und Einheitenfestlegung), U. STILLE. Braunschweig : Friedr. Vieweg and Son 1955 viii+416 p in German. A detailed systematic classification and explanation of the concepts and relations between physical quantities, units and dimensions in use in physics, together with a description of the various standards and constants and their measurement.

Section 1 deals with the general theoretical background, including the recent treatment of Fleischman; section 2–5 respectively with mechanics, heat and thermal radiation, electricity and magnetism, acoustics and light; section 6 with the numerical data and other details of the standards and constants; and section 7 presents in 35 tables a summary of the units, dimensions, definitions and numerical values of the quantities discussed in the previous sections. The recommendations and resolutions of international and other bodies regarding units and standards are quoted in the original and include those up to the end of 1954, while the approximately 1000 literature references include work up to the middle of 1954. An important reference and source book giving both the present agreed values and nomenclature and also previous developments and changes.

Dimensions of a Solid Angle, O. REEB. Optik v12 n4 1955 p 196–9 in German. Reasons are given for assigning to solid angles a dimension which is independent of the dimensions of other quantities, not excluding the dimension of a plane angle.

Conversion of Inch and Metric Sizes on Engineering Drawings, L. W. NICKOLS. Eng v199 n5174 Mar 25 1955 p 409–11 ; Engr v179 n4653 Apr 1 1955 p 409–11. Factors involved in converting British system of linear measurement on engineering drawing to metric, and conversely ; logical and simple scheme for interconversion described. Communication from NPL.

The Decilit : a New Name for the Logarithmic Unit of Relative Magnitudes, V. V. L. RAO AND S. LAKSHMINARAYANAN. Letter in J Acoust Soc Am v27 n2 p 376–8 Mar 1955. The standard magnitude ratio of $10^{0.1}$ is accepted as a useful device for the specification of relative magnitudes. The significance of such a standard-magnitude ratio when considered as the basis of a unit is discussed. The name decilit is suggested.

Units and Systems of Weights and Measures, L. V. JUDSON. NBS Cir n570 May 21 1956 29 p. Data on origin, development, and present status of units and standards, together with general information about metric system, and usage of standards of length, mass, time, and capacity in United States and in Great Britain ; tables of weights and measures.

The Standard of Length and the Standard of Time, A. PÉRARD. Nature (London) v177 May 5 1956 p 850–1. Comments on the article by Clemence and mentions that Clemence mistakenly confused the micron with the angström as the length which is subject to experimental determination. The meter as defined in terms of wavelength, using the wavelength of the red Cd line as 0.643 846 96×10^{-6}m, is strictly equal to the meter defined by means of the Pt-Ir prototype and thus though the standard is changed the unit of length is not.

The Units of Time and Length, L. ESSEN. Nature (London) v180 July 20 1957 p 137–8. The constancy of the velocity of light is regarded as an essential feature of any system using a wavelength standard of length. An ideal system would define units of length and time in terms of the wavelength and frequency of radiation from a given source, but in practice the Cs line could be used for standard frequency and a suitable light-source for standard wavelength. Consideration is given to the time system in which interval is based on the atomic unit and epoch on astronomical measurements.

Origin of Foot-Measure, C. ST. C. DAVISON. Engr v184 n4778 Oct 4 1957 p 418–21. Historical development of measures of length since Tower of Babel, as illustrated by display at Science Museum and underlined by educational display on history of measurement standards set up by General Motors Corp at their Indiana plant.

Secular Changes of the Units and Constants of Physics, A. H. COOK. Nature (London) v180 Nov 30 1957 p 1194–5. It is argued that absolute changes in physical quantities are indetectable experimentally and that only changes in ratios of quantities are measurable. The bearing of this argument on the choice of basic units is discussed and it is pointed out that secular changes in non-dimensional ratios do have physical significance.

What Will New International Inch Mean to U.S. Metal-Working? Am Mach v103 n4, 6 Feb 23 1959 p 89–93, Mar 23 p 137–8. Various opinions presented.

Atomic Standards of Length and Time, H. BARRELL and L. ESSEN. Sci Progr v47 Apr 1959 p 209–29. Comprehensive review. 31 references.

The Basis of our Measuring System, A. G. McNISH, NBS. Proc IRE v47 n5 May 1959 p 636–43 10 refs. Present units and standards, from prototypes to electricity standards; physical constants as standards.

Length and Time in the Problem Range of the Physikalisch-Technischen Bundesanstalt PTB, U. STILLE Z angew Phys v11 n8 Aug 1959 p 316–23 in German. A review in which the units, standards and methods of measurement of length and time, with particular reference to the practice at the PTB, are briefly surveyed. Some 150 references.

Units of Weight and Measure (United States Customary and Metric): Definitions and Tables of Equivalents, L. V. JUDSON. NBS Misc Publ n233 62 p 1960. The units of length, area, volume, capacity, and mass in the United States are defined. Tables of interrelation and tables of equivalents for these units in the metric system and in the U.S. customary system are given. All values in the text and in the tables have been revised to be in accord with the Federal Register announcement of July 1 1959, an announcement entitled "Refinement of values for the Yard and Pound" in accordance with an agreement among the directors of National Standards Laboratories of English-speaking nations to obtain uniformity in precise measurements involving the yard and the pound. The long tables were all recomputed on an automatic computer and printer. This is a revision of Misc Publ n214 1955.

Search for a Fundamental Length in Microscopic Physics, W. A. McKINLEY. Am J Phys v28 n2 Feb 1960 p129–34. This paper reviews some of the attempts to introduce into microscopic physics a constant of fundamental length. These theories aim to restrict the notion of localizability in the domain 10^{-13} cm or smaller in an effort to remove the well-known divergences which arise in modern field theory.

The Change in the Definition of the Meter and Other Important Decisions of the International Conference for Weights and Measures, J. STULLA-GÖTZ. Acta Phys Austriaca v14 n3–4 1961 p 317–23 in German. A brief record of the reasons for the adoption of the orange-yellow emission line of krypton-86 as the light source for the definition of the meter in terms of light waves. A summary of the new International Unit System is also given.

The New Standard for the Meter, L. E. HOWLETT. Can J Phys v39 n4 Apr 1961 p 639–641. On 14 October 1960 at the 11th International Conference on Weights and Measures, the physical prototype for the International Meter, a platinum iridium bar bearing two fine lines, which since 1889 has preserved the world's basic unit of length, was relegated to the position of an honoured scientific museum piece by the adoption of the following resolution to base henceforth the International Meter on a wavelength of light: "The meter is the length equal to 1650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of the atom of krypton 86."

Decimal System, Yes—Metric System, No, B. L. WEINER. Civ Eng (N.Y.) v31 n6 June 1961 p. 58–9. Author advocates changeover to some decimal system in order to eliminate manhour losses inherent in use of non-decimal quantities, but opposes adoption of metric system, because he considers units thereof artificial and impractical; he recommends keeping present unit values of English system unchanged, but to express their divisions and multiplications by decimal numbers.

On Relation Between Old and New Definition of International Metre, K. H. HART, K. M. BAIRD. Can J Phys v39 n6 June 1961 p. 781–7. In October 1960, Eleventh General Conference of Weights and Measures adopted as new definition of International Meter 1,650,763.73 wavelengths in vacuum of unperturbed .606μ line of Kr86; measurements, in terms of new definition, on four copies of meter which were well known in terms of former International Meter prototype are reported.

On The Definition of the Metre in Terms of a Light Wavelength, E. ENGELHARD, R. VIEWEG. Z angew Phys (Germany) v13 n12 Dec 1961 p 580–96 In German. A general survey of the subject. A description is given of the 86 Krypton discharge tubes and the specified operating conditions which minimize the minor sources of error for the new monochromatic light standard.

Conversion Factors and Tables, Brit Stand Instn—BS 350 pt2 1962 293 p. Tables of equivalent values of quantities expressed in different units, and summary tables of principal conversion factors from pt1; they apply in metrology, mechanics, and heat.

Meter, H. BARRELL. Contemporary Phys v3 n6 Aug 1962 p 415–34. History of establishment of meter; measurement of arc of meridian and its accuracy; international prototype meter and its recalibration; light waves as standards of length; isotope sources of monochromatic light; history of optical meter; definition of meter unanimously adopted by 11th Gen Conference of Weights and Measures; Engelhard hot cathode krypton-discharge lamp recommended by Conference. 36 refs.

How to Adapt Metric System, J. B. BAKER. Iron Age v190 n9 Aug 30 1962 p 121–3. Five considerations for exploring possibility of converting to metric system are discussed including management's attitude, drawing, tool, machines and materials.

Millionths or Microns, Which Measuring System, D. B. DALLAS. Tool & Mfg Engr v49 n4 Oct 1962 p 75–8. Reasons for change in measurement practice and arguments against conversion are discussed; important problems of unavoidable long conversion period and high cost of conversion are considered.

Unit of Length, J. TERRIEN. Zeit Instrumkde (Germany) v70 n11 Nov 1962 p 271–8 in German. The development of the international unit of length, the meter, is reported, beginning with the origin of the Metric System in France during the French Revolution, the creation of the meter unit of length derived from a particular dimension of the earth, leading to the French "Metre des Archives" in the form of an end-standard, further on to the International Prototype Meter in the form of a line-standard and finally to the new meter definition using a wave-length of the radiation emitted by atoms of the krypton nuclide Kr^{86} given in 1960 by the Eleventh General Conference of Weights and Measures. The measuring techniques and the scientific problems connected with the various forms of the meter, especially the physical foundation of the new wavelength definition of the meter and the important part played by the International Bureau of Weights and Measures during the development of the meter

is taken into closer consideration. Further possibilities in the near future are discussed. Translation available at NBS Library.

New Definition of the Meter, E. A. VOLKOVA. Meas Techns 1962 n8 Feb 1963 p 626–30 1 fig 8 refs. Translated from Izmer Tekh n8 p 5–8 Aug 1962. Describes in a popular manner the essence of the new definition of the meter, its significance, and the possibility it provides for a further raising of the accuracy of linear measurements.

The International Committee on Weights and Measures. Nature (London) v197 Mar 16 1963 p 1055–6. Describes the October 1962 meetings of the committee which were held in Paris. Proposals were made which, when formally adopted, will result in improved or extended bases for length and temperature. Included were 12 new secondary wavelength standards of length based on lines of Kr^{86}, Hg^{198} and Cd^{114}. There were six proposals to modify the International Practical Temperature Scale : (1) incorporate the T_{58} (He^4) and the T_{62} (He^3) scales in the International Scale ; (2) define the equilibrium boiling points of hydrogen and oxygen to be 20.267 °K and 90.17 °K ; (3) incorporate a Pt resistance scale between the hydrogen and oxygen points ; (4) eliminate the sulphur point (444.6 °C) and replace with the zinc point (419.505 °C) as modified in following section ; (5) change the values of the zinc (419.505 °C), silver (960.8 °C) and gold (1063 °C) points by about +0.07, +1.1 and +1.5 degrees respectively ; (6) replace the standard thermocouple on the scale with the Pt resistance thermometer. The International Committee also adopted two new prefixes for denoting submultiples of units. They are : femto, 10^{-15}, symbol "f", and atto, 10^{-18}, symbol "a".

Integration of British and Metric Systems, M. MATEOS, ASME-Paper 63-PROD-24 for meeting May 7–9 1963 4 p. Study of possibilities of complete change to metric system ; author proposes adjustment of British system to cushion shock of transition to metric system and shows that conversion from proposed metrified British system to metric can be done easily.

United Kingdom Standards of Yard in Terms of Metre, P. H. BIGG, P. ANDERTON. Brit J App Phys v15 n3 Mar 1964 p 291–300. Intercomparisons of United Kingdom yard standards (formerly known as imperial standard yard and its parliamentary copies) and their determination in terms of international meters; by Weight and Measures Act 1963 yard unit is equal to 0.9144 wagelength meter.

1.2.3. Measurements in Two- and Three-Dimensional Coordinates

See also subsection 4.4.

Micrometer for Photographic Plate Measurement, A. WOLFER. Zeit InstrumKde v27 Oct. 1907 p 297–301. Description of a new micrometer made by Toepfer, of Potsdam, for measuring rectangular coordinates on photographic plates.

Herbert Microscopic Measuring Machine. Am Mach. v53 July 22 1920 p 187. The machine has a table capable of 12-in. longitudinal movement by accurate amounts by insertion and removal of hardened steel measuring rods between flat contact pieces. The table carries a pair of centers, one of which can be adjusted crosswise to enable accurate alignment of work. A microscope fitted with two crosshairs, one rotating with the outside tube and the other rotating with the eyepiece, is mounted on a compound slide controlled by micrometer screws. The outer tube of the microscope has a dial reading to half degrees and the eyepiece has a vernier reading to one minute of arc. A light projector is fixed to the machine and will project parallel rays of light through a lens upon a mirror and past the work.

Wickman Universal Gage Measuring Machine, Am. Mach. v53 Dec 2 1920 p 1068a. This machine gives comparator readings of diameters and pitches to an accuracy of 0.00001 in., and, it is said, has proved capable of obtaining comparator measurements of length and diameters to an accuracy of 0.000005 in. Magnification is carried out by a combination of mechanical and optical means ; a mechanical magnification of 60 to 1 is magnified approximately 40 times by means of light, resulting in a magnification of 4,000 to 1, which eliminates the personal element. Capacity : Length gages up to 12 in. ; major, core and effective diameter measurements of screw plug gages up to 6 in. diameter ; pitch of screw plug gages up to 4 in. diameter.

Measuring by Optical Means. Machy (N.Y.) v32 May 1926 p 695–7 6 figs. Applications of two optical instruments, developed by Bausch and Lomb Optical Co., Rochester, N.Y., intended for use in shop, tool-room and inspection department ; one is a direct-reading thickness measure for accurate measurement to 0.0001 in.; other is toolmaker's microscope, applicable in connection with screw threads, gages, small jigs and other parts, consisting essentially of a base on which is mounted a work-table that may be moved longitudinally and transversely beneath a vertical microscope by means of micrometer screws which actuate separate slides. The microscope is adjustable on a post that is fastened to the rear of the base. Angular measurements can also be made by means of graduated collars and rotatable cross lines in the focal plane of the eye-piece.

A Two-Coordinate Measuring Machine. Am Mach v69 Nov 1 1928 p 706–7 ; Instrum v1 Sept 1923 p 419–20 1 fig. Measuring machines made by Société Genevoise d'Instruments de Physique of Geneva, Switzerland is designed to measure in two coordinates at same time ; in one direction measurements of 16 in. (400 mm.) are possible ; in other direction measurements of 4 in. (100 mm.) can be made. The object to be measured is placed on a table which moves in one direction on V and flat ways under the action of a precision micrometer screw which causes motion of the table through 16 in. The microscope is carried on a slide by which it is moved across the table by a similar micrometer screw through a range of 4 in. See also Am Mach v73 Dec 4 1930 p 900.

Compound Measuring and Gauging Table. Machy (London) v36 Aug 1930 p 697–8. Compound table developed by Alig and Baumgartel having traverses of 22 and 28 in. Screws are provided for approximate setting. Settings are made with end standards and a sensitive dial gage.

Société Genevoise Universal Two-Coordinate Measuring Machine. Am Mach v73 Dec 4 1930 p 900. This two-coordinate measuring machine is intended for general use in inspection departments of industrial plants. Provision is made for testing thread gages, micrometer screws, worms and taps for pitch, angle of profile, and diameter by means of an optical method. A heavy cast-iron bed supports the two slides which move at right angles. The longitudinal slide has a travel of 16 in. It has an opening to permit illumination from below. Pieces to be measured are not clamped to this slide, but to one of three interchangeable fixtures. A transverse carriage serves to carry the sighting microscope for measurements in the other coordinate. The front part of the transverse carriage has a vertical slide on which the tool holder can be adjusted in height. The minimum free distance between the T-slotted table and the tool holder is 3 in., the maximum $6\frac{1}{4}$ in., while the distance from the table to the transverse carriage is $2\frac{11}{32}$ in. A 6-in. circular table is furnished extra.

Single Element Verniers Reading Two to Three Dimensions, R. E. LEWIS. Rev. Sci Instrum v21 p 647–9 July 1950. See abstract under 3.6.3.

An Investigation of the Errors of Co-ordinate Machines Using Light Beams, R. PUTSCHBACH. Zeit angew Phys v3 n9 1951 p 329–32 in German. The Saladin co-ordinate generating machine using the reflection of a light beam from two orthogonal plane mirrors, is shown to suffer from asymmetrical pin-cushion distortion arising from the variation of the optical path length on rotation of either of the mirrors. An additional reflection from a cylindrical mirror between the two plane mirrors renders the distortion symmetrical, so that it can be corrected by simple optical methods.

The Coordinate Setting Machine, as sponsored by the U.S. Air Force, Published by Fairchild Aircraft Division, Hagerstown, Md., Apr 1952. Contents : Introduction ; its background ; establishing the collimation line ; setting the machine to dimensions ; setting a typical fitting ; the universal positioner ; optical rectangle ; conclusion ; specifications.

Universal Measuring Machine for Three-dimensional Forms. Machy (London) v86 n2220 June 3 1955 p 1207–9. New machine introduced by Precision Grinding, Ltd, Surrey, based on machine designed during war for inspection of three-dimensional cams ; with modifications it is now employed as universal measuring machine ; measuring head and various arrangements for measuring cams, gears, threads, length and gap gages, etc.

Les Appareils d'Optomécanique, M. PAUL. Rev Gén de Mécanique v39 n82 Oct 1955 p 343–50, v40 n85 Jan 1956 p 29–34. Application of optical instruments to industrial measurement and control. Oct 1955 : Optical control of alignments ; comparators ; profile projectors. Jan 1956 : Application for control of machines.

Toolmaker's Microscope Measures Without Contact, W. P. CHRISTOPH. Am Mach v102 n3 Feb 10 1958 p 116–8. Three-dimensional microscope described provides for direct measurement of three coordinates in mutually perpendicular system without contacting object ; third dimension obtained from indication on scale of vertical measuring screw ; problems to be handled with instrument are those which present serious measuring difficulties ; more convenient and quicker measurements possible ; optical features.

Photoelectric Indicator for Precision Setting in Co-ordinate Measurements [on Photographic Plates], E. DJURLE AND G. GRAN. J Sci Instrum v35 n8 Aug 1958 p 304–5. The indicator presents the intensity in the line or point to be measured as mirror images on an oscilloscope and uses the traces as coincidence marks. Measurements can be made in two co-ordinate directions with a standard deviation of 0.3μ or better for the setting on a line or point.

On the Positioning of a Point Using RI, S.-Y. HORI, Y. OKAMOTO, H. UTUMI, N. MORITA. Report of the Central Inspection Institute of Weights and Measures, Japan, v8 n3 report 19, 1959 in Japanese. It is the purpose of this report to describe a method for positioning a point in an opaque material by the utilization of RI. The position of a point which is in an opacity or intercepted by an opaque material has been obtained by the intensity of radiation and the absorption coefficient of radiation ; a new instrument is contrived which is able to carry out the positioning of a point only by a single scanning basing upon the triangle surveying method. Studying errors crept into this method, this instrument is proved to have a good accuracy generally less than about 30μ. The authors think that, as this method is applicable to the radiation thickness meter and general tracer experiments, will be also usable for the study of flow phenomena in a metal constitution and circulatory system of living body.

New Instrument for Three-Dimensional Inspection, A. G. JONES. Inst Prod Engrs J v38 n8 Aug 1959 p 455–8.

Instrument enables measurements of accuracy of 10^{-4} in. without correction, on curved or flat surfaces ; it consists of low powered microscope fitted with cross graticule in focal plane and illuminating system mounted on a jig borer ; unit has been used successfully for three years in measurement of wind tunnel models and many general engineering metrology problems ; diagrams and graphical data.

The Moore Universal Measuring Machine. Moore Special Tool Co. 1960. Provides a combination of rectilinear and angular positioning with electronic indicator or microscope supported on an accurate, rotatable spindle.

Position Transducer Using a Divided Circle and Coded Scale, I. R. YOUNG. J Sci Instrum v37 n4 Apr 1960 p 125–7. A small transducer is described in which a coded scale is used to distinguish the lines on a divided circle. This unit is intended as a positional reference in a large data-collecting system. The circle and code are both detected photoelectrically, through using very different cells and lamps. In order to keep the instrument diameter small, the coded scale is made in drum form.

A Semi-Automatic Apparatus for Evaluating Stereoscopic Cloud Chamber Photographs, T. HOLTWIJK. Nederlands Tijdschrift voor Natuurkunde v26 n5 May 1960 p 150–2 in Dutch. A stereo-viewing system is described for determining the position coordinates of cloud-chamber tracks from stereophotographs. The two stereoplates are projected on to a screen. The Z-coordinate of a given point on the track is determined by superimposing the two images and the X- and Y-coordinates determined by moving a positioning mark on to the point. The position coordinates are converted to an electric signal which in turn is fed into a "Zebra" computer. The equipment has been used in conjunction with a 5 MeV betatron.

Accumulating Digitizer System, T. H. FIELDS, R. W. FINDLEY. Rev Sci Instrum v31 n12 Dec 1960 p 1312–7. System for digital measurement and automatic recording of linear or angular position ; adding-substracting scaler is used to accumulate pulses generated by digitizing element ; performance of system, as used for coordinate measurements on bubble chamber photographs.

Apparatus for Automatic Treatment of Photographs Obtained From Bubble Chambers. E. M. ANDREJEV, P. HIRŠL, G. M. KADIKOV, R. POSE, M. I. POPOV, V. V. SMIRNOV, N. S. TOLSTOJ, I. A. ZARUBIN. Nuclear Instrum and Methods (Netherland) v11 n2 May 1961 p 297–306. A description is given of an automatic apparatus for coordinate method application to photographs taken from bubble chambers. The accuracy of the coordinate measurements on the film is 2–4 microns. Tracking velocity (over the film) reaches 3 mm/sec. The coordinate readings are punched on perforated tape, and they are ready to be put into electronic computers for further mathematical treatment.

Numerical Control Opens New Horizons in Inspection Practice, H. W. BREDIN, Machy (N.Y.) v67 n9 May 1961 p 124–7 ; Machy (London) v99 n2545 Aug 23 1961 p 413–14. Recently developed universal measuring machines equipped with numerical control provide rapid and automatic means of checking most complicated components ; design and operation of 8-axis measuring machine developed by Pratt and Whitney Co. West Hartford, Conn ; digital read-out of inspection results ; inspection data used for design purposes.

New Developments in Coordinate Measurements, T. S. GLADILINA. Meas Techns 1961 n3 Nov 1961 p 178–82 7 figs 1 ref. Translated from Izmer Tekh n3 p 4–7 Mar 1961. Describes the development of a coordinate measuring microscope MKI intended for accurate and productive

measurements of coordinates in miniature details, as well as for the measurement of distances and angles. The maximum lengths measured by the MKI in two mutually perpendicular directions are 100×100 mm, the microscope graduations for measuring length amount to 1μ and for angles to 10 sec.; the error in length measurements amounts to 2μ.

Inspection of Gauging Dimensions Involving Linear and Angular Measurements, J. C. EVANS, C. O. TAYLERSON. G. B. Nat Phys Laboratory—Notes on App Sci n27 1962 p 1–42. Publication serves as practical guide to inspectors concerned with examination of position gages and related work involving simultaneous linear and angular measurement; measuring block described may provide convenient means of inspecting other types of precision work.

Inspection Time Slashed on Parts Adaptable to Coordinate Measuring Techniques, C. H. WICK. Machy (N.Y.) v69 n2 Oct 1962 p 107–9. Inspection time was reduced by about 80% (on applicable parts) and quality control greatly improved by means of Sheffield-Ferranti coordinate measuring machine at Plymouth (Mich) Div of Burroughs Corp; hole and surface locations can be quickly and accurately measured on this machine, with dimensions of both X and Y coordinates being displayed simultaneously on direct readout panel; lengthy and laborious bench checks with gage blocks, surface plates, and height gages are no longer required.

Inspecting True Position Tolerances for Round Holes, J. V. LIGGETT. Assembly & Fastener Eng v5 n10 Oct 1962 p 32–5. Simplified inspection method is outlined and shortcuts which can be adopted in operations are indicated; relating location to hole size; converting coordinates to radial measure; establishing datum point; example showing drawing of part to be inspected, and inspection report form which gives necessary calculations.

New Three-Coordinate Universal Measuring Machine. Bul 1312GB Société Genevoise d'Instruments de Physique, Geneva 1963 4 p 4 figs. Uses standard steel scales with readings on micrometer projection screens. Measuring range is $16 \times 8 \times 8$ in. Numerous accessories are listed.

Picomm Coordinate Measuring Machine. Bul. D82 Pratt and Whitney Co., Inc. 1963 6 p. Measures the relationship of points, holes, and surfaces to an accuracy of 0.001 in. Gives decimal readout of X and Y coordinates and may be operated with a printer.

Calibration of Precision Coordinate Comparator, G. H. ROSENFIELD. Photogrammetric Eng v29 n1 Jan 1963 p 161–73. Procedures for calibrating screw-type, precision coordinate comparator; errors to be calibrated are periodic screw-error, scale-error and secular screw-error, curvature and weave of ways, and nonperpendicularity of axes; periodic error is calibrated using 2 mm scale graduated into 0.1 mm increments; calibration model is formed by least squares sine wave fit; scale-error and secular screw-error are calibrated using 240 mm calibrated scale graduated into 1 mm increments; calibration model is formed by least squares polynomial fit and harmonic analysis; work done in connection with RCA Ballistic Camera Review Project.

Look at Optical Tooling, D. J. FAIRFIELD. Machine & Tool Blue Book v58 n6 June 1963 p 84–91. Discussion of processes utilized by optical tooling including autocollimation, auto-reflection, planizing, plumbing and leveling; examples of optics employed on machine tools in order to achieve required standards of precision to keep chuck jaws on lathe parallel to axis of rotation, to align ways and bed, etc; checking out of rotational error in rotary tables' alignment and positioning of huge and intricate welding fixtures; optical tooling used for checking machined workpieces.

X-Y-Z Measurement. Prod Technol v1 n8 Nov. 1963 p 312–3. Three-dimensional inspection machine, introduced by Ferranti Ltd, is designed for rapid inspection of high precision parts, without loss of accuracy in measurement, and incurring strain on part of operator using machine; layout of machine is similar to that of vertical milling machine; tee-slotted table carries workpiece and is mounted on coordinate (x-axis and y-axis) slides and probe unit moves on vertical (z-axis) slideways on front of machine column; measuring capacity is 10 in. on all 3 axes; at temperature of 68 F, accuracy of plus or minus 0.0002 in. is obtainable in x-y plane and plus or minus 0.0003 in. in combination with z-axis.

New Higher-Accuracy Three-Axis Measuring Machine. The Sheffielder v10 n1 1964. Workpiece can be measured in X, Y, and Z planes in a simple progressive action without resetting. Applies moiré gratings with photocell reading heads and digital readout to 0.0001 in.

New Production Equipment. Ferranti 3-Dimensional Measuring Machine, G. W. MASON, A. J. BARKER. Machy (London) v104 n2668 Jan 1 1964 p 37–8 1 fig. Machine is based on the Ferranti co-ordinate inspection machine but incorporates a vertically-adjustable, counterbalanced measuring head. Movements are measured by individual moiré diffraction gratings and photoelectric scanners.

1.2.4. Surveying Methods Applied to Large Mechanical Structures

Surveying Instruments Enter Shop, P. KISSAN. Civ Eng (N.Y.) v19 n11 Nov 1949 p 27–9. Surveying instruments have important assets which are lacking in shop measuring equipment; they can easily provide accuracy of 1/1000-in. at 20 ft; for shop conditions, usual field procedures must be modified and new methods developed; problem is outlined and suggestions for its solution are offered; technique was developed to provide precision in large parts such as jigs built to very small tolerances, used in production of interchangeable parts.

Maximum Likelihood Estimates of Position Derived from Measurements performed by Hyperbolic Instruments. E. LUKACS. J Res NBS v47 Sept 1951 p 197–201. Certain electronic surveying instruments—referred to as hyperbolic instruments—determine the difference between the distances from fixed stations to a moving object. Data obtained from a single observation yield one relation between the three coordinates of the moving object and restrict it to a hyperboloid of revolution. To locate a position in space, observations are taken, more than three equations for the three coordinates are obtained. In general these equations will not be compatible; it is then a statistical problem to find an estimate for the unknown position. In this paper maximum likelihood estimates are obtained for positions in space derived from such hyperbolic data.

A Laboratory Method for Determining the Angles Subtended by Distant Objects, K. GROSSFIELD. J Opt Soc Am v42 Oct 1952 p 754–5. A method is described for the determination of the small angle subtended by a distant object. Rays from the object are passed through a biprism, thus causing an interference pattern. If the object is considered as two separate sources, then by altering the position of the biprism the interference pattern caused by one of these sources may reinforce or blur the interference pattern caused by the other. A relation similar to that of a two-slit stellar interferometer has been derived and tested by experiment. Hence the angle subtended by the object can be evaluated.

The Precise Establishment of Long Co-ordinates in Factories, O. S. READING. U.S. Coast and Geodetic Survey. Paper n30 Symposium on Engineering Dimensional Me-

trology, NPL Oct 1953 p 485–93 4 figs. Describes system using rays of light, avoiding well known causes of refraction, and sensitive levels. Recent developments greatly facilitate the precise establishment of long coordinates.

An Interferometric Method of Distance Measurement; Frequency Modulation Radar, G. BROUSSAUD. Rev Opt v35 n11 Nov 1956 p 593–603 in French. The equations governing the measurement of distance by optical interference methods are developed to include distance measurement by f.m. radar. This latter method differs from optical techniques not only in the wavelength employed but in the kind of problem which it solves.

Electro-Optical Distance Measuring, A. BJERHAMMAR. K Tekn Högsk Handl n151 1960 101 p. A report on the examination of the reliability of a quartz crystal of BT cut used as an electro-optical light modulator at frequency 4 Mc/s. A theoretical analysis is made and at proper adjustment the fundamental frequency is obtained without distortion of even harmonics. Odd harmonics give no errors in a suitable phase discriminator. A 70% modulation is obtainable. Zero point drift of the instrument is studied. At a distance of 10^2 cm the standard deviation of a single measurement is ±1.1 cm. The instrument, described in detail, is called a Terrameter. Practical operating ranges are 50 m to 5 km. Total power consumption is 5.5W. Theory of modulation is studied in detail. 120 oscillograms are reproduced.

An Electro-Optical Device for Measuring Distance, A. BJERHAMMAR. J Geophys Res. v65 n2 p 412–7 Feb 1960. A light beam is modulated at 4 Mc/s by passage through a piezoelectric quartz crystal between polarizers. The beam is transmitted over the distance to be measured and returned to a photocell. The output from the latter, together with a signal from the oscillator, is fed into a phase-sensitive superheterodyne circuit. The arrangement is suitable for distance from 50 m to 5 km. At 1 km the standard deviation of a single measurement was found to be ±11 mm.

Physical Principles of the Electro-Optical Determination of Distances, A. KAROLUS. J Geophys Res v63 n2 Feb 1960 p 394–403. The principles of distance meters based on the methods of Fizeau and Karolus for the measurement of the velocity of light are discussed. The discussion is concerned primarily with the quantitative evaluation of the systematic errors in the methods of modulating light and of light and phase measurement. It is concluded that detailed study is necessary to develop a meter sufficiently accurately for geodetic applications.

Increased Accuracy of Measurement by Means of Tape Measures, B. E. KOSTICH. Meas Techn 1959 n4 May 1960 p 249–51 2 figs 3 refs. Translated from Izmer Tekh n4 Apr 1959 p 7. Discusses accuracy of measurement in applying tapes in heavy engineering.

Application of an Optical Inner Base Range Finder in a Factory Arrangement for Checking Dimensions of up to 25 m, B. E. KOSTICH. Meas Techn 1959 n6 June 1960 p 413–5 2 figs 4 refs. Translated from Izmer Tekh n6 June 1959 p 19. The application of instruments and length measurement methods used in surveying for the dimension control in heavy machine construction has aroused much interest. The TsIZM measuring device is based on the optical system of a range finder with a variable parallax angle, which secures an accuracy greater than that of the variable base method.

Simultaneous Adjustment of Angular and Distance Measurements, F. F. CEELY, JR. J Geophys Res v65 n9 Sept 1960 p 2845–1. The development and use of electronic distance-measuring instruments has posed the problem that many of our triangulation networks have become a mixture of triangulation, trilateration, and traverse, espe-

cially in the areas where control is needed for the interstate highway program. A method of adjusting triangulation, trilateration, and traverse simultaneously is presented in this paper. The formulae, methods, and techniques were devised in an attempt to make an adjustment that gives a satisfactory solution with minimum distortion to both angular and distance measurements. A presentation of several approaches to the problem is made with emphasis given to the application of these methods to an intermediate-sized electronic computer.

Distance Measurement by Means of a Light Ray Modulated at a Microwave frequency, K. D. FROOME, R. H. BRADSELL. J Sci Instrum v38 n12 Dec 1961 p 458–62. Describes an experimental equipment (known as the "NPL Microwave Mekometer") using elliptical polarization modulation of a light beam at 9400 Mc/s and intended for the accurate measurement of distances of the order of 50 m. The beam is returned from a distant reflector to the modulator at which the ellipticity is either increased or cancelled. A knowledge of the speed of light and the modulation frequency serves for derivation of the modulation wavelength; the distance from reflector to modulator is then obtained in terms of the number of modulation wavelengths in it.

Optical Tooling for Precise Manufacture and Alignment, P. KISSAM. McGraw-Hill Book Co. Inc. 1962 272p. Subjects covered include the optical-tooling method and procedures, optical principles, optical instruments and their tests and adjustments. Optical tooling is a system of measurement and alinement utilized for the precise control of large sizes. The fundamental accuracy of optical tooling depends on the use of the telescopic sight, the use of gravity as a reference direction and the application of many special optical devices, generally of the same nature as very precise surveying instruments.

Effect of Chromatic Aberrations on the Sighting Accuracy of Geodetic Telescopes, K. E. NIGGE. Zeit InstrumKde (Germany) v71 n3 Mar 1963 p 67–72 in German. By means of two theodolites with lens-system telescopes and two with mirror-lens telescopes, the problem of achromatism of the surveying type of telescopes was studied experimentally. The main consideration was how the accuracy of sighting with triangulation theodolites is influenced by parallax due to inexact focusing caused by insufficient correction of the chromatic aberrations.

An Alignment Interferometer, J. B. SAUNDERS. Appl Optics (USA) v2 n5 May 1963 p 541–2. An interferometer is illustrated which permits very accurate alignments of points along a straight line several miles long. An error of 1/10 of a fringe spacing corresponds to less than 0.4 mm for a distance of 1.6 km with a wavelength of light 5600 A and a 25 cm diameter mirror on the interferometer. Ample illumination is obtainable with zirconium arc lamps.

Keeping Abreast of Instrumentation Development, A. E. BUSCH. Surveying & Mapping v23 n2 June 1963 p 275–82. Industrial surveying instruments are considered which utililze fundamental principles of alignment, and angle or distance measuring, but which have been refined, automated and applied to various types of problems, including missile tracking, fire control and even contour analysis of parabolic surfaces; alignment telescope, jig transit, visual and electronic autocollimators, and special radar alignment telescope used in Nike missile tracking system, are described; work to produce new types of cinetheodolite is reported; importance of use of survey equipment by qualified operators is emphasized.

The NPL Mekometer, R. H. BRADSELL. Trans Soc Instrum Techn Nov 13 1963 5 p 2 figs 7 refs. Describes an electronic device for the measurement of distances of the order of 50 meters to an accuracy of about 0.05 mm. Applies the method of coincidences to several different

modulation frequencies of light which is elliptical polarization-modulated by a crystal of ammonium dihydrogen phosphate subjected to a microwave field.

Optical Tooling for Profit, L. HURTT. Naval Engrs J v76 n3 June 1964 p 461–5. Optical tooling is adaptation of surveyors methods and instruments to manufacturing tasks; instruments include jig transit, precision level, right-angle devices, optical micrometer, optical tooling scale and tapes, and these are defined; application of "Master Planes Procedure", which is establishment of master horizontal and vertical reference planes, is explained; diagrams show examples of optical tooling as applied in marine industry.

1.3. Precision, Accuracy, Uncertainty

1.3.1. General

Discussion of the Precision of Measurements, S. W. HOLMAN. Technol Q v1 n 2, 3, 4 1887. Notes of a brief lecture course on the laws governing the precision of measurements, with application of the methods of least squares.

Die Sicherung richtigen Längenmasses unter besonderer Berücksichtigung der Endmassnormale (Accuracy in End-Standards of Length), H. STADTHAGEN. Zeit VDI v55 Sept 9 1911 p 1525– 9. The reasons for the uncertainty in the use of these standards are discussed; and suggestions are submitted for the removal or mitigation of the errors.

Elements of the Precision of Measurements and Graphical Methods, H. M. GOODWIN. McGraw-Hill Book Co., N.Y. 1913 104 p. Precision discussion of direct measurements; deviation and precision measurements; weights and weighted mean; criterion for rejecting observations; computation rules and significant figures; precision discussion of indirect measurements.

Measurement and Errors in Manufacturing, G. S. RADFORD. Mgmt Eng v1 n5 Nov 1921 8 p 2 figs. Discusses evolution of measuring, selection of characteristic qualities, selection of standard samples, measurement by comparison with a scale, the measuring instrument, measurement and accuracy, precision in measurement, theory of errors, cure for errors.

Über die Grenze der physikalischen Messgenauigkeit (The Limits of Accuracy in Physical Measurement), W. BLOCK. Zeit Instrumkde v44 Aug 1924 p 366–70. A concise summary of the limits of accuracy of measurement of physical quantities based on the fundamental units of time, mass and length. It is shown that almost theoretical accuracy can be obtained in the case of mass and length units. Paper furnishes a useful collection of details concerning limits of accuracy in physical measurement of standard units. Maximum accuracy of length and mass measurements equals 5×10^{-7} and 5×10^{-8}.

Einige Bemerkungen zur Fehlerrechnung bei technischen Messungen (A few Remarks Regarding Estimation of Errors in Technical Measurements), G. BERNDT, Zeit Feinmech und Präzision, v3 July 5 1925 p 139–41.

Correction of Data for Errors of Measurement, W. A. SHEWHART. Bell System Tech J v5 Jan 1926 p 11–26 6 figs. Discusses error corrections of data taken to show quality of a particular lot, or taken periodically to detect significant changes in quality of product, or taken to relate observed deviations in quality of product to some particular cause.

Erreurs de Mesures; Erreurs et Tolérances de Fabrication des Calibres; Interchangeabilité des Pièces Filetées (Errors of Measurement; Errors and Tolerances of Manufacture of Gages; Interchangeability of Threaded Parts), L. FRAICHET. Services Techniques de L'Aeronautique Bul Technique n61 Sept 1929 38 p 8 figs (in French), Chapter 1 deals with measurement of angles such as those of a trapezoidal gage, measurement of small angular differences, taper gages, and squares. Chapter 2 gives the mathematical relationships of errors in measurement of pitch diameter, pitch, and flank angle by means of wires of any thread angle. Chapter 3 deals with standardization of threads and interchangeability of threaded parts.

Über die Dezimalgleichung beim Ablesen von Skalen (Decimal Equation Reading of Scales), H. BAECKSTROEM. Zeit für Instrumkde v50 Nov Dec 1930 p 609–24 665–79 36 figs. Nov: Subjective division of scale interval symmetry of subjective interval at various locations of division; calculation of corrections; series of experiments by Grossmann; calculation of average error. Dec: Calculation of average error from complete series of observations; influence of number of observations on decimal frequency, and of nonuniform division on exactness; test results. Bibliography.

Die physikalisch-theoretischen Grenzen der Messbarkeit, W. GERLACH. VDI Zeit v81 n1 Jan 2 1937 p 2–7. Physical theoretical limits of possibilities of measurements; author shows how in light of modern developments in measuring technique, limits of measurements are only determined by developments in physics and discusses present day possibilities under headings: small energy, measurement of atomic values, etc.

Fehlertheorie und Ausgleichrechnung und Ihre Anwendung auf betriebsmässige Längenmessungen (Error theory and compensation calculation and their application to operational length measurements). H. SCHMIDT. Werkstattstechnik und Werksleiter v36 n23/24 Dec 1942 p 2–4 1 fig 5 refs.

Experimental Data and "Sufficient" Accuracy, H. A. HUGHES. Nature (London) v158 July 6 1946 p 29.

The Fundamental Problems of Experimental Physics, J. HOUGH. Am J Phys v19 Dec 1951 p 489–99. An elementary treatment of the nature of an experiment is given in order to demonstrate the various factors which must be considered in planning an experiment. Particular attention has been paid to the factors on which the accuracy of the final result depends; and it has been found desirable to introduce two new quantities, the reading and experimental limits, which give a measure of the maximum accuracy of a measurement and an experiment, respectively, obtainable with the particular apparatus.

On Absolute Measurement, E. DORSEY, C. EISENHART. Sci Monthly v77 n2 Aug 1953 p 103–9. Theory of errors, averaging, quaesitum, definitive value, dubiety, procedure, report, miscellaneous.

Engineering Dimensional Metrology—Proc of Symposium held at NPL, Oct 21–24 1953 2 v. Her Majesty's Stationery Office, London, 1955 689 p. Collection of 40 papers covering measurement problems relating to workshop inspection, pneumatic gaging, machine tools, gear measurement, small scale and large scale metrology, surface finish, and related subjects.

Das Genauigkeitswese in der technischen Normung (The Essentials of Accuracy in Technical Standardization), J. ICKERT. Springer Verlag 1955 99 p 51 figs 67 refs. Investigates the general principles of accuracy in relationship to technical standardization. General bases of accurate gaging and uncertainties in standards.

How to Appraise Accuracy in Measurement, W. J. DARMODY. Am Mach v100 n22 Oct 22 1956 p 130-2, 48 pointers to help evaluate workpiece, measuring or gaging instrument, reference standard, environment of measurement, and human element in measurement.

Measurement Error Detection and Correction. W. J. HILL, Tool Engr v42 n6 June 1959 p 73-8. Inspection problems encountered when material supplied by outside sources must meet rigid requirements of components in control system; approach to inspection of gyro bearings was to determine repeatability of shop and supplier measuring equipment, average difference in measurement between them, and correction factor.

Ueber die Messunsicherheit beim Messen von Durchmessern Ueber 500 mm im Grossmaschinenbau, L. WIZENEZ. Werkstattstechnik v49 n6 June 1959 p 323-9. Inaccuracies in measurement of diameters of over 500 mm in construction of heavy machinery; attempt made to determine systematic measuring errors according to their size and importance; factors discussed which influence measurement of large diameters, such as temperature, gravity, measuring force, etc.

Propagation of Error in a Chain of Standards, A. G. McNISH, J. M. CAMERON. IRE Trans vI-9 n2 Sept 1960 p 101-4 2 figs. Discusses the concept of traceability in standards and how errors are propagated in a chain of standards. Experimental examples are given.

Investigation into Accuracy of Industrial Measurement of Sizes between 0.2 Inch and 5 Inches, P. W. HARRISON. Instn Mech Engrs-Proc, v175 n3 1961 p 211-34. Report of study by NPL on behalf of Brit Standards Instn, concerned with Int Organization for Standardization revision of system of limits and fits which will include enlarged section on measuring instruments; work pieces were circulated to 40 firms whose measurements were compared with those made at NPL; comparisons are made with earlier work on sizes 4-80 in.

Systematic Errors in Standards of Measurement, W. J. YOUDEN, NBS. AOA Meeting, Feb 1961 6 p 1 fig.

Investigation into the Accuracy of Industrial Measurement of Sizes between 0.02 in. and 5 in., P. W. HARRISON. Inst Mech Engrs, 1961 15 p 7 figs 5 refs. Work-pieces were circulated to forty firms whose measurements were compared with those made at NPL. The algebraic mean error of these measurements at different diameters, although having a distinctive pattern, was small in relation to the spread of individual errors about this mean. Errors on external measurements were less than those on internal measurements, and the report discusses this and other characteristics in relation to the techniques of measurements used. Some optimism is apparent in the estimates of accuracy made by the participating firms. The results of this investigation are linked with those of an earlier investigation covering the size range 4 to 80 in.

An Analysis of Measurement Errors as Applied to Calibrations, J. R. MILLER III. Calibration Center, AOMC, Redstone Arsenal, 3 p 3 refs. Deals with: (1) bounds to be placed upon the uncertainty of a reported value. (2) propagation of errors in a chain of standardization or measurement laboratories.

How to Handle Errors in Measurements, R. P. BENEDICT. Prod Eng v32 n41 Nov 13 1961 p 93-5. Three questions discussed are finding best way to report uncertainties, how error in measurement will be propagated into result, and how uncertain results may be converted into meaningful test interpretation; examples given and precautions recommended.

Measurement Problems in Physical Experiments, J. P. KOHN. Instrumentation v15 n4 1962 p 10-13. Definitions of accuracy, precision and sensitivity; problems in selecting instruments according to these characteristics; examples of pressure measurements and studies of solid state materials and corrosion rates of metals.

On Realistic Measurement of Precision and Accuracy, C. EISENHART, NBS. ISA-Nat Aero-Space Instrumentation Symposium 8th-Proc 1962 p 75-83. Nature and objectives of measurement; measurement as production process; correction and adjustment of measurements; law of large numbers and mathematical formulation of bias and precision of measurement process; variations of procedure, apparatus, observers, and environmental conditions allowable in "repeated" applications. 21 refs.

Basic Principles and Accuracy of Measurement in Relation to ISO System of Limits and Fits, L. W. NICKOLS, NPL, Paper n3, Nat Conf on the Accuracy of Industrial Measurement of Length and Diameter, Apr 17-18 1962 22 p 10 figs 4 refs. Discusses interpretation of limits of size, error of a measuring instrument, relation between the inaccuracy of the measuring process and the safety margin, effect of errors of form of the workpieces, influence of workshop conditions on accuracy of measurement including the effect of temperature and the influence of the workpiece on inaccuracy of measurement.

Industrial Needs as Reflected by NPL Investigations on Accuracy of Measurement, P. W. HARRISON. Machy (London) v100 n2585 May 30 1962 p 1237-42. Reference made to 2 extended investigations carried out by NPL to 'establish accuracy of measurement of size currently achieved in British industrial firms; method used was to select appropriately shaped workpieces having internal and external diameters from 0.02 in. up to 80 in.; parts were measured first at NPL under optimum conditions, and then by private firms; summary given on manner in which results were examined; conclusions drawn.

Basic Principles and Accuracy of Measurement in Relation to ISO System of Limits and Fits, L. W. NICKOLS. Machy (London) v 101 n2594 Aug 1 1962 p 235-41. Discussion of some problems which are being faced in preparation of Part 2 of new ISO system and possible ways of overcoming them; system now in course of preparation, will give recommendations for dimensional inspection concerned with principles of gaging, design of gages, measuring instruments, and accuracy of measurement; interpretations of limits of size; relation between inaccuracy of measuring process and safety margin; effect of errors of form of workpieces.

Realistic Estimates of Errors in Measurements, W. J. YOUDEN. ISA-Proc Preprint 44.5.62 for meeting Oct 15-18 1962 4 p. It is emphasized that concept of error in measurement has meaning only in terms of use to which measurement is put; method for experimental estimate of realistic errors is given together with some efficient methods of tracking down most important sources of error.

Accuracy Analysis of Measurements, W. J. DARMODY. ASME-Paper 62-WA-280 for meeting Nov 25-30 1962 p 5. Total or system concept of measurement is useful approach to constructive analysis of measuring accuracy; elements useful as guides in analyzing measurement accuracy are considered as follows—standard, workpiece, instrument, person, environment.

The Accuracy of Industrial Measurement of Length and Diameter. Proc Conf n14 NPL Apr 17-8 1962 Her Majesty's Stationery Office, London, 1963 437 p illus. Twelve papers with discussions.

Uncertainties in Calibration, W. J. YOUDEN. IRE Trans Instrum (USA), vI-11 n3-4 Dec 1962 p 133-8. Presents some methods for making comparisons between standards and items undergoing calibration. These methods may be

used in a variety of measurements. The purpose is to accumulate data that provide objective estimates of the precision and that are also useful in detecting sources of systematic errors. This purpose is achieved by using some standard statistical designs in the scheduling of the work program. The problems of stating the uncertainty and of combining the uncertainties in a chain of calibrations are discussed.

Error Analysis in Metrology, D. B. SCHNEIDER. Misc Publ 248 1963 p 93–102. Analytical method developed at Boeing Primary Standards Laboratory is presented that recognizes and combines quantitative values for systematic and random component errors which significantly influence measurement results; included in method is technique for determining confidence interval of uncertainty; example of application of technique is illustrated by calibration of optical pyrometer.

Measurement Errors—Identification, Detection, Evaluation and Expression, A. J. PLOURDE. NBS Misc Publ 248 1963 p 103–9. Definition is given of measurement uncertainty and methods for evaluation of uncertainty are recommended; paper is based on concepts developed at Metrology Dept of Bureau of Naval Weapons, Pomona, Calif.

Measurement-Agreement Audits—Method for Increasing Confidence in Measurements, P. M. RIVOT. IEEE Int Convention Rec v11 pt5 (Aerospace & Navigational Electronics, etc) 1963 p 264–9. Causes for measurement incompatibility and some measurment-agreement-audit techniques for increasing confidence in compatibility of measurements; measurement agreement audit can be considered system for checking and having necessary adjustments made in accuracy of calibrations, measurements, and tests by submitting appropriate samples or measurement devices for calibration, meaurement, or test.

Correlation of Certain Basic Terms in the Field of Measurements, A. B. SHAEVICH. Meas Techns 1962 n10 June 1963 p 805–7 4 refs. Discussion by N. Y. Krupp p 807. Translated from Izmer Tekh n10 p 1–2 Oct 1962. Discusses meanings of terms such as precision, accuracy, and reproducibility.

Determining the Precision of Tolerance-Limited Controlling and Measuring Devices, B. A. VIGMAN, B. B. DUNAEV. Meas Techns 1963 n1 Aug 1963 p 16–9 4 figs 2 refs. Translated from Izmer Tekh n1 p 11–4 Jan 1963. Develops an analytical-graphical probability method which provides a single-valued determination of the precision required for a tolerance controlling and measuring device for a given set of parameters.

Geometrical and Physical Limitations in Metrology, J. C. MOODY. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 567–73. Published by ASME. Refinements in metrology are explored from point of view of engineers in metal working industry; measurement of flatness, parallelism, straightness, roundness, and surface finish; measurement of elastic and permanent compression, deflection, and surface deformation; problems arising from effects of temperature and of heat transfer on objects being measured, and on measuring machines or references.

Natural Boundaries in Metrology, L. W. NICKOLS, P. W. HARRISON. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 574–84. Published by ASME. More practicable approach than development of completely new techniques of measurement, which must necessarily be few in number, is seen to be improvement of accuracy of existing measuring techniques by carefully analyzing sources of error and taking necessary action to minimize errors; influence of errors is discussed that arise from standard, measuring equipment, process of comparison used, variations in ambient temperature and personal errors of

inspector; ways are discussed in which some of these errors can be counteracted. 18 refs.

Variation in Contact Error Between Repeatedly Wrung Surfaces, E. G. THWAITE, R. T. LESLIE. Brit J App Phys v14 Oct 1963 p 711–3 1 fig 4 refs. A controlled experiment is described for determining the variability of contact error between highly flat steel surfaces when repeatedly "wrung" together; this led to an estimated standard deviation of 0.292×10^{-6} in. for the distribution of the contact error and an "on the average" tolerance limit about the mean at the 90% level of $\pm 0.52 \times 10^{-6}$ in. A linear increase of length with serial order of wringing of approximately 0.08×10^{-6} in. per wringing was observed and has been attributed to a progressive formation of asperities on the surfaces.

Neuere Untersuchungen über Messunsicherheit (Recent Experiments Regarding Measurement Uncertainty), P. LEINWEBER. Werkstattstechnik v54 n5 1964 p 230–6 2 figs 5 refs. Measuring results on indicating length measuring instruments were reported in earlier publications, and proposals were developed for definitions of the concept "measurement uncertainty" and for characteristic numerical values for the accuracy of measuring instruments. Here these proposals are discussed on the basis of further measurements, and objections raised against them are treated.

Measurement Error Propagation, J. R. MILLER III. Instruments & Control Systems v37 n6 June 1964 p 133–4. Propagation of error in chain of measurements is discussed; procedure is described for determining error introduced by standards and instruments used; procedure eliminates need for any predetermined accuracy ratios (10:1, 5:1, 4:1, etc) but requires scrutiny of each component of system to determine which part of error is systematic, and which part random.

Uncertainties in Measurement, R. P. BENEDICT. Electro-Technology v74 n4 Oct 1964 p 51–3. Simple rules for determining maximum certainty of result which is related to one or more measured independent variables; experimental uncertainties; application of method to practical example dealing with measurement of pressure using fluid meter.

Guaranteeing a Measurement and Gage Selection Guide, W. B. McCALLUM. ASME Paper 65-Prod-2 for presentation at the Metals/Production Eng Conf June 9–11 1965 5p refs. Discusses the major variables encountered in a measuring system and establishes a technique of numerically evaluating their total effect in relation to an accuracy ratio between the measuring instrumentation and the product tolerance at a specific confidence level. By applying this technique more than 100 measuring devices have been evaluated. Some of the results are tabulated for instruments used by certain people under specific conditions.

1.3.2. Instrumental Errors

Variance of Measuring Instruments and its Relation to Accuracy and Sensitivity, F. J. SCHLINK. J. Washington Acad Sci v8 June 19 1918; NBS Sci Paper n328 p 741–64 7 figs. The terms accuracy, sensitiveness, and variance are quantitatively defined. Discusses types of variance, means for reducing variance, and relation of variance to useful sensitivity.

Genauigkeiten der Messzeuge (Accuracies of Measuring Tools), R. P. SCHRÖDER. Der Betrieb v4 n9 Feb 11 1922 p 269–74 in German. Definition of the concept of accuracy. Dependability of accuracies. End measures. Primary standards. Comparison standards. Testing standards. Working standards. DIN 168. Standards of production.

Genauigkeitsansprüche an Mikrometer und Fühlhebel (Accuracy Claims Regarding Micrometers and Indicators), G. BERNDT. Der Betrieb v4 n9 Feb 11 1922 p 280–4 13 refs. Micrometers: Relation of measurement and reading accuracy of screw micrometers; progressive and periodic thread errors; deviation from planeness and parallelism of the measuring surfaces; fluctuations of the measuring pressure; bending open; errors of adjustment; influence of temperature; measuring accuracy; use with measuring machines. Indicators: Good definition of the short lever arm or combintaion of mechanical and optical amplification; influence of measuring pressure; multiple levers (dial gages).

Recent Developments in the Art of Fine Measurement, J. E. SEARS. Eng v121 June 4 1926 p 652–4 8 figs. Recent experience shows that it is not possible to get agreement of interpretation between different observers of lines better than 0.00001 in., and this accuracy could be surpassed at present by material end standards with ends furnished optically flat and parallel, and by natural standard based upon wave-lengths of light; author refers to advance made in this direction; interference methods of measurement; triode valves applied to measurement of small displacements; measurement of internal diameters.

Genauigkeit von Messgeraeten, G. KEINATH. Archiv fuer Techn Messen v4 n46 Apr 1935 (J 021–1) p T54 2p. Precision of measuring instruments; analysis of concept of accuracy; accuracy requirements and guarantee; difference between accuracy in reading of instruments and as applied to measurements; practical tolerances. Bibliography.

Errors in Measurement of an Object by the Microscope, F. EHRENHAFT. CR Acad Sci v204 Jan 4 1937 p 40–1. Two particles identical in substance and size are separately measured visually or photographically in the field of a microscope. The particles are then moved together till they touch. The diametrical measurement at right angles to the line joining their centers gives a check on the first measurement; the difference between this and that along the line of their centers gives the correction to be applied to the measurement of single particles.

Accuracy of Measuring Instruments, G. H. BARKER. Power and Works Engr v33 n381 Mar 1938 p 110–5. Discussion on accuracy of means of measurement, its determination and proof and accuracy with which measurements are made; intrinsic and practical accuracy and true values; expression of "limits of error"; percentage and absolute errors; practical accuracy of fluid flow meters; accuracy tests against measured true values.

Die Angabe der Genauigkeit bei Längenmessgeräten (The Specification of Accuracy in Length-measuring Devices), H. SCHMIDT. Werkstattstechnik/Der Betrieb v37/22 n10 1943 p 375–6 6 refs. English translation available.

Accuracy and Geometry of Precision, E. W. PENNINGTON. Tool and Die J v 9 n8, 10, 11, Nov 1943 p 90–2, Jan 1944 p 99–101, Feb p 102–3, v10 n2 May 1944 p 90–2. Nov 1943: Discussion of requirements of accuracy of (1) position or adjustment, (2) size, and (3) form, and fulfilment of these requirements through flat surface plate. Jan 1944: Illustrated description of Whitworth's method of making or originating true flat surfaces and straight edges. Feb: Commentary on important combinations of flat surfaces or straight edges, i.e., angles. May: Methods outlined for producing true and self proving 30, 45 and 60° angles.

La Métrologie dans l'Industrie Moderne, W. RUGGABER. Rev Universelle des Mines v4 n2 Feb 1948 p 176–85. Metrology in modern industry; importance of precision measurement and errors due to instruments, discussed; temperature and elastic deformation; instruments made by Société Génévoise d'Instruments de Physique, including microscope and profile projectors, described and illustrated.

Physical Limits of Some Measuring Processes, A. MOTTU. Microtecnic v3 n2, 3 Mar–Apr 1949 p 85–90, May–June p 98–111. Measurement of line standards; inherent errors of microscope and means for minimizing them; errors inherent to scale ruling; choice of magnification power; comparison of line standards; factors influencing measuring accuracy; photoelectric process; profile projectors; surface quality measurement using Schmaltz's method, interference microscope, and "Talysurf" surface meter.

Errors of Second-Order Measuring Instruments, E. T. BENEDIKT. Rev Sci Instrum v20 April 1949 p 229–33. The various types of error which affect the result of a measurement performed by an instrument behaving as a second-order linear instrument are defined. The theoretical systematic error is shown to be caused by the (dynamical) lag with which the instrument responds to the signal. If the damping is high, this type of error is $\propto$ the rate of change of the signal. The accidental error resulting from input noise and accidental changes of the instrument constants is considered. It is shown that all these effects can be represented by an effective input noise. A formula for the mean square error in the indication of the instrument is given in terms of the correlation function of the above effective noise. Related theoretical questions on random functions are also discussed.

Notes on the Care and Use of Electrical Instruments, F. D. WEAVER, Instrum v23 n12 Dec 1950 4 p 5 refs. Precautions that should be observed by users of electrical instruments to enable them to achieve greater accuracy in measurement and to extend the useful life. Sources of error.

Measurement Errors—Classification and Interpretation, J. C. BOONSHAFT. ASME Paper n53—A–219 for meeting Nov 29–Dec 4 1953 6 p. Classification and appearance of errors contributing to uncertainty of measurement with industrial indicating and recording instruments; design details and measurement situations which affect them; special reference made to mechanical pneumatic transmission and receiver devices; relationships and typical figures are given to show technique of evaluating precision, or internal consistency.

Some Present Day Trends in Engineering Metrology, C. O. TAYLERSON. Instn Prod Engrs J v33 n4 Apr 1954 p 233–9. Progress at National Physical Laboratory, in development of precision instruments for measurements of kind required in machining, toolmaking, etc; optical measurement aids; microscopes and screw checking devices; autocollimating telescope; angle gage blocks; pneumatic gaging; examples of dynamic metrology.

Standard Calibration Methods for Measuring Instruments, J. A. HARRINGTON. ISA J v1 n7 July 1954 p 24–7. Importance of accurate dimensional control in industrial measurement and methods necessary to maintain precision; standard inch and its relationship to meter; use of light waves; some common errors of measurement and how to overcome them in different kinds of gages; problems in measurement of surface roughness.

Instrumental Drift, W. J. YOUDEN. Sci v120 n3121 Oct 22 1954 p 627–31. Drift is usually explored by making series of repeated measurements on same object; problem discussed of how operator can "forget" previous readings so that subsequent readings will not be influenced by earlier ones; comparison of actual and calculated drift; application of statistical methods in checking instrument performance.

Scale and Reading Errors of Electrical Indicators, F. D. WEAVER. Instrum & Automat v27 n11 Nov 1954

p 1812–4. Errors limit accuracy of even best electrical indicating instrument to about 0.1%; sources of errors are analyzed, and National Bureau of Standards calibration methods presented.

Ten-Millionth of an Inch, I. C. GARDNER, NBS. Ordnance v39 n210 May–June 1955 pp 896–901 12 figs. Analyses sources of error for measurements to 10^{-7} in.

Messfehler bei optischen Messgeräten (Measuring Errors with Optical Measuring Apparatus), L. MEYDING. Feinwerktechnik v62 n9 Sept 1958 p 319–22 7 figs 4 refs in German. As with other measuring instruments, optical instruments also have certain errors. If one would minimize measurement errors the limitations of the measuring instrument must be known. This work considers the limitations and the sources of errors.

How to Conquer Gaging Errors, C. W. KENNEDY. Iron Age v182 n17 Oct 23 1958 p 70–2. Nine pitfalls of precision gaging are wear, dirt, looseness, pressure, deflection, temperature, vibration, geometry, and approximation; detection of faults; their causes and remedies.

Measuring of Contact Gaps by the Absolute Interference Method, I. T. UVERSKII. Meas Techns 1958 n3 Nov 1959 p 304–6 2 figs. Translated from Izmer Tekh n3 May–June 1958 p 46. Describes investigation of accidental and systematic errors introduced by the measuring contacts of length measuring instruments operating on the contact principle.

Analysis of the Results of Checking Gauges and Instruments, E. F. DOLINSKII. Meas Techns 1958 n3 Nov 1959 p 273–82 1 ref. Translated from Izmer Tekh n3 May–June 1958 p 22. The general problem of analyzing results of checking gauges and instruments can be divided according to the number of check "points" and the type of prevailing errors into the following categories: checking constant-value gauges; checking sets of gauges and instruments with constant systematic errors only; checking instruments with random errors only; checking instruments with systematic and random errors, which is the general case. Deals with large scale testing of mass produced measures and measuring instruments when the aggregate of both the tested and reference measures and measuring instruments is sufficiently large. Methods of calculations, however, are applicable to small groups of reference measures and instruments, using the discrete distribution of probable error densities which corresponds to the given number of instruments and their errors. This is only possible if the errors of the available measures are determined with sufficient accuracy by more accurate methods than those normally used in checking these measures.

Instrument Uncertainties, L. P. ENTIN. Control Eng v6 n12 Dec 1959 p 95–8, v7 n2 Feb 1960 p 75–8. General aspects of instrument uncertainties of zero, such as those depending on manufacturing misalignment, ambient temperature variations and hysteresis; total zero uncertainty; uncertainties of scale factor and instantaneous slope, as related to specifying linearity, tolerance, excitation, and resolution.

New Limits of Accuracy, L. POLK. Machy (N.Y.) v66 n7 Mar 1960 p 128–9, 188. Aspects of precision and accuracy as they affect national capability, in manufacture and measurement, to "zero in" on target in space or on market objective in expanding programs of new product development; seventh decimal accuracy on 4 in. gage block; measurement of internal diameters; from laboratory accuracy to machining tolerances.

Evaluating Error of Measurement of Attribute Gages, G. E. SORBER, Western Elec Engr v4 n3 July 1960 p 26–31. Method for evaluation of errors in "go-no-go" gages is based on application of mathematical Probit Method technique originally developed in biological sciences.

A Method of Determining Variance in the Presence of a Linear Systematic Error. A. YU GIDEL'. Meas Techns 1959 n12 Sept 1960 p 928–31 2 figs. Translated from Izmer Tekh n12 Dec 1959 p 6. The determination of the variance of a series of measuring instrument readings is possible not only with constant external conditions but also in the presence of a systematic error. The method here developed provides the determination of the variance of instrument readings in the presence of a systematic progressive linear error.

Influence of Measuring Force, Stylus Radius, and Surface Finish on Accuracy of Measurement of Work-Pieces by Comparator, L. W. NICKOLS, T. R. J. OAKLEY. Instn Mech Engrs Proc v175 n3 1961 p 195–210, 223–34. Information was required to enable recommendations on engineers' measuring instruments; sizes of work pieces were measured using stylii of different radii under successively increased measuring forces; sizes at any one point were influenced mainly by alterations in measuring force; surface texture of work piece had greater effect than stylus radius on size variations.

Source of Measurement Error in Instrumentation Systems, R. CERNI. ISA-Proc. Preprint 19–LA–61 for meeting Sept 11–15 1961 7 p. Errors due to equipment, interference, installation, response, and operation of complex measuring instruments and systems; generalized methods for their elimination or minimization.

Observation Accuracy in Relation to the British Standards Institution's Draft Recommendation for Industrial Instrument Scale Design, J. SPENCER. Brit J App Phys v12 n12 Dec 1961 p 712–14. The correct specification of industrial instrument observation and experimental results are presented for two examples of scale design from the British Standards Institution draft recommendations. These results show that the design performance (95% of all scale value for a scale commencing at zero) is achieved providing that observers have a minimum of practice and are allowed a maximum of two seconds observation time under adequate illumination.

Error Bands, A. A. ZUEHLKE. Instrum & Control Systems v35 n4 Apr 1962 p 132–3. "Errorband" concept, representing upper and lower limits of deviation from zero error for defining instrument performance without onerous testing and calculations of many individual errors involved; example of potentiometer transducer.

Sources of Instrument Error, R. CERNI. ISA J v9 n6 June 1962 p 29–32. Measurement inaccuracies due to equipment, interference, installation, or dynamic response errors.

Interchangeable Errors in Instrument System, G. M. ANDERSON. AIEE Trans v81 pt1 (Communication & Electronics) n61 July 1962 p 191–2. Relation of interchangeable error to deviations, from nominal or standard values, of parameters of system components, to make possible control of total error by means of suitable tolerance limitation on component parameters; analysis developed for two-component system comprising transmitter and indicator can be easily extended to include systems comprising three or more components. Paper 59–156.

Classification of Measuring Devices by Their Accuracy, A. I. KARTASHEV, D. L. ORSHANSKII. Meas Techn 1962 n6 Dec 1962 p 447–51 2 figs. Translated from Izmer Tekh n6 p 1–4 June 1962. The category characterizes the degree to which a measure of measuring instrument approaches its maximum attainable accuracy with the existing technique for measuring the given physical value. The class of accuracy indicates the tolerated and actually attainable limiting measurement error.

Determining the Error of an Automatic Measuring, Testing, and Sorting Machine, I. B. GERTSBAKH. Meas Techn 1962 n7 Feb 1963 p 533–7 2 figs. Translated from Izmer Tekh n7 July 1962 p 1–4. Develops theory and method for determining the mean-square error, σ, of the measuring unit in an automatic testing and sorting machine when it is being checked under workshop conditions. This is based on the knowledge of the amount of components which are allocated to the same group in consecutive sorting.

Utilizing the Error Compensation Phenomenon for Raising the Precision of Measuring Information Systems, N. A. CHEKHONADSKII. Meas Techn 1963 n1 Aug 1963 p 3–7 4 figs 5 refs. Translated from Izmer Tekh n1 p 3–6 Jan 1963. Some of the errors produced by random external disturbances in links of a measuring information system can be compensated by suitably selecting certain characteristics of these links, thus greatly raising the accuracy of the system. The use of special transducers, which respond to the external effects and feed signals corresponding to these effects to the main channel of the measuring information system, raises considerably the precision of such systems under operational conditions.

Condition and Tasks of Metrology in the Field of Linear and Angular Measurements, L. K. KAYAK. Meas Techns 1963 n11 Apr 1964 p 893–7 2 figs 4 refs. Translated from Izmer Tekhn n11 p 1–5 Nov 1963. Discusses raising the precision in measuring standards of length; raising accuracy in reproducing the meter on reference installations; reducing the error in the methods of transferring the values of unit lengths to reference and working measures and instruments; problems of the automation of linear measurements; angular measurements; dilatometry.

Neuere Untersuchungen ueber Messunsicherheit (Recent investigations on uncertainty in measurements), P. LEINWEBER, Werkstattstechnik v54 n5 May 1964 p 230–6, Measuring uncertainty (MU) of measuring device comprises accidental and undetermined systematic defects, and is numerically expressed by plus or minus MU = plus or minus 2 s where s is standard deviation established by statistical methods; further proposals for definition of term "measuring uncertainty" are discussed on hand of measurements carried out, and of objections raised by various workers.

Measurement Error Propagation, J. R. MILLER, III. Instrum & Control Systems v37 n6 June 1964 p 133–4. Propagation of error in chain of measurements is discussed; procedure is described for determining error introduced by standards and instruments used; procedure eliminates need for any predetermined accuracy ratios (10 : 1, 5 : 1, 4 : 1, etc) but requires scrutiny of each component of system to determine which part of error is systematic, and which part random.

1.3.3. Statistical or Mathematical Treatments

Adjustment of Observations, N. CAMPBELL. Phil Mag v6 n39 Feb 1920 p 177–94. Develops zero sum method of adjustment, said to be much simpler and more convenient practically than the conventional method of least squares and equally valid.

Theory of Errors and Least Squares, H. JEFFREYS. Roy Soc Proc v138 Oct 1 1932 p 48–55. It is shown that in the absence of previous knowledge of the probable degree of precision of a set of observations, the probability of a value of h, the precision constant, lying within the range dh is dh/h. This result, applied to the theory of least squares, indicates that when the number of observations is small, the probability of error is more widely distributed than is given by the usual formula.

Mechanical Adjustment of Observations by Least Squares, B. GERMANSKY. Zeit für Techn Phys v14 n9 1933 p 370–2. The observed points are plotted on graph paper, and pins stuck into the paper at points simply related to these. Rubber bands parallel to the Y-axis are stretched, one over each pin, and passing over a metal rod which automatically takes up the position of the best straight line to represent the observations.

Method of Least Squares, A. S. EDDINGTON. Phys Soc Proc v45 Mar 1 1933 p 271–8. Furnishes a concise treatment of combination of observations.

Messfehler und ihre Zusammensetzung, A. KONEJUNG. Zeit des Bayerischen Revisions-Vereins v37 n18 Sept 30 1933 p 175–8. Errors in measurements and their analysis; errors in products and quotients; increase in accuracy by calculation of average values.

On the Statistical Theory of Errors, W. E. DEMING, R. T. BIRGE. Rev Mod Phys v6 July 1934 p 119–61. Reprinted with additional notes 1937 15 figs 47 refs.

Theory of Errors, H. KAISER. Zeit für Techn Phys v17 n7 1936 p 219–26. The theory of errors of observation is worked out on the basis of probability theory.

Richtige Summen und Mittelwertbildung, HUBER. Waerme v59 n41 Oct 10 1936 p 668. Summation and averaging examples given of how error may be introduced by incorrect application of experimental or test data in determination of mean or summation values.

Abbreviated Method and Suggested Cheap Mechanical Device for Calculating Standard Deviations of Observations, J. L. SPENCER-SMITH, H. A. C. TODD. Textile Inst J v28 n2 Feb 1937 p T21–6. Rapid graphic method of calculating deviation of set of observations, by means of Galton's "ogive" curve, applicable in measurements on textiles, etc; comparison of results with root mean square standard deviation; probable error of method is 3.5%; application of method as integrator for routine testing machines. Bibliography.

Les Erreurs Accidentelles de Mesure et d'Observation, P. SAGASPE. Arts et Metiers n202 July 1937 p 158–66. Theoretical mathematical treatise on accidential errors in measurements and observation of instrument indicators.

Application of Theory of Measurements to Certain Engineering Problems, L. E. WOODMAN. Missouri Univ School of Mines and Met Tech Series Bul v15 n11 June 1942 41 p. Per cent of deviation; percent of error; weighted mean; precision measures; notation in powers of ten; significant figures; graphical representation of errors; results; variation of functions; propagation of errors; adjustment of observations by method of least squares.

Fehlertheorie und Ausgleichrechnung und ihre Anwendung auf betriebsmässige Längenmessungen (Error theory and compensation calculation and their application to operational length measurments), H. SCHMIDT. Werkstattstechnik und Werksleiter v36 n23/24 Dec 1942 4 p 5 refs.

On the Postulate of the Arithmetic Mean, M. BOLDRINI. Comment Pont Acad Sci v10 n1 1946 p1–4. In Italian. Discusses the circumstances under which the arithmetic mean of a set of observations can be taken as a valid representative of the set.

Improvement of Precision by Repeated Measurements. Application to analytical Control Methods. J. MANDEL. Indus Eng Chem (Analyt Ed) v18 May 1946 p 208–4. This article critically examines replication of measurements as a means of increasing precision. Formulae are provided for evaluating such improvement of precision

in any given case and for computing confidence limits in routine analysis.

Linear "Curves of Best Fit," A. E. W. AUSTEN, H. PELZER. Nature (London) v157 May 25 1946 p 693–4. Discusses the procedure for finding the best estimate of the relation $w = Pv$ when both w and v are subject to normal errors. The solution given is of wide application.

Linear "Curves of Best Fit" and Regression Lines, D. V. LINDLEY. Nature (London) v158 Aug 24 1946 p 272–3. Austen and Pelzer's solution is not new. It is important to distinguish between the above lines; the former estimate the constant of proportionality between true values, the latter provide the best estimate of a true value from observed values.

On the Representation of an Experimental Law by an Approximate Law and a Curve of Deviation, P. C.R. VERNOTTE. Acad Sci Paris v223 Dec 23 1946 p 1105–7. In French. A discussion of the treatment of errors in the values of quantities determined by experiment. It is shown how the curve of deviation allows the experimental values to be regularized.

Over-Estimation of Probable Errors, R. T. LESLIE. Nature (London) v160 Nov 29 1947 p 751–2. The usual formula for the combination of probable errors is invalid when the observed quantities are subject only to errors in reading scales, which are therefore limited in size. Alternative formulae are worked out for this case.

Graphisches Verfahren zum Ausgleich wiederholter Messungen, W. LEDE. VDI Zeit v90 n3 Mar 1948 p 89–90. Graphic method for averaging of repeated measurements; method described can be used without numerical calculations; it makes use of transparent triangular scale, shown in drawing.

Separation of Errors by Calculus of Probabilities, J. MEURERS. Zeit angew Math. Mech v28 p 183–6 June 1948. In German. A method of separating the errors of two different measuring methods applied to the same object of measurement, when the effect of the errors of either method on the results is unknown.

The Numbers of Observations Needed in Experiments Leading to a t-Test of Significance of a Mean or the Difference of Two Means, G. P. SILLITTO. Res (London) v1 Aug 1948 p 520–5. The numbers of observations needed in experiments requiring statistical methods for their interpretation depend on the risks which can be tolerated of reaching two distinct kinds of erroneous conclusions. For the frequently occurring experiments involving simple comparisons of the mean of a sample with a standard value or with the mean of another sample, tables are presented showing the numbers of observations needed in relation to the tolerable risks of the two kinds of error, the precision of the experimental work, and the magnitude of the difference which the experiment is required to detect, if it exists. The use of these tables is illustrated by examples.

The Foundation of the Calculus of Observations and the Method of Least Squares, J. M. TIENSTRA. Bul Géodésique n10 Oct 1948 p 289–306. In English. An attempt to provide a new basis, free from "metaphysical conceptions" and resting on "physical facts and sharply formulated hypotheses about properties of series of observations."

Distribution of Range-Finding Errors, J. H. CALDWELL, K. H. SPRING. Letter in Nature (London) v 166 Nov 25 1950 p 906–7. The frequency distribution of error expressed as $y = $ range error/(true range)^2 is found from trials to depart from the normal form and to show significant skewness. This skewness is shown to arise from the approximation use, which implies that equal range

errors will arise from equal angular errors of opposite sign. After making allowance for this, the distribution is found to be symmetrical although still not normal.

Statistical Analysis of Errors in Point Gauge Measurements, G. D. RANSFORD. Houille Blanche v6 n4 July–Aug 1951 p 518–24. Method is applicable when no standard measuring equipment is available; sources of error include calibrated scale length due to temperature changes; application of "analysis of variance" to solution of problem; readings taken with 5 similar point gages on 6 different water levels at rest, show that maximum probable error is plus or minus 0.2 mm. (In French and English).

The Reliability of Measured Values—Fundamental Concepts, C. EISENHART. NBS Rept n 1600 15 Apr 1952 43 p 3 figs. Discusses: inter-relations of bias, precision and accuracy; comparison of an accurate biased procedure with an inaccurate biased procedure; evolution of a real-life direct-measurement process.

Calculation of Accuracy of Results of Graphical Square Intercomparisons, P. M. GILET, G. S. WATSON. Austral J Phys v6 June 1953 p 155–70. Graphical squares of two types are used for calculating the results of intercomparisons of standards of length, mass and other quantities, and the results of calibration of scales. By means of graphical squares, estimates of the true values or "improved" values are obtained from observations. From the differences between the improved and observed values, the residuals, a measure of the accuracy of intercomparison, may be obtained. In this paper expressions are derived which enable the calculation from the residuals, of accuracies of observed values, of improved values and of various quantities derived from the improved values.

The "Best" Straight Line Among the Points, R. H. BACON. Am J Phys v21 Sept 1953 p 428–46. The familiar method of fitting a straight line to a set of experimentally observed points by use of least squares is reviewed, and variations of it briefly discussed. Then methods, apparently not so familiar to many physicists, for estimating the adequacy of the fit thus obtained, and for comparing the results of several such experiments, are explained. A few of the principles of mathematical statistics underlying these methods are given in the appendix.

Sets of Three Measurements, W. J. YOUDEN. Sci Monthly v77 n3 Sept 1953 p 143–7 4 refs. Discusses the significance of differences between two or more measurements in relation to uncertainty.

Units for Measuring Variations in Measurements, W. J. YOUDEN. Metal Progr v64 n3 Sept 1953 p 91–6, 96B. Three units for measuring variation among measurements include range of observation, average deviation and standard deviation; their computation; number of measurements needed; examples given showing how to make use of information about variation exhibited by group of numerical quantities; statistical table for appraising variability is presented.

Rejection of Outlying Observations, F. PROSCHAN. Am J Phys v21 Oct 1953 p 520–5. Makes available to the physicist two of the modern statistical tests for possible rejection of outlying observations. These two methods have been selected because they apply in a majority of the actually occurring situations and because they are so easy to use.

Investigation of Errors of Observation, R. T. LESLIE. App Statistics v3 n2 June 1954 p 112–5, supp plate. Statistical theory of errors is often applied to measuring precision of observations of physical quantities without due consideration being given to question of independence of errors from various sources; features of apparatus designed to investigate this problem as it affects observa-

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tions made with optical instruments incorporating reference lines, graticules, etc.

Sensitivity—Criterion for Comparison of Methods of Test, J. MANDEL, R. D. STIEHLER. J Res NBS v53 n3 Sept 1954 (RP2527) p 155–9. Single criterion is presented by which relative merit of methods of test can be evaluated; main advantage of new criterion, referred to as sensitivity, is that it takes into account, not only reproducibility of testing procedure, but also its ability to detect small deviations in characteristic to be measured; applicability to chemical analysis, etc.

Tables of Error Function and Its Derivative. NBS App Math Ser n41 Oct 22 1954 302 p. Improved tables of error function, or probability integral to 15 decimal places for values of argument x from 0.0000 to 1.0000, and from, 1.000 to 5.946 and over at intervals of 0.0001 and 0.001 respectively; applicability of tables to problems in refraction, conduction of heat, and other fields of physics, to variety of problems in theory of probability and mathematical statistics.

Practical Application of Uncertainty Calculations to Measured Data, L. W. THRASHER, R. C. BINDER. ASME Paper n55—A–205 for meeting Nov 13–18 1955 5 p. To assess reliability of measurements, it is desirable to classify two types of measurements: multiple sample and single sample; case for single sample has not been established; it is proposed that tester estimate his error, uncertainty interval, and give odds that error would be less than uncertainty interval if measurement were repeated many times; numerical example.

A Theory of Certainty. II Application to Metrology, M. C. CAMARGO. Anales de la Real Sociedad Española de Fisica y Quimica v52 (A) n1–2 Jan–Feb 1956 p 43–58. In Spanish. A mathematical discussion of theory of errors on the postulate that errors above a certain size are impossible (not very improbable, as on the Gaussian treatment). A formula is obtained which gives the probability that the true value lies between any two given limits. The size of the graduations of the measuring instrument is taken into account. An expression is also obtained which serves as a numerical measure of the departure from the Gaussian distribution.

Statistical Approach to Spatial Measurement, A. M. RUSSELL. Am J Phys v24 n8 Nov 1956 p 562–7. A method of determining length is described which reduces the measurement to a counting operation. The same technique is then applied to the measurement of flat areas and sections of the surface of a sphere. The limits of error are discussed and in particular the dependence of the error upon shape and the choice of a lattice is observed in the measurement of flat areas. Some possible applications are suggested.

Limit of Usefulness of Repeated Measurements, R. I. YANUS. Fiz Metallov i Metallovedenie v4 n2 1957 p 369–74 in Russian. It is shown that Gogoberidze and Kirillov's opinion, that repeated measurement of a particular quantity by the same instrument can reduce the probable random error of the measurement only to the error in reading the indication of the instrument, is valid only for those trivial cases in which the numerical results of all measurements are equal.

Korekcja Przypadkowych Uchybow Pomiarowych na Zasadzie Ciaglosci Przez Przestawianie Zmiennych, M. MAZUR, M. KRUSZYNSKI. Archiwun Elektrotechniki v6 n3 1957 p 461–72. Correction of casual measuring errors; method of transposition of variables, which permits correction of casual errors without increasing amount of measuring points; applicability of method in cases where curve graphs have to be drawn on base of small amount of measuring points.

Theory of Error, Y. BEERS, New York Univ. Addison-Wesley Publ. Co. Inc. 66 p 4 illus, paperbound. 2d Ed 1957. Presents the basic principles of the theory of error and illustrates them by direct application to actual laboratory experiments. In preparing the revised edition major attention was devoted to the sections on definition of a standard deviation, rejection of data, the standard deviation in an average value, and best fit of a straight line. Although intended primarily for students in advanced undergraduate physics laboratory courses, the book is adaptable to a wide variety of uses. Contents: Introduction. Definitions. Classification of errors. Random error of a measured quantity. Propagation of error. Special topics in the adjustment of data. The statistical errors of nuclear physics. Examples. References.

On the Quantization of the Measured Quantity in the Static Measurement, M. MORIMURA. Report of the Central Inspection Institute of Weights and Measures, Japan, v7 n2 report 15 1958 in Japanese. As the measuring system has various sources of error, the measured value obtained from it is necessarily quantized. The "quantum" of the measured value in the static measurement by the linear system with the scale-pointer display corresponds to the "scale unit" defined by D. M. Mackay. As the measured quantity has the probability distribution, it is more desirable to use the concept of average scale unit weighted by the distribution than to apply directly the scale unit in Mackay's sense. Under some reasonable assumption for physical system, the equation for the average scale unit was formulated. On the other hand, the optimal way to maintain the given precision is to minimize the labor necessary to do it, and the optimal condition was derived. For the case of two simple examples, that is, for the δ-distribution and uniform distribution in the measured quantity, the above conditions are calculated and shown graphically.

On the Statistical-Graphical Evaluation of Results of Measurments, W. EHRENBURG. Zeit angew Phys v9 n3 Mar 1958 p 147–51 in German. This paper describes the use of graphs of cumulative distribution functions plotted on probability (normal law) graph paper, with special reference to (1) estimation of standard deviation, (2) dissection into two, or more, normal distributions, and (3) finding normalizing transformations. There is also a theoretical discussion of methods of estimating probabilities.

Engineering Statistics, A. H. BOWKER, G. J. LIEBERMAN. Prentice-Hall Inc. 1959 585 p illus. Contents: Histograms and empirical distributions; other probability distribution; significance tests; tests of the hypothesis about a single parameter; tests of hypothesis about two parameters; estimation; analysis of variance; analysis of enumeration data; statistical quality control and control charts; sampling inspection.

Die Messunsicherheit und ihre Bedeutung fuer Masstoleranz und Fertigungstoleranz, R. NOCH. Werkstattstechnik v49 n1 Apr 1959 p 195–9. Uncertainties of measurement and their importance to dimensional and machining tolerances; statistical analysis of measurements shows why tolerances indicated by designer cannot be fully utilized in production; it is claimed that improved measuring techniques are economically justified, especially for costly workpieces.

A Method of Calculating the Experimental Error with a View to its Elimination, P. VERNOTTE. CR Acad Sci (Paris) v248 n21 May 25 1959 p 2968–9 in French. If the physical quantity sought is a linear function of the measured data the experimental error can be expressed as a series of functions with periods 2, 3, 4. . . . See CR Acad Sci (Paris) v245 n18 Oct 28 1957 p 1521–2. These functions can be eliminated by summing the data two at a time, three at a time, etc. The result obtained then lies between a definite maximum and minimum. As an example the

method is applied to some preliminary measurements of g by the free fall in vacuo method made at the Pavillon de Breteuil.

Utilization of the Theory of Random Functions in Metrology, N. A. CHEKHONADSKII, Meas Techns 1958 n2 Aug 1959 p 121–6 2 figs 2 refs. Translated from Izmer Tekh n2 Mar–Apr 1958 p 3. A problem in the field of metrology is examined in the solution of which the methods developed by the theory of random functions can be successfully used. Article derives a general expression for the resultant error of a measuring system.

Statistical Analysis of Measurement Data. Special Report. ISA J v6 n9 Sept 1959 p 74–84. Two companion papers dealing with problems of "data indigestion" in some branches of engineering, such as in aeronautic research and flight data acquisition ; Less Data—More Information, E. J. DURBIN, 74–9 ; discussion of transducers statistically analyzing measurement signals and transmitting only their information content ; How to Make Power-Spectral Density Analyses of Measurement Signals, A. R. SOFFEL, 80–4 ; practical example of how to extract information from random electrical signals.

A Graphic Method of Determining the Statistical Mean and Mean-Square Deviations, D. V. ALIAB'EV. Meas Techns 1958 n3 Nov 1959 p 282–4 1 fig. Translated from Izmer Tekh 1958 n3 May–June 1958 p 28. The similarity of formulas for determining the statistical mean and the center of gravity of a homogeneous body permits one to use, in working out observation results, the well-known graphical methods applied for determining the center of gravity. The graphic method of determining the statistical mean and the mean-square deviation is speedier than the analytical method and prevents any gross errors occurring.

Determination of the Measurement Error of Linear Dimensions due to Misalignment, G.S. SIMKIN, Meas Techns 1958 n4 Dec 1959 p 399–403 4 figs 2 refs. Translated from Izmer Tekh n4 July–Aug 1958 p 15. In measurements carried out on a comparator or a horizontal optical comparator a misalignment of the part being measured with respect to the line of measurement is always possible. The errors, due to misalignment can become especially large when, in measuring long lengths, such relatively inaccurate instruments as end-measuring rods, slide gages, etc., are used. Article considers a law of the distribution of errors due to misalignment which is interesting in itself, and also gives some equations for the determination of the size of this error occurring in various length measurements.

On the Quality Evaluation of Methods for Checking Measurements Instruments, I. V. DUNIN-BARKOVSKII, A. N. KARPASHEVA, Meas Techns 1958 n6 Mar 1960 p 616–24 3 figs. 1 ref. Translated from Izmer Tekh n6 Nov–Dec 1958 p 6. As is known, the basic task of the testing and checking of measurement instruments, is that of verifying certain given properties of the latter and, primarily, their accuracy. On the basis of the state of contemporary statistical mathematics, it is possible to formulate and scientifically substantiate objective criteria for the reliability of methods of checking measuring instruments.

A Variant Least-Squares Method of Solution of a System of Observation Equations. J. L. STEARN, H. RICHARDSON. J Geophys Res v65 n4 Apr 1960 p 1308–9. A simple method for dropping an observation in the calculation of least-squares estimators of parameters.

Some Problems Connected with the Application of Random Functions in Metrological Practice, G. S. SIMKIN. Meas Techns 1959 n4 May 1960 p 241–5 1 fig 7 refs. Translated from Izmer Tekh n4 Apr 1959 p 1. Discusses determination of errors of glass scales, clock-type indica-

tors, and micrometers. In a number of cases the use of random functions in estimating the accuracy of means of measurement enables one to obtain a better estimate of their accuracy. Random functions may be used with great advantage to study the stability of the process of manufacture of measuring instruments.

Evaluation of Circular Components by the Harmonic Analysis Method, M. S. MIRKIN. Meas Techns 1959 n12 Sept 1960 p 946–52 7 figs 2 refs. Translated from Izmer Tekh n12 Dec 1959 p 19. In many instances of machining error analysis, it is important to establish from the total measured error the value and direction of its components in all the points of a machined surface. Since the machining process is periodic and consists of a complete cycle, the variation of the error of a circular cross section detail is a function of the angle of rotation. Analysis of various periodic processes is usually carried out by their expansion into trigonometrical series of the Fourier type. The analysis of the error by means of such a function has not only a nominal value, but it reveals the sources of the separate components of the total error, thus reflecting the actual nature of their origin. Thus, the error expressed by the first term represents eccentricity ; the remaining terms represent the deviations of the cross-sectional shape from a circle.

Measurement Accuracy as Weighting Factor in Statistical Treatment of Data, D. M. ASPINWALL, J. R. REY. ISA-Proc Preprint 66–NY60 for meeting Sept 26–30 1960 6 p. Possibilities of improving usefulness of measurement instrument by considering effect of measurement accuracy on estimated mean and variance of measured quantity ; use of maximum likelihood theory to extract full information from set of data with different degrees of accuracy.

Probability and Experimental Errors in Science, an Elementary Survey, L. G. PARRATT. John Wiley & Sons, Inc. N.Y. 1961 255 p. Chapter Headings : Early developments : Ideal games. Direct measurements : simple statistics. Statistics of measurements in functional relationships. Normal probability distribution. Poisson probability distribution.

On Realistic Measurement of Precision and Accuracy, C. EISENHART. ISA-Nat Aero-Space Instrumentation Symposium 8th-Proc 1962 p 75–83. Nature and objectives of measurement ; measurement as production process ; correction and adjustment of measurement ; law of large numbers and mathematical formulation of bias and precision of measurement process ; variations of procedure, apparatus, observers, and environmental conditions allowable in "repeated" applications. 21 refs.

How to Analyze Statistical Instrumentation Errors, P. F. HOWDEN. Electronic Equipment Eng v10 n6 June 1962 p 68–9. Statistical approach is presented for estimating instrumentation errors that occur within instrument, that are injected at input, or which occur at output.

Estimating Experimental Errors, H. WEISS. Machine Design v34 n13 June 7 1962 p 154–7. Basic mathematical descriptions of types of errors in experiments, tolerances, and measurements ; algebraic methods for adding, subtracting, multiplying, and dividing values for which error must be stated ; example given concerns determining area tolerance obtained in manufacture of rectangular metal plate to length of 2 plus or minus 0.001 in., and width of 3 plus or minus 0.002 in.

Normal Law of Measurement Error Distribution, G. S. SIMKIN. Meas Techns 1962 n4 Sept 1962 p 271–2. Translated from Izmer Tekh n4 p 3 Apr 1962. Actual distribution law is often unknown and it is important to determine what it is.

Realistic Estimates of Error, W. J. YOUDEN. ISA -J v9 n10 Oct 1962 p 57–8. Discussion of some common mis-

understandings that may arise when comparing measurements; weakness of duplicates; comparative and absolute values; method of estimating error.

Intercomparisons of Laboratory Test Results, J. MANDEL. ISA-Proc Preprint 44.3.62 for meeting Oct 15–18 1962 5 p. Representation of measurement process in terms of statistical model taking account of experimental errors in measurements; use of model for characterization of precision, both within and between laboratories, is illustrated.

Realistic Estimates of Errors in Measurements, W. J. YOUDEN. ISA-Proc Preprint 44.5.62 for meeting Oct 15–18 1962 4 p. It is emphasized that concept of error in measurement has meaning only in terms of use to which measurement is put; method for experimental estimate of realistic errors is given together with some efficient methods of tracking down most important sources of error.

Uncertainties in Calibration, W. J. YOUDEN. IRE Trans Instrum vI–11 n 3–4 Dec 1962 p 133–8. Presents some methods for making comparisons between standards and items undergoing calibration. These methods may be used in a variety of measurements. The purpose is to accumulate data that provide objective estimates of the precision, and that are also useful in detecting sources of systematic errors. This purpose is achieved by using some standard statistical designs in the scheduling of the work program. The problems of stating the uncertainty and of combining the uncertainties in a chain of calibrations are discussed.

Error Analysis in a General Physics Laboratory, W. B. PACKARD, G. G. WOOTAN. Am J Phys v31 n1 Jan 1963 p 62–3. Suggests that the error in a function of measurement(s) may be measured in terms of maximum error, without introducing considerations of probability. The "Maximum error" for a direct set of measurements is estimated as the maximum absolute deviation from the arithmetic mean. It is pointed out that care must be taken in deriving maximum errors of derived quantities. Thus if the maximum error in S is s, the extreme measured values of $P=S+S^{-1}$ are not $(S-s)+(S+s)^{-1}$ and $S+s+(S-s)^{-1}$. Unfortunately the authors state that the limits are $S-s+(S-s)^{-1}$ and $S+s+(S+s)^{-1}$, which is not true if $0 < S-s < 1 < S+s$.

System-Error Analysis, L. COCHIN, R. ISAKOWER. Prod Eng v34 n3 Feb 4 1963 p 61–5. Method is described for determining contribution each component adds to total error of measuring or indicating system; evaluation of total system error, done in tabular form as in table presented, permits immediate identification of troublesome areas in system.

Realistic Evaluation of Precision and Accuracy of Instrument Calibration Systems, C. EISENHART. NBS J Res Eng & Instrumentation v67C n2 Apr–June 1963 p 161–87. Calibration of instruments and standards is refined form of measurement; measurement operation cannot be regarded as constituting measurement process unless statistical stability of type known as state of statistical control has been attained; "allowable variations" must be of sufficient scope to bracket circumstances likely to be met in practice; indication on precision must be based on appropriate random sampling of this likely range of circumstances. 80 refs.

Statistical Fluctuations and Errors in Measurements, M. DUQUESNE. Microtecnic v17 n4 Aug 1963 p 142–50. Discussion on origin and limit of validity of principal distribution laws applied to study of characteristics of measuring instruments and exploitation of results obtainable, particularly in measurements of radioactivity.

Experimental Statistics, M. G. NATRELLA. NBS Handb 91 Aug 1 1963, Supt. of Documents, U.S. Gov't Printing Office. In 5 sections: 1 basic concepts and analysis of measurement data; 2 analysis of enumerative and classificatory data; 3 planning and analysis of comparative experiments; 4 special topics; 5 tables.

Precision Limit Obtainable in Automatic Statistical Treatment of Repeated Measurements Results, P. V. NOVITSKII, Meas Techn 1963 n5 Nov 1963 p 365–71 3 figs 11 refs. Translated from Izmer Tekh n5 p 1–6 May 1963. The labor spent on eliminating random errors is 20–200 times greater than that spent on eliminating systematic errors. Present achievements in the field of computers and cybernetics open up wide prospects for the automation of measurements and for incorporating automatic computers in measuring equipment, thus sharply increasing the possible number of obtained and processed measurement results and raising in a new manner the available means for improving the precision of measuring instruments.

The Meaning of "Least" in Least Squares. C. EISENHART, NBS. J. Washington Acad Sci v54 n2 Feb 1964 p 24–33 28 refs. The method of least squares as a valuable tool in applied science stems in part from the algebraic and arithmetical advantages of "least sum of squared residuals" and in part from estimates of "least mean squared error" in the important case when the end results are linear functions of the basic observations—a unique property.

Graphico-Analytical Determination of the Mean-Square Systematic Error in Discrete Measurements, I. M. SHENBROT. Meas Techn 1963 n8 Feb 1964 p 638–43 5 figs 7 refs. Translated from Izmer Tekh n8 p 6–10 Aug 1963. Presents a convenient graphico-analytical method of determining the quadratic mean error from a correlation function $B(\tau)$ graph for several types of discrete measurements.

1.3.4. Personal Equation

Sehen und Messen (Sight and Measurement), HANS SCHULZ. Zeit der Duetschen Gesellschaft für Mechanik und Optik Mar 15 1920 p 25–28; Zeit Techn Physik v1 n6–7 1920 p 116–121, 129–37. A careful, partly mathematical treatment of the effect of the eye on the accuracy of measurements. The cases considered are length measurements, photometric comparisons, interference measurements, and microscopic measurements. The limit of accuracy depends even more, in some cases, on the nature of the eye than on the limitations of the apparatus employed. The limit of accuracy attainable in interference work is put at 0.05μ and in microscopic measurement at 0.6μ.

Personality in the Estimation of Tenths, S. ALBRECHT. Astron J v33 n13 Dec 11 1920 p 103–12 45 figs. The subject is treated under three headings: Part 1 deals with personal scale obtained from observations made in connection with the regular program of circle observation, i.e., estimations of tenths on the telescope and circle micrometers and on thermometer scales; in part 2, estimations made on specially drawn scales are discussed; and part 3 contains supplementary remarks.

Note on Estimation of Tenths, P. KIRKPATRICK. Phys Rev v19 May 1922 p 545. Shows systematic error occurs with a group of observers in the process of estimating tenths of the interval between two parallel lines.

Physiological Limits to the Accuracy of Visual Observation and Measurement, H. HARTRIDGE. Phil Mag 6th ser v46 July 1923 p 49–79. Definition of the limits to

accuracy considered; acuity of the eye for grating and double star test objects and for contours; coincidence, interpolation, and contact methods of measurement; measurements of depth and distance; comparison methods of brightness and color measurement.

Psychologische Einflüsse bei Toleranzmessungen und Grosszahl-Auswertungen (Psychological Influences with Tolerance Measurements and Large-Number Evaluations), K. DAEVES, K. SCHIMZ. Stahl und Eisen v50 1930 p 1467–9 2 figs 6 refs. In measuring product from a manufacturer by a user over a period of years this investigation showed an increasing tendency for a worker's measurements to deteriorate from relatively exact measurements to estimated values. This shows up first as a neglect of values 1 and 9 and later 4, 6, and 7. Wave patterns of frequency curves made up from groups have their source in the inequality of even and odd numbers in the range of 0 to 4 and 5 to 9.

Estimation of Tenths on a Scale, H. BÄCKSTRÖM. Arkiv f Mat Astron och Fysik (Stockholm) v23A n21 1933 p 1–43. An investigation of the systematic errors occurring in the decimal estimation of the readings of scales.

Inspector's Errors in Quality Control, J. M. JURAN. Mech Eng v57 n10 Oct 1935 p 643–4. Quality is measured by human inspector; it is therefore of considerable importance to consider manner in which fallibility of inspection can arise; inspectors' errors divided into: errors in reading measuring instruments, errors in judgment, and in recording.

Precision Measurements with the Micrometer Eyepiece, H. RUHLE. Zeit für InstrumKde v58 Sept 1938 p 355–74. The author is concerned with the errors which arise in setting the cross-wire of a micrometer onto the edge of a luminous object, due to contrast effects in the eye. In the experiments the luminous "object" consisted of the image of an illuminated aperture, formed by a telescope objective. The actual size of the image was determined by calculation and compared with the apparent size given by the micrometer settings. The variations of the error with object brightness and exit pupil size were determined. The results are interpreted, taking into account the contrast sensitivity of the eye and the "grain" of the retina.

Personal Equation of Men and Machines, J. R. PARKS. Tool Engr v19 n3 Oct 1947 p 43–5. Statistical method of obtaining and expressing individual precision of production machines (and setups) of same class, duty, capacity and manufacture; use of standard deviation "S" as measure of personal equation; example of data and calculations involved.

On Estimation of Tenths, J. VOLGER. App Sci Res vA1 n3 1948 p 215–8. Test made to check possibility of estimating to one-tenth of scale unit, position of pointer on scale of given instrument; results obtained using 100 artificial scales and 55 observers.

Errors in Scale Estimation, A. J. BIRCH, D. K. C. MacDONALD. Res (London) v1 Mar 1948 p 287–8 2 figs 1 ref. A histogram of the frequency of observations at each 0.1 of a scale interval shows a crowding effect about the scale lines. Two probable causes are discussed. Discussion by E. Eastwood Sept 1948 p 575–6 2 fig 2 refs. A histogram shows tendency to exaggerate the mid-interval points as well as the scale divisions.

Some Variables Influencing Vernier Acuity. I. Illumination and Exposure Time. II. Wave-length of Illumination, K. E. BAKER. J Opt Soc Am v39 July 1949 p 567–76.

Functions relating vernier acuity, or coincidence acuity to illumination have been obtained for 2 different exposure times and at 3 regions of the visible spectrum. An apparatus providing the necessary stimulus controls has been described in detail and the procedure is fully explained.

An Optical Illusion Affecting Instrument Cross-Wires, S. TOLANSKY. Lab Prac v9 n9 Sept 1960 p 635–7. A description is given of an optical illusion which confuses the estimate of colinearity when inclined lines cross a broad image. The nature of the illusion is examined and found to depend on (a) angle of inclination of the crossing lines and (b) the width of the object. The way in which this illusion might affect cross-wire settings is considered.

Realistic Estimates of Error, W. J. YOUDEN, NBS. ISA-J v9 n10 Oct 1962 p 57–8. Discussion of some common misunderstandings that may arise when comparing measurements; weakness of duplicates; comparative and absolute values; method of estimating error.

Measurement Uncertainty, D. B. SCHNEIDER. ISA-Proc Preprint 44.1.62 for meeting Oct 15–18 1962 4 p. Largest element of uncertainty in assignment of limit of error is shown to be ignorance of individual performing analysis concerning error; method is presented for squeezing down on error until certainty is reached that limit of error just barely contains error.

Appraisal of Current Measurement Personnel and Effect upon Quality of Measurement, C. D. FERRIS. ISA-Proc Preprint 44.4.62 for meeting Oct 15–18 1962 6 p. Appraisal of competencies and deficiencies of personnel and resultant effect upon measurement quality as revealed by regular course work and special programs presented at Center for Measurement Science; particular areas of concern are lack of realization of physical limitations of equipment and technology, statistical treatment of data, and setting of confidence limits.

Visual Factors in Size Measurement by Microscopy, W. N. CHARMAN. Optica Acta (Int) v10 n2 Apr 1963 p 129–39. In estimating the size of an isolated object by visual observation of its image as formed by a microscope objective, the characteristics of the eye as well as the physical light intensity distribution in the image must be taken into account. Experiments are described in which the visual sizes of circular objects of known size are measured as a function of the instrumental magnification, the retinal illumination and the adaptation of the eye, these results being discussed in relation to the corresponding diffraction images and the properties of the eye.

Investigation of an Observer's Error in Estimating by Eye Fractions of a Scale Graduation, I. D. FAINERMAN. Meas Techns 1963 n10 Mar 1964 p 832–4 4 figs 5 refs. Translated from Izmer Tekhn n10 p 21–3 Oct 1963. The comparison of the observer's readings and the reading errors on linear and curved scales shows, as was to be expected, that the greatest accuracy is attained for a scale spacing fraction of 0.5; moreover, the reading accuracy of the circular scale is smaller than that of the linear scale. Tests have shown that in determining the observer's error of reading measuring instrument scales it is necessary to distinguish and account separately for the "individual scale of readings" and the "individual scale of rounded-off readings." The scale spacing fraction of 0.5 has the largest frequency when the effect of rounding-off is eliminated. Certain individual reading errors are larger on a circular scale than on a linear scale. The observer's individual error is accounted for as a normal systematic error. Further exhaustive investigation of this error is envisaged. In particular, it is advisable to continue the search for new scale designs in order to raise the accuracy of reading and reduce the observer's individual errors.

1.4. Temperature Effects and Measurement

Temperature Variations of Cast-Iron Divided Circles, F. GÖPEL. Zeit für Instrumkde v32 Feb 1912 p 33–43, Communication from the Physikal Techn. Reichsanstalt. Method for determining accurately the variations of scale divisions with different temperatures is described and illustrated, with tables showing actual results.

On the Choice of a Uniform Temperature for the Calibration of Measuring Instruments (Sur le Choix d'un Degré Uniforme de Temperature pour l'Etalonnage des Instruments de Mesure), C. COCHET. Rev Gen de l'Électricité, v4 Nov 16 1918 p 740–2. Report of Commission de Normalisation des Ingenieurs des Arts et Metiers de Boulogne-sur-Seine, recommending adoption of 0 deg. cent. as standard.

Der Einfluss der Temperatur auf die Längenmessungen (The Influence of Temperature on Length Measurements), G. BERNDT. Der Betrieb v4 n1 Oct 8 1921 p 1–8 7 figs in German. By experiments the time was determined which is necessary for equalization of temperature of different measuring tools with that of the environment when set on iron plate and in air. For the future the theory of the experiment will be established on the basis of simplifying assumptions and therefrom the determining coefficient of the external heat conduction for the heat exchange as well as the heat transition number.

Temperature of Adjustment of Industrial Gages (La Temperature d'Adjustage des Calibres Industriels), A. PÉRARD. Genie Civ v90 June 25 1927 p 621–4 3 figs. Plea to German Industrial Standards Committee to readopt adjustment of 0 deg. instead of 20 deg. cent.; discusses requisite precision for industrial gages and necessity for standardization of temperature of adjustment.

Temperature Adjustment of Length Standards (La Temperature d'Adjustage des Etalons Industriels, des verificateurs et des pieces mecaniques), L. GRAUX. Genie Civ v91 Sept 10 1927 p 250–2. Discusses adjustment on basis of standard meter at 0 deg. or at +20 deg. cent.

Temperature of Standardization of Industrial Gages (La Temperature de Definition des Calibres Industriels), C. E. GUILLAUME. Rev Gen de l'Électricité v23 Jan 14 1928 p 73–6. Object of article is to emphasize importance of decision made by German Commission fixing 20 deg. cent. as temperature of standardization; after stating necessity of unification of temperature in all countries and difficulties which have arisen, author gives some reasons which have moved him in stating troublesome effect German decision can have on desired unification.

Concerning Standardization Temperature of Industrial Gages (A Propos de la Temperature de Definition des Calibres Industriels), A. PÉRARD. Rev Gen de l'Électricité v23 Jan 28 1928 p 169–70. Discussion of reasons for not considering temperature of 20 deg. cent. as temperature for standardization rather than 0 deg. cent.; takes into account coefficient of expansion.

Temperature of Definition of End Standards, G. K. BURGESS, Director NBS. Letter to Members of International Committee on Standard Temperature for End Gages. June 20 1928. Presents results of survey of U.S. National organizations and manufacturers of tools and gages. Unanimously in favor of 20° C for reasons stated.

Temperature of Adjustment for Industrial Standards of Length. (Ed.) Mach (London) v33 Feb 7 1929 p 596. Discusses changing British practice from 62° to 68°.

Temperature Control Gives True Leadscrews, F. SCHOEFFLER. Am Mach v87 n17 Aug 19 1943 p 90–2.

Influence of temperature change on work and machine is particularly important when chasing accurate leadscrews; article discusses development and use of special precision lathe, installed with Zeiss measuring equipment in constant temperature room, for chasing leadscrews.

Thermometric Scales and Expansion Coefficients, J. M. T. VIDAL. CR Acad Sci (Paris) v233 p 469–71 Aug 6 1951 in French. The scales of two thermometers, which depend on the expansion of different substances, are shown to form a projective series and the law of expansion relative to a thermometer is deduced. Some experimental data quoted from the literature is given in support of the results.

Contribution à la Métropole Industrielle des Longueurs, P. GRAND. Rev Gén Mécanique v36 n41, 42, 45 May 1952 p 135–40, June p 167–70, Sept p 293–6. Contribution to industrial measurements of length, with reference to parts of large dimension; influence of ambient temperature in workshops; permissible deviation between temperature of gage and object being measured; measurement of steel parts with steel and wooden gages, and light alloy parts with steel, light alloy and wooden gages; diagrams.

Errors in Temperature Measurement Due to the Construction and Situation of Thermometers, F. LIENEWEG. Archiv Tech Messen n196 (Ref V 2165–2) p 107–10 May 1952 in German. Errors due to the lag of the thermometer and the surrounding medium, and, for the resistance thermometer, the heating error, are considered. By expressing the various heat exchanges in terms of equivalent thermal conductivities, and by using the values, obtained experimentally, of the errors of a thermometer in the two media, still air and stationary water, it is shown that the errors for any medium can be expressed simply. Graphical representations to assist calculations in any practical case are given.

A Recording Device for Surface Temperature Measurements, N. SASAKI, A. KAMADA. Rev Sci Instrum 23 June 1952 261–3. By means of a small heating coil, the temperature of a thermocouple junction is made to oscillate regularly between two temperatures T_1 and T_2. Simultaneously the junction makes about one contact every two seconds with the surface being measured. A short-period galvanometer in the thermocouple circuit produces on a moving photographic film a serrated sine curve whose serrations vanish once for every half-oscillation at a point that corresponds to the surface temperature T_3, provided T_3 lies between T_1 and T_2. This mode of measurement minimizes disturbances due to air currents. Alternatively, use of a thermocouple with two adjacent junctions is proposed. A simple but accurate portable thermostat for maintaining reference junctions at temperatures somewhat higher than room temperature is also described.

Temperature Measurement in Engineering, v1, H. D. BAKER, E. A. RYDER, N. H. BAKER. John Wiley & Sons, Inc., N.Y. 1953 179 p. First of two-volume work is primarily concerned with thermocouple techniques and includes chapters on fundamentals, basic information necessary for design of temperature measuring apparatus, and specific designs for measuring internal temperatures and temperature gradients in solid bodies. Eng Soc Library, N.Y.

Measurements with Small Resistance Thermometers for Industrial and Laboratory Purposes, O. WINKLER. Arch Tech Messen Issue 205 Ref v212–2 Feb 1953 p 31–2. In German. A note describing small resistance thermometers and their associated measuring bridges. The resistance at 0°C is 50Ω. Over the range 0–50°C the scale is linear to about 4%.

Preparation and Use of Cells for Realization of Triple Point of Water, C. R. BARBER, R. HANDLEY, E. F. HERINGTON. Brit J App Phys v5 n1 Jan 1954 p 41–4. General Conference of Weights and Measures in Oct 1948 passed resolution that zero of International Temperature Scale should be defined as temperature 0.0100 °C below that of triple point of water; technique used at Teddington, England for preparing cells for realization of triple point of water is described; results obtained over extended period.

Thermistors vs Thermocouples For Temperature Measurements, R. P. BENEDICT. Elec Mfg v54 n2 Aug 1954 p 120–5. Critical evaluation of thermoelectric properties of old and well known thermocouple and newer thermistor; parallel calibration tests show greater sensitivity, higher stability, and shorter thermal time lag for thermistor.

Electrical Parasites Hamper Temperature Measurement, D. J. PEARSE. Steel Processing v41 n1 Jan 1955 p 22–3, 52. Accuracy of measurement affected by parasitic currents induced into thermoelectric circuit; potential dangerous sources of alternating current such as electric machinery, power lines, heating elements, etc, and their elimination; a-c stray pick-up filter circuit at instrument thermocouple junctions will by-pass stray currents and reduce their effect to negligible proportions.

Influence de la Température sur l'Étalonnage des Jauges, P. GRAND. Rev Gén de Mécanique v39 n74 79, 83, 84 Feb 1955 p 39–45, July p 247–54, Nov p 395–400, Dec p 445–50, v40 n86, 88 Feb 1956 p 81–7, Apr p 159–64. Influence of temperature on calibration of gages; environmental temperature in measuring shop; temperature of materials subjected to different environments; calibration on measuring machine; comparator calibration; errors of calibration due to temperature variations.

Thermistor Electric Thermometer, R. W. WOODS. Sci v121 March 4 1955 p 337–8. Continuous measurements of rectal, subcutaneous, and skin-surface temperatures of mice were made with thermistors in bridge circuits. Nineteen such circuits were connected to a bank rotary switch so that any temperature could be selected and measured on a valve voltmeter. The range was 0–50 °C and the sensitivity about 1%.

Response of Temperature Measuring Elements to Thermal Transients, J. A. CLARK. ASME Paper n55—SA–18 for meeting June 19–23 1955 19 p. Study concerned with requirements of modern automatic control and regulation which demand increased speed of response from all measuring and recording instruments; review of available data on behavior of instruments sensing and controlling temperature, during any temperature change i.e., transient period. Bibliography.

Effect of Unstable Thermal Conditions during the Testing of Long Gage Blocks, J. C. MOODY. Metrology of Gage Blocks, NBS Cir 581 Nov 7 1957 p 67–70 1 fig. Supt. of Docs., Gov't Printing Office, Washington, D.C. On the basis of a series of tests a technique for the testing of long blocks was established.

A Thermal Enclosure for a Microscope, A. BONETTI, A. E. SICHIROLLO. "Particle Photography" Conf, Montreal, 1958 p 354–6 in French. To reduce the considerable fluctuations in the position of the image seen in microscopes with fluid drives, produced by thermal gradients, an isothermal enclosure was designed. In particular the construction of such a unit for the Koristka MS–2 microscope is described and the position stability of the image discussed.

Effect of Temperature Conditions and Coefficients of Thermal Expansion on Accurate Gaging, N. F. KANS. Indus Quality Control v15 n3 Sept 1958 p 22–7. Article

is limited to problems encountered using indicator gages with separate gage masters; most methods of accurately determining piece size at 68 F fall into one of two categories; no gage reading compensation required and gage reading compensation required; types of problems occurring in industry; recommendations made; series of examples illustrate effects of temperature variation on materials.

A Method of Maintaining Temperature Control over a Wide Range, H. L. ALLSOPP, D. F. GIBBS. J Sci Instrum v35 n11 Nov 1958 p 395–7. It is sometimes desirable to control the temperature in an apparatus without having to use a bath of stirred liquid as a means of maintaining thermal equilibrium. The apparatus described is applicable to such cases, thermal equilibrium being maintained by a stream of gas that is brought to the required temperature in a heat exchanger. The system is effective in the range from −150° to 200 °C, and the temperature stability varies from about ±1 °C in the range from 20° to 200 °C, to ±5 °C, below −110 °C.

New Standards of Resistance and Temperature Measurement, P. H. HUNTER. Western Elec Engr v3 n1 Jan 1959 p 2–8. Techniques employed at Western Electric's North Carolina Works Standards Laboratory to establish and maintain reproducible standards of great accuracy; multichannel data recording; development of precise oil bath temperature control; resistance fixed points; data processing.

On Maintaining an Object at a Uniform Temperature, C. M. CARMICHAEL, A. D. MISENER. Can J Phys v37 n7 July 1959 p 890–3. The apparatus consisted of a sealed 18 in. long, 6 in. dia. steel chamber with heating coils wound on its outer surface. A 12 in. copper cylinder of 4 in. dia., supported inside the steel chamber, acted as a uniform temperature enclosure and objects of various shapes and thermal conductivities were suspended on nylon threads inside the enclosure. A pressure of 10^{-2} mm Hg was maintained in the apparatus to eliminate convection. Two types of measurement were made (within range 20° to 100 °C) to investigate the equilibrium temperature over the surface of an object in relation to the temperature over the enclosure surface. In the first, the copper enclosure was maintained at uniform temperature (to within about 0.003 °C) and the temperature of the object showed a standard deviation of about 0.002 °C. There was considerable drift. In the second, a temperature gradient was set up along the length of chamber, enclosure and object, of up to 2 °C. There was approximately a 10-fold reduction in gradient from chamber to enclosure to object.

Investigations of the Influence of Temperature Variations on the Readings of a Comparator with Large Mechanical Magnification, R. NOCH, H. HÜHN. Zeit InstrumKde, v67 n11 Nov 1959 p 285–8 in German. Mechanical comparators with high magnification for linear measurements can alter their readings due to the influence of small changes of temperature. The paper deals with the influence of a slight heat source, for example an operator or a lamp, on comparators with the graduation of 0.0001 mm.

Surface Temperature Measurement, W. K. MOEN. Instrums & Control Systems v33 n1 Jan 1960 p 70–3. Magnitudes and sources of error sometimes encountered during measurement of surface temperatures; effects of convection; changes in thermocouple design and in selection of wire size needed for measurement of higher surface temperatures in laboratory testing.

How Temperature Affects the Measurement of Aluminum, J. C. MOODY. Tool Engr v44 n2 Feb 1960 p 68 4 figs. Describes experiments devised and conducted in seven major manufacturing plants to demonstrate thermal ef-

fects, leading to better appreciation of the relationship between temperature and dimensional control.

Comments on Various Temperature Combinations, I. H. FULLMER, NBS. 1960 4 p. Gives historical background of three standard temperatures; discusses importance of knowing coefficient of thermal expansion accurately, and discusses proposed change to 23 °C. (Not published.)

Automatic Precise Recording of Temperature, G. S. ROSS, H. D. DIXON. J Res NBS Eng & Instrumentation v64C n4 Oct–Dec 1960 p 271–5. Apparatus is described which automatically and continuously records small temperature changes, and which comprises platinum resistance thermometer, modified G–2 Mueller Wheatstone bridge, d-c amplifier, and potentiometer, strip-chart recorder; high stability of system obviates need for frequent zero checking; instrument is most useful when maximum temperature range is 1°; similar arrangement using different equipment is also described.

Empirical Determination of Thermocouple Characteristics, R. P. BENEDICT, H. F. ASHBY. ASME Paper 61—WA–19 1961 17 p. A systematic approach leading to a unique empirical determination of individual thermocouple characteristics is described. This is based on the application of four premises whose formulation is justified by the results. Typical thermocouple calibration data are analyzed, and the most probable results are presented. Improved tables of thermocouple reference values are given.

Bibliography of Temperature Measurement January 1953 to June 1960, C. HALPERN, R. J. MOFFAT. NBS Monogr n27 Apr 6 1961 13 p. More than 500 literature citations to field of temperature measurement are presented; references were collected from scientific and technical literature and government reports; compilation is divided into number of categories based on type of instrument used; some references to calibration of instruments and to scientific theories, on which temperature measurement is based, are also presented.

Celsius versus Centigrade : The Nomenclature of the Temperature Scale of Science, H. F. STIMSON. Sci (USA) v136 Apr 20 1962 p 254–5. The temperature scale known to U.S. scientists as centigrade was, in many countries, called Celsius after the inventor. In 1948 the 9th General Conference on Weights and Measures, representing the 33 nations that subscribed to the Treaty of the Meter, adopted the name Celsius as standard. For a variety of reasons the name did not become popular in the U.S. At the 11th General Conference in 1960 the scale was redefined so that the lower fixed point became the triple point of water with value 0.01 °C; thus making the adjective centigrade incorrect. The name Celsius is correct and its use by U.S. scientists would help to make the nomenclature of temperature uniform in all countries.

Precision Temperature Measuring Equipment, J. J. HUNTER. J Brit Instn Radio Engrs v24 n3 Sept 1962 p 251–9. Describes the development of a resistance thermometer of high accuracy together with its associated bridge circuit. The thermometer is of the dual-element type in which two coils of metal having different temperature coefficients of resistance are incorporated in the sensing head. The change in the resistance ratio of the two coils gives a unique indication of temperature. The bridge circuit developed for use with the thermometer employs the transformer ratio arm method which allows highly accurate and stable ratios to be produced. A modified potentiometer recorder automatically balances the bridge and provides direct read-out. A further refinement is the addition of a shaft digitizer which gives a record for the temperature in a form suitable for automatic data logging. The whole apparatus is stable and robust and can be used in industrial applications.

Surface Temperature of Thin Sheets and Filaments, J. M. BENSON, R. HORNE. Instrums & Control Systems v35 n10 Oct 1962 p 115–17. Instrument and method of measuring temperature of surfaces with thermocouple probe that is directly heated by electric power supply so that null type reading is obtained with no heat flow to or from surface; temperatures of running threads were measured to accuracies of order of ½ C; special form of probe is suited to measuring temperature of moving threadline of nylon and similar textile material.

Bibliography of Temperature Measurement July 1960 to December 1962, C. HALPERN. NBS Monogr 27 supp 1 1963 14 p. About 700 references are presented, collected from scientific and technical journals and reports on investigations sponsored or conducted by various governmental agencies; English, German, and French journals, and translations in English of Russian journals are covered, as well as more commonly used abstract journals.

Temperature Error in Equipment for Measuring Large Dimensions, I. P. VAGANOV. Meas Techns 1962 n8 Feb 1963 p 644–6 1 fig 1 ref. Translated from Izmer Tekh n8 p20–2 Aug 1962. For the purpose of determining the error due to the variations during measurement in the temperature of the measured object and measuring equipment the changes in the actual length of measuring devices due to oscillations in the air temperature of the testing premises and the effect of the heat in the operator's hands transmitted to the measuring equipment during measurements were determined experimentally.

Direct Relative Humidity Indication from Dry and Wet Bulb Temperatures, P. NORDON, N. W. BAINBRIDGE. J Sci Instrum (GB) v40 n3 Mar 1963 p 136. By means of a simple thermistor network, the electrical output of a dry and wet differential thermocouple psychrometer can be converted to indicate relative humidity directly, obviating the need for an independent measurment of the dry junction temperature. It is shown that such a network is capable of indicating relative humidity to ±2% of humidity over an approximate ambient temperature range of 56 to 98 °F and a relative humidity range of 30 to 100%.

Mechanical Design of Large Solar Telescope, H. HWANG, S. SACHS. ASHRAE J v5 n4 Apr 1963 p 35–46. Account of cooling problems and their solutions in design of structure to house solar telescope at Kitt Peak, Ariz; thermal analysis to determine feasibility of controlling temperature of exterior skin of telescope, and methods and feasibility of controlling thermal conditions within building enclosure, so as to minimize or eliminate thermal currents in optical path; cooling load computation and solution of boundary conditions.

Thermography-New Data Source, Principles and Applications. Automatic Control v18 n5 June 1963 p 22–3, 57. Infrared thermograph is described that makes precise, noncontact temperature surveys that do not alter temperatures being measured; it is applicable in determining temperature distribution in machines, electronic equipment and chemical and processing equipment.

Recording Small Temperature Changes, D. H. NALLE. Meas & Control v2 n9 Sept 1963 p 363–7. Principles of platinum resistance temperature measuring elements are explained, used in conjunction with high-speed oscillograph for recording plant temperature variations as small as 0.01 °F.

Measuring Temperature, L. G. RUBIN. Int Sci and Technol n25 Jan 1964 p 74–88 6 figs. Although temperature is one of the primary quantities, along with length, mass, and time, it is much subtle conceptually and much more difficult to define. Article discusses the multiplicity of temperature scales—thermodynamic scales, practical temperature scales, and others.

Determination of Temperature Corrections for The Dimensions of Machine Details, M. G. BOGUSLAVSKII. Meas Techns 1963 n10 Mar 1964 p 829–32 2 figs 3 refs Translated from Izmer Tekh n10 p 19–21 Oct 1963. A semiconductor thermometer with a special transducer is described which is convenient for measuring the temperature of flat, spherical, and fashioned outer and inner surfaces. The special transducer provides temperature measurements lasting not more than 10 sec. The error in measuring temperature does not exceed ±0.3°. The technique for determining corrections of temperature deviations from the normal of the article and the measuring instrument by means of a semiconductor thermometer and special graphs raises the accuracy of measurement and productivity in manufacturing precision articles on metal-working machines, and reduces the percentage of rejects due to inaccurate measurements.

Effect of Temperature on Errors of Instruments in the Course of Measurements. N. N. MARKOV, G. B. KAINER, P. A. SATSERDOTOV. Meas Techns 1963 n11 Apr 1964 p 888–902 2 figs 1 ref. Translated from Izmer Tekhn n11 p 5–9 Nov 1963. An investigation was conducted which shows that in computing temperature errors for hand-operated instruments it is necessary to take into account the deformations of components which produce the largest measurement errors. The design formulas recommended in the literature for determining temperature deformations cannot be used for practical purposes, because it is virtually impossible to determine the temperature which affects the deformations, and linear expansion coefficients are seldom known. In all measurements temperature oscillations were observed within the range of a few degrees even in a single instrument.

A Dilatometer for Measurement of Dimensional Changes in Metals Due to Irradiation, K. ISEBECK. Zeit Angew Phys (Germany) v17 n7 Oct 14 1964 p 497–504 in German. The metal specimen is coupled mechanically to a parallel plate condenser so that changes in length alter the condenser gap and unbalance an a.c. bridge. Relative length changes of 10^{-8} can be detected and specimen temperatures held constant to better than 0.01°C between −20 and 100° C. Effects of alpha particle irradiation on pure gold at various temperatures and subsequent relaxation have been measured using the method.

Thermal Effects in Dimensional Metrology, J. B. BRYAN, W. B. BREWER, E. R. McCLURE, J. W. PEARSON. ASME 65–PROD–13, Metals Engineering and Production Conference, June 9–11 1965 25 p 15 figs 12 refs. A Lawrence Radiation Laboratory investigation shows that in the field of close-tolerance work, thermal effect is the largest single source of error, large enough to make corrective action necessary if modern measurement systems and machine tools are to attain their potential accuracies. A simple, quantitative, semi-experimental method of thermal-error evaluation is developed. A relatively simple device to monitor the thermal environment and automatically effect error compensation is proposed. Includes glossary of terms, drift-check procedure, and method for determining frequency response of a measuring system.

Calibration and Use of Liquid-in-Glass Thermometers, J. F. SWINDELLS NBS Monogr n90 1965 p1–23. This monograph, which supersedes Circular 600, contains information of general interest to both manufacturers and users of liquid-in-glass thermometers, as well as those who wish to calibrate thermometers or submit them to the National Bureau of Standards for calibration. Instructions are provided for applicants requesting calibration services, and the techniques and equipment used in the calibration procedures are described. Important elements of thermometer design are discussed, and factors affecting the use of common types of liquid-in-glass thermometers are included together with tables of tolerances and reasonably attainable accuracies. The calculation of corrections for the temperature of the emergent stem is given in detail for various types of thermometers and conditions of use.

1.5. Deformation, Deflection, and Wear

Miscellaneous Papers, H. HERTZ. Translated by D. E. Jones and G. H. Schott. 1896. Contains translations of two papers on ball bearings. The best theoretical data available "on the contact of elastic solids", p 146–62; and "on the contact of rigid elastic solids and on hardness", pp 163–183.

Ball Bearings for Optional Loading (Kugellager für beliebige Belastungen), R. STRIBECK. Zeit VDI v45 Jan 19, 26 1901 p 73–9 118–25 25 figs. (1). The precedent conditions at point of pressure. (2). Experiments relative to the pressing together of hardened steel balls and plates. (3). Loading with the entry of the elastic limit in its relation to ball diameter. (4). The equation for the permissible loading. (5). The frictional work of ball bearings. (6). Experiments with ball bearings.

Steel Ball Bearings. Eng v71 Apr 12 1901 p 463. An illustrated account of the investigations of R. Stribeck, on behalf of the German Arms and Ammunition Works of Berlin. An important contribution to the solution of difficult mechanical problems. Based on Hertz's theoretical work and carried out experimentally. Numerous graphs and tables. (French translation in Revue de Mécanique, April 1901.)

Application of Elastic Solids to Metrology, C. CHREE. Phil Mag Nov–Dec 1901 p 532–58 594–616; Proc Phys Soc v18 1901–3. p 1–57 7 figs. Fundamental equations; suspended and supported solids; pressure of surrounding medium; solid surrounded by varying medium, aeolotropic solids, cylinder suspended from the rim; solid cylinder or prism with axis vertical-complete solution; flask containing liquid, hollow cylinder containing or surrounded by liquid; spherical shell containing and surrounded by liquid; cylinder under pressure a quadratic function of Z; general properties, influence of cavities, gravitation, etc.; standards of length; applications of Bernoulli-Euler method; bar under additional weight; numerical applications to standards of length; application to deflexion-bars of magnetometers; concluding remarks.

Test Methods for Hardened Steel with Reference to Spherical Form (Prüfverfahren für gehärteten Stahl unter Berücksightigung der Kugelform), R. STRIBECK. Zeit VDI v51 Sept 14 1907 p 1445– 51 9 figs. Results of Tests. Elastic and permanent deformations. (1) Pressure experiments. (2) Bending experiments.

The Elastic Indentation of Steel Balls under Pressure, C. A. BRIGGS, W. C. CHAPIN, H. G. HEIL, NBS. ASME Trans v40 n1643 1918 p 139–48 6 figs. Reports results of experiments with balls pressing against flat surfaces. Results show that the identation is proportional to the two-thirds power of the pressure.

Comparator for a Vertically-Placed Standard Meter, G. DIMMER. Akad Wiss Wien Ber 129 1920 p 223; Zeit für InstrumKde v42 Jan 1922 p 24– 7 Abstract. Hooke's law would give a different length for a metal standard meter according as it lies horizontal or vertical. This difference in length is known from given values of Young's modulus. The apparatus actually used to measure this difference consists of a frame carrying the meter, which can rotate on a horizontal axis on a large graduated circle attached to a vertical wall. Measurements

of the length are made with microscopes as in the ordinary comparator. The results for meters of steel, iron and platinum are in general agreement with Hooke's law.

Über die Gültigkeit der Hertzschen Formeln zur Berechnung der Abplattung von Messkorpern (Regarding the Validity of the Hertz Formulas for Computing the Deformation of Measuring Bodies, G. BERNDT. Zeit für tech Phys v3 n1 1922 p 14–21, n 3 p 82– 7. See also Zeit für Feinmech und Praäzision n 19–20 1923 p 210.

The Contact Area of an Elastic Sphere When Compressed Between Flat Elastic Plates, J. GOODMAN. Eng, v116 Aug 3 1923 p 133 4 figs. Methods of ascertaining area in contact between a steel ball and steel plates, and results of tests. Contact area is larger than Hertz theory indicates (13%). Hertz terms defined.

Applied Elasticity, J. PRESCOTT. Longmans, Green and Co. 1924. Chapter 19 is on elastic bodies in contact.

Some Effects of the Atomsphere upon Physical Measurements, E. W. WASHBURN, Sci v61 Jan 16 1925 p 49–56. Presence of atmosphere in contact with substance or system subjected to quantitative investigation affects situation in two ways namely, (1) direct-pressure effect, and (2) air-solubility effect.

Deflection of Bars, J. H. DOWELL. J Sci Instrum v3 June 1926 p 305– 8. The question of the best position of the supports of bars for accurate optical benches, such as etalon mounts, is considered, and the deflection of the bars is calculated and depicted.

Die Abplattung von Stahlkugeln und Zylindern durch den Messdruck (The Oblateness of Steel Balls and Cylinders due to Measuring Pressure), H. BOCHMANN. Zeit für Feinmech und Präzision v35 Apr 27 May 11 25 June 8, July 6 20 1927 p 95–100 110–4 122–5 134–9 161–165 175–178. The Hertz theory, review of literature, experimental arrangements, experiments on steel balls between planes, groove experiments and steel balls, experiments on steel, wires between planes, experiments on bores between planes, general evaluation, miscellaneous cylinder experiments, experiments on crossed cylinders, groove experiments on steel wires, summary.

Richtige Unterstutzung länger Parallelendmasse in zwei Punkten. (Proper Support of Long Parallel End-Standards at Two Points), E. PREGER. Zeit für Feinmech und Präzision v35 July 20 1927 p 169–74. Theoretical discussion.

Die Abplattung von Stahlkugehn und Zylindern Durch den Messdrucke (The Flattening of Steel Balls and Cylinders by Measuring Pressure), G. BERNDT. Zeit für Instrum Kde v48 Sept 1928 p 422–32. Discusses the Hertz theory, previous work on its proof, experimental arrangement, experiments on steel balls between steel planes, steel balls in a steel V groove, steel cylinder between two steel planes, experiments on crossed cylinders, steel cylinder in a V-groove. Summary.

Interferometer Method for Investigating the Form of Steel Balls and for Testing Hertz Pressure Equations (Interferometrische Methode zur Untersuchung von Stahlkugeln auf ihre Gestalt sowie zur Prüfung der Hertzschen Druckgleichungen), O. SCHÖNROCK, E. EINSPORN. Zeit für InstrumKde v49 July and Aug 1929 p 317–31 369–385 8 figs. (1) Introduction; (2) Interference patterns as basis; (3) the method; (4) effect of plate pressure, temperature, and air pressures; (5) accuracy of measurement; (6) definition of the roundness of balls of designated sizes; (7) specific weights of steel balls; (8) summary.

Stresses Due to the Pressure of One Elastic Solid Upon Another, H. R. THOMAS, V. A. HOERSCH. Univ Illinois Eng Experiment Station Bul 27 n 46 July 15 1930 56 p 4 figs. Review of theories and results of theoretical mathematical analysis of problem; check of mathematical solution; tests of cylinder on plane; tests of crossed cylinders; effect of various factors on calculated stresses; numerical examples.

A Simple Approximate Theory of the Pressure Between two Bodies in Contact, J. P. ANDREWS. Proc Phys Soc London v43 Jan 1 1931 p 1–7 25. When two solid bodies are pressed together without any point exceeding the elastic limit, their common area of contact is frequently circular, and in such cases the normal stress at each point of this area may be calculated by a simple approximate method giving results correct, as a rule, to within 1 or 2 percent. The principle remains near-true for elliptical areas of contact.

Deformation of Sensitive Levers, G. BERNDT, W. VOGT. Zeit für Instrumtkde v58 Oct 1938 p 389–408. The authors discuss the deformations which tend to falsify the measurements made with various types of lever. Such deformations are principally of three kinds; (1) Hooke's law compression due to forces uniformly distributed over the cross-section; (2) Hertzian flattening of curved surfaces; (3) Bending, resulting in variation of the distance from the support. These effects are thoroughly investigated for six different types of levers comprising (a) simple optical lever, (b) simple mechanical lever, (c) double mechanical lever with one lever working on a geared drive, (e) meter mechanism with spur-wheel worm and wheel drive, (f) torsion and electric levers. The results obtained are tabulated and discussed.

Young's Modulus of Diamond, P. R. PISHAROTY. Indian Acad Sci Proc A v12 Aug 1940 p 208–11. It is shown that the section of the elastic surface of a cubic crystal by an octahedral plane is a circle. Voigt's "scale and telescope" method for determination of Young's modulus of crystals is improved by the use of a narrow slit and a long focus camera, the shift being recorded photographically and measured by a Hilger micrometer. The experimental value of Young's modulus of diamond in any direction lying in the octahedral plane is found to be 5.5×10^{12} dynes/cm². The maximum value for a cubic crystal being in a direction normal to this plane, a higher value for a rod cut normal to the octahedral plane may be expected.

A Simple Method of Finding Poisson's Ratio, M. D. WALLER. Phys Soc Proc v52 Sept 1940 p 710–3. The paper describes how Poisson's ratio can be measured in terms of the ratio of 2 specified natural frequencies of a vibrating free square plate. Results for glass, steel, brass, copper and aluminum, are given. It is suggested that such a simple method of estimating this elastic constant might be of value in the determination of deformation under measuring force.

Precision Extensometer and Its Use for Measurement of Poisson's Ratio, W. LETHERSICH. J Sci Instrum v21 n10 Oct 1944 p 180–3. Simple optical arrangement for measuring Poisson's ratio under various conditions of stress and strain.

Analysis of Stresses and Deflections, A. B. JONES, 2 vols. New Departure Div., General Motors Corp. 1946. Contains formulas and graph for solving deformation problems; based on the Hertz equations.

Elastic Constants of Diamond, M. BORN. Nature (London) v157 May 4 1946 p 582. An identity connecting the three elastic constants and the main lattice vibration frequency has been obtained by a reconsideration of Nagendra Nath's theory (Abstr 550, 1935) of the action of second

neighbor as well as first neighbor atom on the vibration of a C atom in the diamond lattice. This is not satisfied by the experimental values of Bhagavantam (Abstr 310, 1945) whose confirmation of Nagendra Nath's theory is here stated to be accidental. The theory of the vibrations of the diamond lattice is briefly discussed.

Indentation Method for Measuring Wear, S. A. McKEE. J Res NBS v39 n2 Aug 1947 RP1819 p 155–61. Method for accurately measuring wear that takes place on bearing surfaces of machinery; measurements of dimensions of indentation marks before and after wear provide means for determining amount of wear that has taken place; apparatus described for measurement of wear in cylinders of aircraft engines. See also Tool Engr v18 n5 June 1947 p 41–3 5 figs.

On Highly Compressible Helical Springs and Rubber Rods, and Their Application for Vibration-Free Mountings, V. J. A. HARINGX. Philips Res Rept 4 p 375–400 Oct 1949. Deals with the behaviour in space of the different types of vibration-free mounting, starting from the simple construction of a resiliently supported body up to the damped dynamic vibration absorber provided with an auxiliary mass. To simplify the problems of forced and free vibrations an attempt is made to split up the movements in space into a number of one- and two-dimensional movements to be treated independently.

Finite Extension and Torsion of Cylinders, A. E. GREEN, R. T. SHIELD. Phil Trans A v244 n876 1951 47–86. The theory of finite elastic deformations of an isotropic body, in which a completely general strain-energy function is used, is applied to the problem of a small twist superposed upon a finite extension of a cylinder which has a constant cross-section. The law which relates the force necessary to produce the large extension, with the torsional modulus for the small torsion superposed on that extension, is given by a simple general formula. The problems of a small twist superposed upon a hydrostatic pressure and tension, are also solved. Attention is then confined to isotropic incompressible rubberlike materials using a strain energy function suggested by Mooney, and the second-order effects which accompany the torsion of cylinders of constant cross-sections are examined.

On the Smooth Reactions of Two Solid Bodies in Contact, J. BOUZITAT. CR Acad Sci Paris 232 Feb 19 1951 683–5. The results originally obtained by Hertz for the distribution of normal pressure and the shape and area of the surface of contact are established by an alternative and more direct method. The resulting distribution of tension in the two bodies near the surface of contact is also discussed.

A Note on Elastic Surface Deformation, M. KORNHAUSER. J App Mech v18 Sept 1951 p 251–2. Surface deformation of elastic bodies having the same modulus is treated by the standard texts on elasticity, but the applicability of the solution is limited to the range of the tables of coefficients presented. This note extends the tables to cover the range that applies to bodies having one principal curvature much larger than the other. Some inaccuracy in the tables in current use also is noted.

Determination of Local Wear by Use of Disappearing Marks. Metallurgia v45 n269 Mar 1952 p 151–3 5 figs. Possibility of measuring wear of metal by noting change in dimensions of depression in surface concerned; marks produced by indentation, by abrasion and by cutting, and their respective advantages; photographs.

Elastic Deformation Effects in Precision Measurement, P. FERGUSSON: Microtecnic v11 n6 Dec 1957 p 256–8. Test on hardened steel balls and rollers, in which deformation under loads of up to 16 lb was measured for varying conditions of point and line contact; test results lead to simplification of Hertz theory, so that all cases of point contact can be expressed in graphical form.

Investigation into One of the Assumptions of the Hertz Theory of Contact, C. STOREY. Brit J App Phys v11 n2 Feb 1960 p 67–8. One of the limitations of Hertz's solution of the contact problem is the assumption that, in the neighborhood of contact, the surface of the bodies and hence, the distance between their corresponding points can be represented by second degree equations. Subsequent theoretical work, mainly by Shtaerman, has provided a more general solution free from this limitation. It is the purpose of the present work to examine the effect of the inclusion of terms of higher degree than the second in the expression for the distance between the two bodies. Attention is confined to spheres and cylinders.

The Influence of Measuring Force, Stylus Radius, and Surface Finish on the Accuracy of Measurement of Workpieces by a Comparator, L. W. NICKOLS, T. R. J. OAKLEY. Inst of Mech Engrs 1961. See 1.3.2 for abstract.

Anti-Distortion Mountings for Instruments and Apparatus, R. V. JONES. J Sci Instrum v38 n10 Oct 1961 p 408–9. Principles for mounting of instrument platforms; for many optical and mechanical instruments, working platform may best be protected from external mechanical distortion by supporting or suspending platform by members, usually 3, whose stiffness is much less than that of platform.

Tables for Calculating the Compressive Surface Stresses and Deflections in the Contact of Two Solid Elastic Bodies Whose Principal Planes of Curvature do not Coincide, A. KOZMA and H. CUNNINGHAM. Industrial Mathematics, Detroit v12 pt 1 1962 p 31–9 1 fig 6 refs. Transcendental equations result from application of the Hertz theory to calculate the stresses and deflections between two solid elastic bodies which are in contact under pressure and whose principal planes of curvature do not coincide. These equations are reviewed, and a more extensive table of applicable special functions is given than has been previously available.

Contact Stress Analysis of Normally Loaded Rough Spheres, L. E. GOODMAN. ASME—Paper 62–WA–19 for meeting Nov 25–30 1962 8 p. Hertz analysis of contact stresses is extended to include effects of friction on interface between 2 elastic spheres compressed along line connecting their centers; problem requires incremental formulation; stress functions of interest in connection with analysis of shear loaded half-space in linear theory of elasticity are developed; distribution of shear stress needed to prevent relative slip of surficial points after they enter contact region is found to be finite everywhere in region.

The Parallelism of a Length Bar with an End Load, D. C. WILLIAMS. J Sci Instrum (GB) v39 n12 Dec 1962 p 608–10. The flexure of an engineer's length bar standard supported horizontally at two positions with a flat wrung to one end is analysed. Formulae are given for support positions which do not introduce errors in parallelism of the ends. The effect of the flexure on the length of the bar is shown to be negligible.

1.6. Vibration Isolation and Control

Vibrationless Supports for Instruments, W. H. JULIUS. Ann der Phys und Chemie 3ser v56 1895 p 151–60. Three wires are attached to an over-head beam at the angular points of an equilateral triangle; carrying at their lower ends a triangular plate for the support of the instrument. The center of gravity of the whole suspended system is to be at the center of the triangular plate. For damping effects of air currents, sidevanes are fixed to the plate which dip vertically into dash pots.

Vibrationless Supports for Instruments, W. EINTHOVEN. Ann der Phys und Chemie 3ser v56 1895 p 161–6. Instruments are supported upon iron plates floating on mercury. Previously used by Michelson and Morley. See Am J Sci v3 p 34.

New Vibrationless Method of Mounting Delicate Instruments (Ueber eine neue erscheutterungsfreie Aufstellung fuer empfindliche Messinstrumente), R. MUELLER. Ann Phys v1 n5 Mar 12 1929 p 613–56 6 figs. Critical review shows that Julius suspension gives satisfactory results in most cases; underlying principles of method depend on three principles; (1) no attempt made to weaken vertical component of vibration; (2) period of translatory vibration in horizontal direction made very large; (3) new form of damping employed using liquid of suitable viscosity.

Air Cushions as Supports for Instruments, E. GEHRCKE, B. VOIGT. Zeit für techn Phys v12 1931 p 684–6. Describes three different methods of combining air cushions with R. Müller's apparatus, to prevent the transmission of vibrations to a table on which apparatus is to be placed. The Müller apparatus absorbs the horizontal tremors satisfactorily, while the air cushoins absorb vertical components. Three different forms of apparatus are described.

Air Cushions as Supports for Instruments, E. GEHRCKE, B. VOIGT. Zeit für techn Phys v13 1932 p 387–90. The arrangement has been tested when used for supporting a galvanometer which is very sensitive to vibration. It was found that the best results were obtained with air at a pressure of about 900 mm of mercury, and that other gases were equally effective.

On Highly Compressible Helical Springs and Rubber Rods, and Their Application for Vibration-Free Mountings, V. J. A. HARINGX. Philips Res Rept v4 Oct 1949 p 375–400. Deals with the behaviour in space of the different types of vibration-free mounting, starting from the simple construction of resiliently supported body up to the damped dynamic vibration absorber provided with an auxiliary mass. To simplify the problems of forced and free vibrations an attempt is made to split up the movements in space into a number of one- and two-dimensional movements to be treated independently.

Etude sur la Flexion des Étalons de Longueur (Study of the Deflection of the Standard of Length), C. VOLET. Trav et Mém du BIPM v21 1952 20 p 3 figs. Equations of the neutral fiber; projection of the neutral fiber; résumé of the formulas and particular cases; application to prototypes of platinum-iridium; traces outside of the neutral fiber; conclusion.

Erschuetterungsfreies Aufstellen und die Erschuetterungsfeste Konstruktion von Messinstrumenten, A. VON WEISS. VDI Zeit v98 n6 Feb 21 1956 p 205–8. Vibration-free mounting and vibration proof construction of measuring instruments; mechanical stress of latter; vibration and bumping test suggested.

Instrumentation Precision as Affected by Vibrational Environment, C. E. WHITE. Avco R.A.D. 201 Lowell St., Wilmington, Mass. May 1959 13 p 9 figs 3 refs. Presents analysis of several commonly used instruments whose functions are reduced by the presence of transmitted vibration, normally considered inconsequential. Case histories of troublesome incidents are outlined; corrective measures are mentioned. A plea is made for a more detailed study of the problem with the hope that the manufacturers of instruments will establish criteria of maximum allowable vibration wherever sensitive instrumentation is employed.

Problems of Insulating Against Shock Loads, R. HAMMOND. Insulation (London) v3 n5 Sept–Oct 1959 p 282–5. At Smith's Stamping Works, Coventry, Brett drop stamp has tup weighing 50 cwt falling through 6 ft 6 in. height with velocity at impact with work being 250 in./sec; electric driving motor and friction clutch lifting gear is mounted on structural steel gantry; foundation comprises concrete lined pit with inertia block resting on 34 helical springs, each consisting of 14 springs; Metropolitan Cammell Carriage and Wagon Co, Ltd, installation described.

Isolation of Vibration When Machine and Foundation are Resilient and When Wave Effects Occur in Mount, A. O. SYKES. Noise Control v6 n3 May–June 1960 p 23–7, 30–8. Isolation by massless spring-dashpot mount or by arbitrary two-terminal mount; limitations in application of single-mount effectiveness theory; effectiveness of mounts in many-mount systems; wave effects in isolation mounts; approximate formulas for estimating effectiveness; estimating characteristic impedances, frequency constants, and damping factors of simple mounts.

Vibration Isolation Design, D. S. HANLEY. Machine Design v32 n16 Aug 4 1960 p 123–8. Description of new method for dynamic analysis of displacement-excited motions where loads carried by spring and damper must be determined; examples illustrate numerical solution of problems.

Shock and Vibration Handbook, C. M. HARRIS, C. E. CREDE. McGraw-Hill Book Co. Inc. New York. 3 vols 50 chapters 1961. Vol. 1: Basic theory and measurements. Vol. 2: Data analysis, testing, and methods of control. Vol 3: Engineering design and environmental conditions. Chapters 30–33 deal with theory of vibration isolation, theory of shock isolation, application and design of isolators, and air suspension and servo-controlled isolation systems. These chapters contain 64 references.

Inherent Limitations of Accelerometers for High-Frequency Vibration Measurements, F. SCHLOSS. J Acoust Soc Am v33 n4 Apr 1961 p 539. When an accelerometer is attached to a vibrating mass the inertia of the transducer together with the elasticity of the mass produce a frequency-dependent error which sets an upper limit to the measurable frequency. A formula is given which enables this critical frequency to be calculated for a large plate. The transducer resonant frequency is assumed to be higher than the critical frequency.

On Certain Dynamic Properties of Elastic Bar Immersed and Non-Immersed in Liquid with Free Surface, J. WIECKOWSKI. Acad Polonaise des Sci Bul Ser des Sci Tech v10 n11 1962 p 635–42. Theoretical investigation of vibration in elastic bar; there exist frequencies of forced vibrations for which progressive mechanical waves propagating from point of excitation are damped; it seems that choice of adequate parameters for machinery foundation can localize vibration at point of excitation.

Vibration Control, K. W. JOHNSON. Sound (USA) v1 n3 May–June 1962 p 34–8. Vibration control by the use of resilient mounts requires the control of the supporting

structure, the correct placement of the isolators, and the control of the internal construction. Emphasis is placed on the correct usage of available commercial mounts. There is some description of the common types of damping now in current use.

Theory of Vibration, G. NISHIMURA, Y. JIMBO, Japan Soc Mech Engrs Trans v28 n191 July 1962 p 859–91. In old theory of vibration prevention, earth's crust is treated as equivalent simple spring-mass system ; in this paper earth's crust is assumed to be infinite elastic medium, and problems of insulation and prevention of vibration of any machine are treated on basis of elastic wave propagation theory ; many new results are obtained which cannot be seen in old theory. In Japanese with English abstract.

Vibroshchup i Vibrometr Dlya Izmerenlya Kolebanii Stankov, S. S. KEDROV. Stanki i Instrum n7 July 1962 p 17–20 ; English translation in Machines & Tooling v33 n7 1962 p. 20–3. Vibration pick-up and seismometer described suitable for measuring vibration of machine tools, particularly for quick estimation of vibration level at various points on machine tool and for determination of vibration areas ; vibration pick-up device with wire strain gages, and vibration seismometer with inductive pick-up work in conjunction with amplifiers, transducers and type N-102 or MPO-2 oscillograph.

Isolators Cushion Industry's Shocks, C. J. VLAHOS. Mill & Factory v71 n3 Sept 1962 p 68–71. Review of operating characteristics of various isolation pads used for absorbing machinery vibrations ; elastomer floor mounts and hangers, rubber channel mountings, rubber truss configurations, mountings of composite materials, and steel springs and their use are discussed.

Vibrazioni Mecchaniche—Teoria Dello Smorzatore Aggiuntivo Nell'-Oscillatore Meccanico a Due Masse, C. BRUTTI. Ingegnere v36 n12 Dec 1962 p 1155–61. Mechanical vibrations ; theory of antivibration mounting investigated by means of mechanical vibrator with two masses ; generally vibration damping of machine part is solved by analogy with single vibrating mass ; this approximation is not sufficient ; approximation with two vibrating masses, which are elastically connected is advanced ; theory with single mass appears as particular case of that two masses.

Electromechanical Machine for Analysis of Periodic Functions, S. C. GUPTA. Electromechanical Components & Systems Design v6 n12 Dec. 1962 p 34–7. Applications of simple Grutzmacher analyzer (1943) for finding amplitude and phase of any harmonic of given periodic wave form quickly and with good accuracy.

Phase Angle in Vibration Work. L. YEH. Instrum & Control System v35 n12 Dec 1962 p 88–90. Application of phase meter by design engineer in troubleshooting, research, and design, especially of rotating machinery ; measurement of modal shape or dynamic deflection forms of structure ; measurement of phase angle between force and velocity in use of impedance technique ; measurements of phase angle for comparison of damping characteristics of similar structures.

Analiticheskoe Vyrazhenie Kharakteristik Rezino-kordnogo Pnevmaticheskogo Amortizatora (Analytical Formulation of Characteristics of Rubberized-cord Pneumatic Shock Absorbers), V. V. IGNATENKO. Izvestiya Vysshikh Uchebnykh Zavedenii, Mashinostroenie n7 1963 p93–107. Strain analysis of pressurized toroidal shock absorbers having shape and construction similar to that of wheel with tubeless tire and placed in horizontal position under machine's base plate ; structural parameters and deformations of shock absorber are determined.

A Vibration Isolating Mounting for a Sensitive Balance, J. A. MACINANTE, J. WALDERSEE, J. Sci Instrum (GB) v40 n2 Feb 1963 p77–8. This note briefly states the general requirements for seismic mountings for sensitive balances, and describes an inexpensive mounting consisting of a seismic slab on helical springs with pitch (bituminous) dampers. This form of damping has overcome the difficulty of maintaining the level of a balance which is supported on "soft" spring isolators.

Floating Foundations Isolate Vibration, Eng v195 n5053 Feb 22 1963 p 296–7 5 figs. Experiences of four firms who have floated equipment or whole rooms on rubber ; two cases pertain to antivibration mountings for roll grinder and for newspaper printing press ; examples of floating rooms are Standards Room at Nat Eng Laboratory and sound studios for BBC, for both of which rubber carpet mountings are used.

How to Analyze Shock Effects, W. P. BARNES. ISA J v10 n3 Mar 1963 p 63–6. Four methods are summarized for analyzing shock effects to valuable equipment ; techniques range from manual methods to those using analog and digital computers.

End to Chatter Problems, R. L. CARLSTEDT. Am Mach/Metalworking Mfg v107 n7 Apr 1 1963 p93–5. New carbide boring bar called DeVibrator, with row of loose slugs inside, can now eliminate chatter problem from boring operations, and in very large measure, also from turning operations ; it operates on principle of dissipating vibrational energy ; design and operation of device which is made in two sizes, DV-4 with 4-in. wheel, and DV-5 with 5-in. wheel, with choice depending on mass of workpiece involved.

Solution to Acute Vibration Problem. Insulation (London) v7 n6 Nov–Dec 1963 p 257. Isolating machine mounts are based on use of molded core of oil-resistant neoprene which is bonded to dished steel upper casing and steel base plate ; mounts were used to eliminate severe vibration disturbance caused by operation of 40 machines for production of nylon fabric at factory in Baldock, England.

Vibration Isolation of a Quasi-Linear System, H. K. SACHS. J Indus Math Soc v14 pt2 1964 p 27–44 10 figs 14 refs. Describes a method for the determination of the transmitted force of a quasi-linear mass-elastic system which is subjected to a harmonic input force. It is shown that even very small non-linearities in the restoring force function affect the dynamic response of the system, yielding an entirely different configuration of transmissibility curves than the linear system. Also, the force transmitted to the supporting structure depends not only on the system parameters and perturbation frequency, but on the relation between the generating force and the perturbation frequency, e.g. centrifugal force excitation of the support structure. Finally, methods for optimization are considered, and it is found that no unique criterion for optimum isolation properties exists.

Vibration Isolation, I. VIGNESS. Physics Today v18 n7 July 1965 p 42–8 9 figs 3 refs. Describes principles and devices that are useful in determining how to isolate equipment from disturbing vibrations. Discusses ; linear single-degree-of-freedom systems ; nonlinear devices ; bouncing ; conventional isolators ; cushioning materials and air springs ; isolators capable of responding in all directions ; pendulum isolators ; multiple-degree-of-freedom linear systems and uncoupled modes of vibration ; center-of-gravity mounting system ; inclined mounts ; dynamic vibration absorbers ; what method to use.

1.7. Effects of Surface State and Texture

How Surface Affects Measurement With Plug and Ring Gages, F. C. HUDSON. Am Mach v56 June 8 1922 p 860, Discusses effects of lubrication.

The Relation of Finish to Life of Plug Gages, L. M. McPHARLIN. Am Mach v66 May 12 1927 p 775–81 16 figs. Tests show that gages with mechanically lapped surfaces have much longer wear-life than hand-lapped gages, which excell ground gages; photomicrographs indicate progressive stages of wear.

Geometrical and Physical Conditions of Polished Surfaces, G. SCHMERWITZ. Phys Zeit v34 Feb 15 1933 p 145–58. Method previously described is applied to determine the minute irregularities in the polished surfaces of precision balls and cylinders made from steel and glass. Cross-sections are usually constant-diameter figures. Variations of a few Angstrom units can be detected. Local variations of the order of 0.003μ occur from time to time due to Brownian movements of particles.

Desired Characters of Surface Finishes, J. E. KLINE. Mech Eng v57 12 Dec 1935 p 749–52; Mech Wld v98 n2555 Dec 20 1935 p 593–5 and 608. Importance pointed out of affinitive surfaces possessing more nearly "run-in" characteristics, other than absolute smoothness; of diametric precision relating to operating tolerances; and of consequent danger of having too smoothly finished surfaces when operated with insufficient running clearances.

Desired Characters of Surface Finishes, E. J. ABBOTT. Mech Eng v58 n9 Sept 1936 p 596–8. List three conclusions; making as objective obtainment of affinitive surfaces possessing more nearly "run-in" characteristics, rather than absolute smoothness; importance of diametric precision relating to operating tolerances; and consequent danger of having too smoothly finished surfaces when operated with insufficient running clearances.

Surface Quality, R. E. W. HARRISON. Am Mach v80 n22 Oct 21 1936 p 878–9. Citation of nine major reasons why surface qualities should be controlled.

L'Étude des États de Surfaces Métalliques. Mécanique v21 n274 Sept–Oct 1937 p 203–16 (discussion) 216–9. Symposium on condition of metal surfaces; Influence of surface condition on sliding forces in clamping fits, O. KIENZLE; New method for measuring condition of machined surfaces, H. TORNEBOHM; Relation between surface condition and luminous dispersion, F. CANAC; Condition of metallic surface qualification and influence of surface condition on fits by pressing, P. NICOLAU.

Étude des couches fines extérieures des Matériaux, N. W. SAWIN. Mécanique v21 n275 Nov–Dec 1937 p 269–75. Study of fine surface finishes of materials; analysis of causes of metal surface wear; results of tests made on Skoda-Sawin machine for study of resistance to wear of machine finishes.

Les États de Surface. Technique Mod v32 n11–12 June 1–15 1940 p 171–3. Study of surface state of metals and its application to metal working; investigation refers to geometric, structural, mechanical and chemical state; illustrated description of surface testing apparatus. Bibliography.

Physics and Chemistry of Surfaces, N. K. ADAM. Oxford Univ. Press, 3d ed 1941. Section V, p 168–208 is a discussion of the general properties of solid surfaces. Succeeding sections deal with spreading and lubrication; fine structure; electrical phenomena at interfaces.

Surface Finish and Structure, J. WULFF. Am Inst Min & Met Engrs Trans (Iron & Steel Div) v145 1941

p 295–300. To ascertain depth and nature of deformation induced by such finishing processes as cold rolling, dry and wet grinding, lapping, honing, sanding, superfinishing, and metallographic polishing, electron diffraction pictures were taken of successively etched 18.8 stainless steel surfaces; there is no intention to imply that results or conclusions apply to all materials although some exhibit deformation effects to corresponding depths. Bibliography.

"Soft Skin" on Highly Finished Surfaces, P. LEINWEBER. Engrs' Digest (Brit Ed) v5 n3 Mar 1944 p 65–7; Engrs' Digest (Am Ed) v1 n5 Apr 1944 p 273–5. It is often claimed by makers of instruments that measuring surfaces have to lapped to obtain high accuracy and to remove soft layer produced by grinding; based on tests, it is concluded that, because of small zone in which existence of soft skin is possible, measuring surfaces should not be lapped; with exception of gages with very small tolerances. English abstract from Werkstattstechnik Betrieb June 1943 p 241–3.

Capillarity of Metallic Surfaces, E. R. PARKER, R. SMOLUCHOWSKI. Am Soc Metals—Preprint n13 for meeting Oct 16–20 1944 10 p. Phenomena observed in brazing and coating operations can be correlated on basis of surface energies and geometrical factors; balance of changes of solid liquid, solid air and liquid air surface energies depends upon capillary roughness of metallic surface; liquid metal spreads best on finely ground or on polished and etched surfaces both of which have fine capillary structure.

Les États de Surface, L. ROBIDA. Technique des Industries Mécaniques 1945 p 51–5. Surface state of metals; definition; micro- and microgeometrical deformations of surface; measurement by means of optical, electric or pneumatic method; state of surface from physicochemical point of view; Chrysler superfinishing process.

Symposium on Surface Finish. Eng v159 n4131, 4132, 4133, 4134, 4135, Mar 16 1945 p 215–20, (editorial comment) p 211, Mar 23 p 237–9, Mar 30 p 258–60, Apr 6 p 277–80, Apr 13 p 299–300; see also Machy (London) v66 n1692, 1693, 1694, 1696, 1697, 1698, 1700, 1703, Mar 15 1945 p 290–2, Mar 22 p 318–21, Mar 29 p 345–8, Apr 12 p 403–5, Apr 19 p 427–9, Apr 26 p 457–8, May 10 p 514–5, May 31 p 596–600; Engr v179 n4653, 4654, 4655, Mar 16 1945 p 218–20, (discussion) p 209–11, Mar 23 p 230–1 (discussion) 234–6, Mar 30 p 250–1; Automobile Engr v35 n461 Apr 1945 p141–6; Engrs' Digest (American Ed) v2 n7 July 1945 p 341–4; S African Eng v56 n4 Apr 1945 p 95. Symposium before Instn Mech Engrs, Mar 9 1945: Structure of Sliding Surfaces, G. I. FINCH; Surface Finish in Relation to Friction and Lubrication, D. CLAYTON; Principles and Methods of Surface Measurement, R. E. REASON; Measurement of Surface Waviness, C. TIMMS; Drawing Office Specification, H. J. GRIGGS; Rational Specification of Surface Finish, W. A. TUPLIN; Requirements in Surface Finish, D. McCONNELL; Surface Finish on Production Methods, W. E. R. CLAY; Results of Modern Practice, F. NOURSE; Continuity in Production of Specified Surface Finish, E. SWAIN; Effect of Fatigue Strength, W. KER WILSON; Locomotive Practice, F. C. JOHANSEN.

New Evaluation of Surface Finishes, W. F. KLEMM. Tool Engr v14 11 June 1945 p 42–4. Analysis of problems in surface wear; methods of inspection of finished surfaces; factors determining stability of bearing or wear surfaces in relation to dimensional characteristics of surface irregularities.

Les États de Surface, LASNIER, PLAGNOL. Soc des Ings de l'Automobile J v18 n4 July–Aug 1945 p 117–30.

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Present knowledge of surfaces; definition; examination with mechanical and optical apparatus, electron microscope, electrical and other methods; study of behavior of surfaces.

State and Properties of Metallic Surfaces, C. H. DESCH. Nature (London) v157 Mar 2 1946 p 271-2. A report of the Paris conference, Oct 23–6 1945 of the Commission Technique des États et Propriétés de Surface des Métaux, established in Aug 1942.

New Developments in Study of Surface Chemistry, E. A. GULBRANSEN. Metal Progr v49 n3 Mar 1946 p 553–9. Review of newly developed techniques and interpretations pertaining to use of electron microscope, electron diffraction camera and vacuum microbalance, as applied to study of fundamental factors involved in relating properties of given surface to any practical problem; physical form of surface; chemical nature of surfaced layer; velocity at which chemical and physical changes occur on or through surface.

L'État des Surfaces Métalliques, P. BASTIEN, C. de SENNEVILLE. Technique Mod v38 n15, 16, 19, 20 Aug 1, 15, 1946 p 169–76, Oct 1, 15, p 223–8. State of metal surfaces. Aug; Physical and physical chemical state; methods of study constitution and structure. Oct: Study of shape of surfaces; macro and micro roughness; influence of surface state on friction, electric conductivity, hardness, fatigue and corrosion.

Surface-Roughness and its Relation to Oil Film Thickness at Breakdown, A. CAMERON. Instn Mech Engrs Proc v161 (War Emergency Proc n48) 1949 p 73–7 (discussion) 77–9; Engr v187 n4868 May 13 1949 p 540–1. Tests show that for Michell pads there is definite relation between surface roughness of rubbing surfaces and calculated outlet film thickness at seizure and at point where initial metal to metal contact occurs; when steel collars are finely finished surfaces sometimes seized on initial contact; thus it may be possible to finish surface too finely or incorrectly.

Surface Reactions of Metals, G. TOLLEY. Metal Industry v75 n4, 5, 6, July 22 1949 p 68–70, 73 July 29 p 89–91, Aug 5 p 112–3. Physicochemical and physicomechanical reactions studied; measurements of surface roughness, surface area determination; experiences in treatment of aluminum foil and chromium plated nickel; corrosion; high temperature oxidation; problems of mechanical wear, friction and lubrication. Bibliography.

Effect of Surface Roughness on Rolling Friction, J. J. BIKERMANN. J App Phys v20 Oct 1949 p 971–5 3 figs 7 refs. Rolling tests showed that the roughest surfaces gave an almost quantitative agreement between this height of elevations and the height of hills calculated from a theory attributing rolling friction to surface roughness.

Surface Finish Control, C. R. LEWIS. Prod Eng v21 n8 Aug 1950 p 91–5. Effect of finish on metallic structure; effect of surface finish on bearing performance; performance of machined parts; test results regarding influence of surface finish on friction, wear, lubrication and fatigue endurance; discussion of new SAE standards. Bibliography.

Surface Finish and Designer, R. P. TROWBRIDGE, Prod Eng v21 n9 Sept 1950 p 122–7. Practical aspects of new approach to measurement, specification and application of surface finish control of metallic parts; types of instruments, standards for various production methods, and physical properties relating to condition of metallic surface are compared and evaluated. Bibliography.

Messung der Oberflaechenguete, G. SCHLESINGER. Springer-Verlag, Berlin, Goettingen, Heidelberg, 1951 248 p, illus, diagrs, charts, tables. Practical applications of results obtained from measurements of surface quality; nature and terminology of surface finish defined; various measuring instruments for macro and micro determination discussed; respective ranges of their applications; results of industrial applications in aircraft, automotive, railroad, tool, electric machinery and other industries, Eng Soc Library, N.Y.

Surface Finish, R. E. REASON. Australasian Engr v44 Oct 1951 p 48–59 discussion 59–64. Difference between primary and secondary texture; methods of measuring surface finish and instruments used for purpose; calibrating surface finish measuring instruments proposed; factors to be considered in identifying optimum surface for particular purpose. Bibliography.

"Gold Standard" Precision Specimens of Surface Roughness, C. R. LEWIS. Standardization v23 n8 Aug 1952 p 238–42. Explanation of production of calibration specimens, with values corresponding to American Standard B46.1–1947 and meeting specifications of B46.2–1952, developed by Chrysler Corp; instructions for use of precision reference specimens of 20, 32, 50, 80 and 125 microin., which are now available.

Properties of Metallic Surfaces. London : Inst of Metals 1953 370 p. [Monograph and Report Series No. 13]. The volume contains 13 papers presented at a symposium held in London in November, 1952. Contents : Specialized microscopical techniques in metallurgy, S. TOLANSKY. Radioisotopes in the study of metal surface reactions in solutions, M. T. SIMNAD. The influence of machining and grinding methods on the mechanical and physical condition of metal surfaces. P. SPEAR, I. R. ROBINSON, K. J. B. WOLFE. The effect of lubrication and nature of superficial layer after prolonged periods of running, F. T. BARWELL. The crystalline character of abraded surfaces, P. GAY, P. B. HIRSCH. The effect of surface conditions on the mechanical properties of metals, mainly single crystals, E. N. da C. ANDRADE. The effect of surface condition on the strength of brittle materials, C. GURNEY. The influence of surface condition on the fatigue strength of steel, R. J. LOVE. The influence of surface films on the friction and deformation of surfaces, F. P. BOWDEN, D. TABOR. Diffusion coatings, D. M. DOVEY, I. JENKINS, K. C. RANDALL. The nature and properties of the anodic film on aluminum and its alloys, H. W. L. PHILLIPS. Chemical behavior as influenced by surface condition, U. R. EVANS. The effect of method of preparation on the high-frequency surface resistance of metals, R. G. CHAMBERS, A. B. PIPPARD.

The Effect of Compressive and Shearing Forces on the Surface Films Present in Metallic Contacts, M. COCKS. Proc Phys Soc (London) B v67 Mar 1954 p 238–48. Two electrical methods were used to examine the extent to which the oxide or other natural surface films can prevent intermetallic contact when metal bodies are pressed together. One consisted of measuring the electrical resistance of the contact, the other of measuring the thermoelectric force which arises when there is a temperature gradient across the film; crossed cylinders were used for the contact members. Precautions were taken to minimize vibration and shearing forces when applying normal loads. The contact resistance was often as large as several ohms, showing that penetration of the films was negligible, and in some cases the variation of resistance and thermoelectric force with load was consistent with the assumption that the contact contained a uniform film. Friction forces up to a certain critical value could generally be exerted in the normally loaded contacts before any metallic contact appeared, and in certain cases the films remained intact even during sliding. When the film was penetrated, the area of metallic contact was small at first, but grew as sliding proceeded; there was a simultaneous growth in the force resisting sliding. Microscopic examination showed that the metal surfaces

suffered severe damage only after an appreciable distance of sliding (of the order of 0.1 mm).

Re-Evaluation of Surface Finish, L. CHANEY, C. H. GOOD. ASME Paper n54—A—192 for meeting Nov 28–Dec 3 1954 9 p. There are no adequate guideposts for really sure surface specifications; what has been done in relating performance to surface finish; importance of "roughness width cutoff" specification; definition of this criterion and implications of its use.

Symposium on Optical and Surface Methods of Non-destructive Testing, S. TOLANSKY, R. W. B. STEPHENS, O. S. HEAVENS. Brit J App Phys Supp n6 (Physics of non-destructive testing) 1957 p S5–S9 S9–S10 S10–S12. I. Tolansky reviews the optical methods used in his laboratory for the examination of micro-structures of metal surfaces. The methods described are two-beam interferometry, multiple-beam interferomtry, the light-profile microscope, optical shadow casting and the total reflection contact method. The usefulness and limitation of each method are discussed. Examples of the application of each method are given. II. Stephens briefly discusses the various types of optical measurement which might be applied to the examination of surfaces. Consideration is given to the possible use for specific problems of the u.v., the visible, the i.r. and the microwave regions of the electromagnetic spectrum. III. Heavens presents a brief survey of the type of information which may be obtained by the application of optical methods to the study of the surfaces of materials. Consideration is restricted to the kind of method which is likely to be of use as a non-destructive test.

Measurement of the Molecular Attraction Between Different Types of Solid Bodies, I. I. ABRIKOSOVA. Zh Eksperimental'noi i Teoreticheskoi Fiziki v33 n3 (9) 1957 p 799–801 in Russian. Experimental data are given for the attractive force and surface energy against the gap between surfaces of fused quartz. These agree with theory and with other experimental work done in a different way.

Surface Characteristics of Gage Blocks, A. G. STRANG. Metrology of Gage Blocks. NBS Cir 581 Apr 1 1957 p 87–97 10 figs. "The quality of the surface microfinish largely governs the ability of the gage blocks to wring together, the resistance to wear, and to some extent the accuracy of length measurement by both mechanical and interferometric methods."

Some Aspects in Production and Measurement of Surface Finish, M. A. CHAPPLE. Australasian Engr May 7 1957 p 57–9, 72. Surface finish as applied to plastic molds, wire drawing dies and gaging surfaces; precision grinding; diamond lapping; types of machines used to check surface finish.

Funktion und Beschaffenheit der technischen Oberflaeche, W. SCHMIDT. Metall v11 n6 June 1957 p 473–80. Function and quality of technical surfaces; characterization of surfaces on basis of tests and measurements; clarification of relations between function and nature of surface; determining conditions for production of prescribed surfaces.

Pruefen und Messen technischer Oberflaechen, A. WIEMER, R. LEHMANN. Technik v12 n7 July 1957 p 477–83. Testing and measurement of surfaces; characterization and determination of surface quality; pertinence to contacts of machinery parts, such as bearings, shafts, gears, gages, press fits, etc.

Surface Finish, K. S. COLLART. Prod Eng v28 n10 Sept 16 1957 p 82–3. How function and economics determine complex relations between size of part, its tolerance, and surface finish; effect of various variables; tool life

as function of surface finish; measuring techniques for constant accuracy of readings.

Experiments Using a Simple Thermal Comparator for Measurement of Thermal Conductivity, Surface Roughness and Thickness of Foils or of Surface Deposits, R. W. POWELL. J Sci Instrum v34 n12 Dec 1957 p 485–92. The thermal comparator described consists of two metal balls similarly mounted in a block of balsa wood, but one is at a slightly lower level so that it touches any surface on which the block rests. After heating to a small fixed temperature excess, the block is laid in contact with the test surface. Differentially connected thermocouples attached to each ball measure the increased rate of cooling of the ball that makes contact. The differential e.m.f. is observed 10 sec after contact is made and is shown to be a function of the thermal conductivity of the material on which the ball rests. When calibrated in terms of at least two substances of known thermal conductivity, determinations of thermal conductivity can be quickly made. The accuracy from single readings made on several alloys of Fe, Al and Mg is about $\pm 6\%$, but Pb departs considerably, due, it is thought, to its softness. The condition of the surface affects the readings, so the calibration should be made for a similar surface condition. Alternatively, the device can be used as a means of measuring the thickness of surface deposits and for non-destructive sorting or identification of solid materials.

Die Oberflaeche von metallischen Werkstoffen, etc. H. WIEGAND. Metalloberflaeche v12 n2, 3 Feb 1958 p 33–7, Mar p 53–8. Influence of surface of metallic materials on service behavior of structural parts; effect of mechanical forces, friction and sliding; influence of corrosion, oxidation, erosion and cavitation on behavior of material; composition of various protective coatings and their effect.

Nature of Mechanically Polished Metal Surfaces; Electron-Diffraction Examination of Polished Silver Surfaces, L. E. SAMUELS, J. V. SANDERS. Inst Metals J v87 pt5 Jan 1959 p 129–35. Electron-diffraction patterns obtained show that range of misorientations, and hence magnitude of deformation at surface, produced by polishing decreases progressively with increasing fineness of polish; with finest polish investigated, misorientations were only about plus or minus 5°; no evidence found of layer of peculiar structure of type postulated by G. Beilby. 29 refs.

Surface Specifications: Their Use and Meaning, C. H. GOOD. Tool Engr v43 n4 Oct 1959 p 77–80. Problems arising in cases where more complete specification is required; need for upper, as well as lower, limit on surface roughness; importance of roughness width cutoff; two ways to determine what roughness width cutoff to specify; surface lay; waviness spacing.

Surface Finish and Other Surface Specifications, F. W. WITZKE. Am Soc Tool & Mfg Engrs v61 book 1 paper 340 1961 15 p 19 figs. Discusses need for further standardization of surface specification, their interpretation and measurement; necessity for all engineering, production and inspeciton personnel to understand thoroughly the fundamentals of surface finish and geometry specifications, and to re-evaluate the capabilities of some of the very common measurement techniques.

Need for Research on Abraded and Polished Surfaces, L. E. SAMUELS. Piating v48 n1 Jan 1961 p. 46–9. Appraisal of some topics which are important for better understanding of nature of surfaces: atomic structure of surface: nucleation of growth and dissolution, surface oxide films; surface plastic deformation: surface flow; surface heating.

A New Look at Some Surfaces with Multiple-Beam Interferometry. Part 1, S. TOLANSKY. Discovery Jan 1961 p 4–13 16 figs 4 refs. By making it possible to look

at surfaces with a vertical magnification of millions, this technique is throwing new light on such widely diverse phenomena as patterns of crystal growth, the wear of glass-cutting diamonds, and the surface distortion from hardness tests and high-speed impacts.

Surface Roughness Effects on Metallic Contact and Friction, M. J. FUREY. Am Soc Lubrication Engrs Trans v6 n1 Jan 1963 p 49–59. Study was made in transition zone between hydrodynamic and boundary lubrication; system used was fixed steel ball riding on rotating steel cylinder; it was found that very smooth and very rough surfaces gave less metallic contact than surfaces of intermediate roughness; very smooth surfaces also gave less friction; 4 different types of antiwear/antifriction additives (including tricresyl phosphate) studied had little effect in reducing surface roughness; with rough surfaces, improvement in load-carrying capacity with increasing viscosity was less than that shown previously with smooth surfaces.

Relationship of Surface Finish to Physical and Functional Behavior, R. COURTEL. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 675–83. Published by ASME. Surface finish is shown to be not, in present state of art, characteristic that can be exactly described and measured; nevertheless, with examples of different metals, it is shown what the problems are and what kind of research is most likely to further state of art.

On the Mechanism of Contact between Metal Surfaces—The Penetrating Depth and the Average Clearance, T. TSUKIZOE, T. HISAKADO. ASME Trans Paper 64–Lub–18 1964 7p 11 figs 7 refs. The analysis of the mechanism of air leakage through the interstices between metal surfaces in contact or of the mechanism of thermal resistance between them is dependent on the average clearance between opposite surfaces or on the distribution of the real contact area; i.e., the mechanism of contact. As-

suming that the distribution curve obtained from the profile curve of the surface has a normal distribution, the relation between the applied load and the average clearance or the penetrating depth, i.e., the distance through which the one surface moves into the other surface, is obtained theoretically. A comparison of calculated values based on this theory with experimental data shows good agreement.

Theoretical and Experimental Relationship between Leakage of Gases through Interface of Two Metals in Contact and Their Superficial Micro-Geometry, G. ARMAND, J. LAPUJOULADE, J. PAIGNE. Vacuum v 14 n2 Feb 1964 p53–7. Flowing rate of gas through interface to two metallic surfaces in contact is in close connection with their micro-geometries; interfacial conductance is proportional to square of mean roughness of surfaces; experimental and theoretical results are in good agreement; phenomena occurring at metal-to-metal contact especially from leak rate viewpoint and measurement of mean roughness of surfaces in contact under loading.

Effects of Roughness of Metal Surfaces on Angular Distribution of Monochromatic Reflected Radiation, R. G. BIRKEBAK, E. R. G. ECKERT. ASME Paper n64–HT–26 Aug 1964 9 p 12 figs 16 refs. A detailed experimental study has been carried out to examine the influence of surface roughness conditions on the reflection characteristics of metal surfaces for monochromatic thermal radiation. Surfaces used were prepared by standard optical grinding techniques using a range of sizes of grit of the grinding compounds. Various definitions of reflectances are presented to facilitate in the discussion of the results. Biangular, specular, and hemispherical-angular reflectance measurements are discussed in terms of the optical root-mean-square surface roughness, wavelength of reflected radiation, and surface material. The experimental results are compared with the available predictions from theoretical analysis.

Addendum to Section 1

1.1. General Physical Metrology

Mensuration for Senior Students, A. LODGE. Longmans, Green and Co., London, 1895 274 p. Boston Public Library; John Crerar Library, Chicago.

Essai de Bibliographie Metrologique Universelle (Attempt at a Universal Metorological Bibliography), P. BURGU-BURU, Auguste Picard, Paris 1932 327 p 4206 refs. Provides references in two parts, 3844 in the French language and 362 in foreign languages, dealing with measurements in a variety of units, ancient and modern. Contains an authors' index.

Mass und Messen im Spiegel physikalisch-technischer Entwicklung (Standards and Measurements as Reflected in Physical, Technical Development). U. STILLE, PTB. Electrotechn und Maschinenbau v74 n2 Jan 15 1957 p 25–9; n3 Feb 1 1957 p 57–63 12 figs 31 refs. Discusses units for length and current; magnetic units; light intensity unit.

Mensuration, R. E. LANGER. Encyclopedia Brittanica, 1959 Ed., v15 p 253–7 2 refs. Defines mensuration as that branch of mathematics which deals with the measures or the approximate measures of lengths, areas, and volumes. Treats the following subjects: I Plane rectilinear figures: (a) elementary plane areas and lengths; (b) general polygons—areas under rectilinear graphs. II Circles: (a) lengths of circular arcs; (b) areas of circular sectors and segments. III Quadrature: (a) areas of plane curvilinear figures; (b) polynominal approximations—Lagrange's interpolation formula. IV Approximate quadrature: (a) the trapezoidal rule; (b) Simpson's rule. V Polyhedral volumes: (a) prisms; (b) pyramids; (c) prismoids. VI Cylinder, cone, and sphere. VII Volumes and surface areas by integration: (a) simple in-

tegrals; (b) multiple integrals. VIII Theorem of Pappus on centroids. IX Approximate volumes.

Measurement Standards, A. G. McNISH. International Sci and Technol n47 Nov 1965 p 58–66 10 figs. All units of measurement, including the ampere of current and candela of light intensity—two base units included in the new International System of Units, are ultimately derived from four original prototype units—the meter of length, kilogram of mass, degree Kelvin of temperature, and second of time. To make all measurement units more effective tools, the standards that physically embody or define three of the prototypes—length, time, and temperature—have been changed in recent years. In the case of length, the change has replaced the man-made meter bar with a more accurate and more easily reproducible natural constant, the wavelength of an energy transition in krypton-86, and before the decade is out this in turn may be replaced by a length standard based on the laser. This rapid overthrow of long-established standards is not without precedent; the second of time has been redefined twice in the last ten years and it soon may be again. Temperature scales seem to have achieved a stability of sorts, however, with the partial success of attempts to relate the International Practical Temperature Scale to the Thermodynamic Scale.

Status of the National Standards for Physical Measurements, R. D. HUNTOON, NBS. Science v150 n3693 Oct 8 1965 p 169–78 8 figs 7 refs. Discusses the evolution of a measuring system, the meter, kilogram, second, and degree Kelvin; the measurement chain for dealing with various magnitudes; and future trends.

1.2.1. General Dimensional Metrology

Längenmessung (Length Measurement), F. GÖPEL, Chapter 2 of Handbuch der Physik, Verlag Julius Springer, Berlin v2 1926 p 42–90 38 figs refs. Discusses the length unit, the embodiment of the length unit, length measurement arrangements, error influences in length measurement, examples from physical length measurements.

Precision Machines and Instruments for the Measurement of Length. G. K. BURGESS, NBS. World Eng Congress, Tokyo, 1929 v5 p1–78 58 figs refs (Paper n335). Distributed by Kogakkai, Marunouchi, Tokyo, 1931. In this paper the importance of progress in the art of length measurement, in science, engineering, and industry, is pointed out; the basis of precision length measurement is discussed, and the following types of measuring apparatus and their uses are described in detail: Comparators for line standards of length; comparators for end standards, gages, and machine parts; comparators for geodetic tapes and wires; precision measurements in geodetic surveying; the use of wavelength standards in the test of end standards and graduation of line standards; optical projection and measuring apparatus and optical measurements: thermal expansion apparatus; optical lever system and optical strain gage; the carbon-pile telemeter; some basic principles of limit gaging; and automatic machine gaging.

Solid Mensuration, with Proofs, W. F. KERN, J. R. BLAND. John Wiley and Sons, Inc. New York 1938 172 p. Chapter headings: 1) Plane figures; 2) lines, planes, angles; 3) solids for which $V = Bh$; 4) solids for which $V = Bh/3$; 5) solids for which $V = $ (mean B) h; 6) the sphere; 7) volumes and surfaces of revolution—polyhedrons; 8) the general prismatoid; 9) summary and review. Aims to present the fundamental, practical essentials of solid geometry in a new and concise but comprehensive manner.

La Métrologie dans les Musées de Province et sa Contribution a l'Histoire des Poids et Measures en France depuis le Treizième Siècle (Metrology in the Musées de Province and its Contribution to the History of Weights and Measures since the Thirteenth Century), A. MACHABEY. Ouvrage publié avec le concours du Centre National de la Recherche Scientifique 1959 512p. Chapter 1 deals with the history of length measures.

Zur Geschichte des Metermasses (Regarding Standards of the Meter Measurement), K. CLUSIUS. Experentia v19 n4; 15 IV 1963 p 169–77 6 figs 12 refs. Discusses the necessity for a universal length standard; regarding natural standards; the Metre des Archives; the diplomatic meter convention and the prototype meter of 1889, division of a fixed meter standard; optical definition of the length unit and the cadmium lamp; the new meter definition with the aid of Kr_{86}; the Kr_{86} lamp; progress in the definition of the meter.

1.2.2. Units of Length and Angle

On the Present State of the Question of Standards of Length, W. A. ROGERS, Proc Am Acad Arts and Sci, Boston v15 1879–80 p 273–312. Presents a consideration of those standards of length which are in actual use, and which have the authority of sanction of either national or international law. Also discusses attempts to establish standards which should conform to a natural unit. Bibliography.

Measures and Weights, L. V. JUDSON, NBS. Encyclopedia Britannica 1959 Ed. v15 p 135–42. Treats in detail the U.S. customary system, the British imperial system, and the metric system. The systems and units used in some foreign countries are briefly considered. Presents table of equivalents. Bibliography.

1.2.4. Surveying Methods Applied to Large Mechanical Structures

Remote-Measuring Wire Distance-Gauge DPD–2, B. E. KOSTICH. Meas Techns n7 Feb 1965 p 576–7 1 fig 5 refs. Translated from Izmer Tekh n7 p 17–8 July 1964. Distance gauge DPD–2 has been developed for measuring lengths up to 30 m at inaccessible places in large-size welded objects.

1.3.1. Precision, Accuracy, Uncertainty,— General

Discussion of the Precision of Measurements, S. W. HOLMAN. 2d Ed. John Wiley and Sons, New York 1901 176 p. Examples include distance by a steel tape and others from physics and electrical engineering.

Elements of the Precision of Measurements and Graphical Methods, H. M. GOODWIN. McGraw-Hill, New York 1920 116 p. Contains classification of measurements, discussions of direct and indirect measurements, deviations, errors, etc.

1.3.2. Instrumental Errors

On the Error in Standards of Linear Measure, Arising from the Thickness of the Bar on which they are Traced, H. KATER. Reprint from Phil Trans London n 23 1830 p 359–81. Describes comparisons of three scales with the Imperial Standard Yard, a bar which is 1.07 in. square.

Precision in Measuring Lengths and Angles in Mechanical Engineering, M. G. BOGUSLAVSKII, L. K. KAYAK. Meas Techns n4 Nov 1964 p 310–3. Translated from Izmer Tekh n4 p 26–8 Apr 1964. Reviews problems of ensuring the precision of technical measurements by means of Soviet measuring instruments. The dimensions of components made on precision metalworking machines are usually checked either by means of measuring tools or directly by measuring instruments. The instrument-making industry has developed in recent years, for the use of factory test laboratories, several new types of measuring instruments which have already passed their state tests, such as a universal measuring microscope, pneumatic micrometer, optimeters, cathetometers, measuring machine, linear-graduated measures, polyhedron quartz prisms, interferometers, etc.

Maximum Deviation in the Readings of Measuring Instruments, A. I. IVANTSOV, V. V. ASANOV. Meas Techns n11 Apr 1965 p 950–3 1 fig 4 refs. Translated from Izmer Tekh n11 p 11–3 Nov 1964. Deals with distribution laws of deviations in the readings of measuring instruments, a deviation being regarded as an error $\Delta \phi$ in the position of the output element (for instance, a pointer).

1.5. Deformation, Deflection, and Wear

On the Flexure of a Uniform Bar, Supported by a Number of Equal Pressures Applied at Equidistant Points, and on the Positions Proper for the Applications of these Pressures in Order to Prevent any Sensible Alteration of the Length of the Bar by Small Flexure. G. B. AIRY. Mem Roy Astron Soc v15 1846 p157–63. Presents a mathematical analysis of the relationship between the positions of the points of support of a length bar and the extension or contraction of the upper surface. A conclusion drawn is that when the bar is on two supports, in order that the extension may be zero, the distance between them must be $a/\sqrt{63}$, where a is the length of the bar. (This is the origin of the now well known "Airy points.") When there are eight supports the distance between each and the next must be $a/\sqrt{63}$. U. S. Naval Observatory Library.

Air Mounts Maintain Surface Plate Flatness, G. E. McKEWEN. Tool and Mfg Engr Apr 1962 2 p 2 figs. When heavy parts are checked on a surface plate, deflection caused by the weight of the part limits measuring accuracy. An air-mount system offsets variations in loading and keeps the surface plate flat. It also eliminates the effects of shock, vibration, and changing temperatures.

Section 2. Length and Diameter Measurements by Interferometry

CONTENTS

2.1. Interferometry, General

Sur les Franges des Lames Minces Argentées, et Leur Application à la Mesure de Petites Épaisseurs d'Air (On fringes with thin silver coatings and their application to the measurement of thin thicknesses of air), C. FABRY, A. PEROT. Ann de Chim et de Phys ser 7 v12 1897 p 475–501. Contents: Fringes with thin silver coatings; fringes of superposition; application of the fringes of superposition to the measurement of short lengths; phase loss; diffusion; conclusions.

Théorie et Applications d'une Nouvelle Méthode de Spectroscopie Interférentielle (Theory and application of a new method of interferential spectroscopy), C. FABRY, A. PEROT. Ann de Chimie et de Phys ser 7 v16 1899 p 115–44 3 figs 4 refs. Contents: Introduction; theory of the interferential apparatus; description of the interferential spectroscope; adjustment; account of one experiment; applications; production of interference with thin glass.

Méthodes Intérferentielles Pour la Mesure des Grandes Épaisseurs et la Comparaison des Longueurs d'Onde (Interferential methods of measuring great thicknesses and the comparison of wave-lengths). A. PEROT, C. FABRY. Ann Chim Phys v16 1899 p 289–338 7 figs 14 refs. More complete and general than previous papers by authors. Contents: Introduction; determination of the numerical order of a fringe including theory of coincidences and effect of phase loss; comparison of wave lengths; measurement of wave lengths for great thicknesses; fringes of superposition with convergent light; use of fringes of superposition for length measurement.

The Interferometer, H. G. GALE. Am Mach v24 July 11 and 18 1901 p 772–5, 799–802. Illustrated explanation of the principle of this instrument and the method of meas-

uring very small distances and angles in terms of the wave length of light.

Direct-Vision Intense Monochromotor, H. DU BOIS. Zeit InstrumKde v31 Jan 1911 p 1–6 and Mar 1911 p 79–87. Communication from the Bosscha Lab. Description of a direct vision instrument constructed to give a bright monochromatic beam from any part of the spectrum. The dispersion is caused by a three-member prism, and the change of color at the eyepiece is caused by a micrometer screw which moves objective and prism together. The readings of the screw are standardized by means of the sun's spectrum.

Measuring the Diameter of the Stars, H. N. RUSSELL. Sci Am Monthly, v3 n2 Feb 1921 p 100–4. Michelson apparatus in which two slits are made in a screen set up in front of the mirror of a reflecting telescope.

Applications of Interferometry, W. E. WILLIAMS. N.Y., E. P. Dutton & Co. 1930 104 p diagrs. Description of various types of interferometers and principles of each type; scientific and technical applications of interference methods are pointed out, and useful lists of references are given; work is useful introduction to subject for engineers and physicists. Eng. Soc. Library, N.Y.

Light Waves in Precision Measuring, E. W. MELSON. Iron Age v136 n2 July 1935 p 14–5, 42 and 44. Measuring by optical flats; checking gage blocks; measuring balls and cylinders; examples of precision.

Resolving Power of Interferometers and their Use as Monochromators, M. CAU, F. ESCLANGON. Rev d'Optique v16 p 41–63 Feb, and Mar 1937 p 93–103. The the-

ories of Fresnel and Gouy are applied to results obtained by using an interferometer as a monochromator and analysing the transmitted radiation in a second interferometer. Either theory will explain the results. The problem is investigated theoretically and experimentally.

Verwendung von Lichtinteferenzen in der technischen Messung, T. ZOBEL. VDI Zeit v81 n22 May 29 1937 p 619–24. Application of light interference in technical measurements review of origin and application of interference phenomena; interferometer of Mach and Zehnder described which separates two light paths in space and can be applied to many technical measurements. Bibliography.

Shop Measurements with Light Waves, J. DAUBER. Mod Machine Shop v16 n4 5 Sept 1943 10 p between p 118 and 130, Oct 15 between p 174 and 198. Article comprises clear and practical exposition of theory of light wave measurement and use of "optical flats" for measuring to millionth of inch.

Light Waves as Standards of Length, H. BARRELL. Res. v1 1948 p 533–40 3 refs. Types of length standards; length measurements by interferometry; the meter and the yard in wavelengths of light; the refractive index of air; measurement of length standards for precision engineering; bibliography.

Applications of Interferometry, W. E. WILLIAMS. Methuen, London 1948. In chapter 5 a Fizeau type of interferometer is described.

A New Principle in Interferometer Design, E. R. PECK, J Opt Soc Am v38 Jan 1948 p 66. Each of the two mirrors of a normal Michelson interferometer is replaced by a pair of mirrors mounted at 90°. The reflection of such a mirror is not affected by rotation about the line of intersection of the pair, and it can thus be mounted on a rotating arm instead of a slide. A further development, using a triple mirror, or a glass corner-cube prism, and needing no angular adjustment at all, is discussed.

Laengenmessung durch Lichtinterferenz, H. WITTKE. Archiv fuer Tech Messen n156, 157, 159, Aug 1948 p T84 (4 p   ), Oct p T97 (4 p   ), Jan 1949 p T6 (2 p   ). Measurement of length by means of light interference. Aug 1948: Part I, II: Historical and general review; determination of short lengths and distances. Oct 1948: Part III, IV: Determination of wedge thicknesses; determination of long sections and distances. Jan 1949: Part V, VI: Instruments employed; calibration of invar wires; accuracy of interferometric length measurements.

Theory of the Corner-Cube Interferometer, E. R. PECK, J Opt Soc Am v38 Dec 1948 p 1015–24. The corner-cube interferometer is analysed geometrically and analytically. When the prisms are used near their axis, the instrument is found to behave essentially like an interferometer using triple sets of front-surface mirrors. Equations are obtained describing the fringe patterns when one prism is used far off its axis, and also when both are used near their axis. These fringe patterns are discussed and illustrated.

Sensitive Adjustment for Interferometer Plates, O. S. HEAVENS. J Sci Instrum v27 n6 June 1950 p 172. System for providing sensitive adjustments of position and tilt frequently required in optical systems employing interferometry; device is of simple rugged construction and is not susceptible to vibrational disturbances; fine adjustment enables points of support of one of interferometer plates easily to be set to within one quarter wavelength.

Multiple-Beam Interferometry, S. TOLANSKY. Endeavour v9 Oct 1950 p 196–202. An account is given of the application of multiple-beam interferometry to the study

of metals, surface polish, hardness testing, and formation of slipbands in stressed metallic crystals. The technique is also used in studying the mechanism of crystal growth in certain minerals, the hardness anisotropy of diamond undergoing abrasion test, and the modes of oscillation of quartz. A new method of obtaining sharp fringes and the adaptation of an older method for examining defects in mica are described.

The Michelson Interferometer at Millimetre Wavelengths, W. CULSHAW. Proc Phys Soc London B v63 Nov 1950 p 939–54. The required frequency stabilization of the 12.5 mm source is achieved by using a high Q cavity as an r.f. discriminator. Wavelength measurements have been made with various spacings of the interferometer, the measured wavelength increasing as the spacing is reduced. Results indicate that the interferometer gives more accurate measurements of the wavelength when operated well in the Fraunhofer region of diffraction. The operating frequency has been measured using a calibrated frequency meter, and hence the velocity of electromagnetic waves deduced. The value obtained for this velocity agrees, within the accuracy attempted with the present instrument, viz. one part in 10^4, with the generally accepted value for this velocity. The possibilities of increasing the accuracy of its determination with the interferometer are discussed. Measurements of the dielectric constants of low-loss materials by means of the interferometer have been made. Results obtained using ordinary commercial sheets of materials agree within a few percent with values obtained otherwise. The use of the interferometer as a substandard of length is also discussed.

A Method for the Adjustment of the Compensator Plate of a Michelson Interferometer, J. E. H. BRAYBON. J Sci Instrum v27 Dec 1950 p 331–2. The method is a modification of the usual interference method of adjustment for parallelism between compensator and splitter plates of a Michelson interferometer. Adjustment is made by reducing to zero the fringes obtained when a spectrometer is used to analyse white light which has passed through the interferometer arm containing the compensator. Parallelism may be assessed to within 0.2′ of arc.

New Techniques in Optical Interferometry. I–V, H. KUHN. Rept Phys Soc Progr Phys v14 1951 p 64–94. Part I deals with optical properties of thin films. Multiple dielectric films, deposited on glass, can have reflection coefficients up to 0.9 for visible light, and much higher values can be reached for silver films. The intensity distribution in the reflected and transmitted light in multiple beam interference is discussed and applied to interference filters. "Frustrated total reflection" filters and polarization filters are briefly described. Part II deals with recent methods of using Fabry-Perot etalons. The theory and practical performance of the double etalon, the photoelectric method of recording etalon fringes and the use of etalons in solar spectroscopy are described. Part III deals with standards and testing methods, pure isotope light sources, testing of gauges, etc., and gives a description of the "wavefront shearing interferometer." Part IV deals with the interferometric study of surfaces, and Part V with recent modifications of the classical methods of interference refractometry and with the application of interferometers to the study of gas flow at high speeds.

Modern Interferometers, C. CANDLER. Hilger & Watts, Ltd. London, 1951. 502 p illus diagrs charts tables (Obtainable from Jarrell Ash Co. Boston, Mass.). Descriptions and simple theory essential for use of interferometers in astronomy, chemistry, engineering, nuclear physics and surveying; material is organized according to prospective use of each type of instrument; diffraction gratings; Fabry-Perot etalon; Twyman interferometer, Michelson interferometer, Lummer-Gehrcke plat; Rayleigh refractometer; Jamin interferometer. Eng Soc Library, N.Y.

An Improved Beam Divider for Fizeau Interferometers, H. BARRELL, J. S. PRESTON. Proc Phys Soc London B v64 Feb 1951 p 97–104. A transparent material, presumed to be TiO₂, is suggested for replacing Al or Ag as a coating for glass beam dividers in Fizeau interferometers, particularly those adapted for measuring length or displacement in the reflected fringe system. The method of depositing the films, and their optical properties, are described; the coatings are very resistant chemically and mechanically. Evidence produced in photographs and microphotometer records, supplemented by calculations of fringe intensity distributions, shows that the performance of the new material in the interferometer is superior to that of Al and plain glass.

A New Constant-Deviation Prism Arrangement, S. MAKISHIMA, Z. KOANA, K. OSHIMA. J Opt Soc Am v41 Apr 1951 p 249–52. Describes a new arrangement which is characterized by higher brightness, greater resolving power and increased accuracy of wavelength as compared with types hitherto known. This arrangement consists of two equal half-prisms placed separately with their divided surfaces outward and a rotative plane mirror properly placed in some position between them. It is easily shown that the condition of minimum deviation is satisfied at every angular position of the mirror. When used as a monochromator, therefore, no errors occur in the wavelengths of emergent rays computed for the condition of minimum deviation, even when errors occur in the mounting of the prisms or the mirror. This was proven by tests on a quartz monochromator constructed on this principle. Further, the aperture of the instrument suffers no change by rotation of the mirror. Since the prisms are held fixed with their divided surfaces perpendicular to the axes of the collimator and the telescope, the aperture remains constant at its largest value available, quite independent of the wavelengths used. This results, naturally, in some gain of resolving power.

Interference Measuring Accurate Within 1/10,000,000 Inch, G. WEBBER. Am Mach v97 n25 Nov 23, 1953 p 121–4. Multiple beam interferometer, world's most precise instrument for determination of length is produced by Webber Gage Co., Cleveland, Ohio; gage blocks are made from chrome carbide which has 30 times greater resistance to corrosion than other carbides and 10 times more resistance than 18–8 stainless steel; measurements with Zeiss instrument are made in three different wavelengths of monochromatic light.

Some Applications of Interferometry to Precision Measurement, C. F. BRUCE. Commonwealth Sci Indus Res Organization Australia, Nat Stand Lab Tech Paper n4 p 16 1954. A general account is given of some applications of optical interferometry to the measurement of length, angle, flatness, surface finish and vibration. Particular reference is made to multiple-beam interferometry and its application to surface structure and vibration problems.

The Interferometry of Length, H. BARRELL. "Maintenance of standards" symposium PTB Feb 1954 p 23–34. The development of the use of a wavelength standard of length is reviewed, and new types of spectroscopic sources for such a standard, using the isotope Hg¹⁹⁸, Kr⁸⁴ or Kr⁸⁶, are described and compared. The techniques and accuracies of interferometric measurements of length, both of standard end gages and of long distances [c. 20 m] for geodetic work, carried out at various national laboratories are reviewed. Some discussion is reported.

Inexpensive Michelson Interferometer, E. F. CAVE, L. V. HOLROYD. Am J Phys v23 n1 Jan 1955 p 61–3. The construction and operating characteristics of a Michelson interterometer designed on kinematic principles are outlined. The main components are ground steel dowel pins and ball bearings which are commercially available. The construction requires only a moderate amount of mechanical skill. Preliminary results indicate that the device

is quite suitable for use in the undergraduate optics laboratory.

An Improved Mirror Mounting for Optical Interferometers, T. F. W. EMBLETON. J Opt Soc Am v45 n3 Mar 1955 p 152–3. A mirror mounting is described which enables the relational adjustments of the optical surface to be made about axes passing through the center of that surface. This feature resulted in considerable simplification of the adjustment of a Mach-Zehnder interferometer in which it was used. Some special properties of the mounting are mentioned.

Metrology of Gage Blocks—Proceedings of Symposium on Gage Blocks Aug 11–12 1955. NBS Cir n581 Apr 1 1957 119 p. Precise Interferometric Measurement of Gage Blocks, E. ENGELHARD; Calibration of Gauge Blocks in Canada, K. M. BAIRD; Use of Light Waves for Controlling Accuracy, F. H. ROLT; Achromatic Interferometer for Gage-Block Comparison, T. R. YOUNG.

Light Waves and Length Standards, I. C. GARDNER. J Opt Soc Am v45 n9 Sept 1955 p 685–90. Historical review of early standards of length and of presently used Imperial Standard Yard, International Prototype meter and red spectral line of cadmium; discussion of various sources of monochromatic radiation for providing length standard in terms of light wavelength.

Precision to Fraction of Light Wave, M. S. HOSKINS. Machy (NY) v62 n7 Mar 1956 p 190–3. Types of interferometers used with gage blocks to determine precise measurement between two parallel surfaces of gage; light sources employed; fringe pattern, spacing of fringes and fringe behavior; how interferometer picks up light wave interferences.

Fine Measurements, J. R. ADAMS. J Sci Instrum v33 n10 Oct 1956 p 369–75. The limitations of the existing legal standards of linear measure are considered. The use of light waves as a universal reference of linear measure depends on the availability of a source of truly monochromatic light and considerable progress has been made using the isotope Hg¹⁹⁸. Many aspects of engineering require measurements accurate to a few micro-inches and instruments capable of meeting such demands have been designed. Several typical instruments, together with details of the principles on which they are based, are briefly reviewed.

Interferometric Measurements in Metrology, M. F. ROMANOVA. Optika i Spektrosk v3 n5 1957 p 457–72. In Russian. This review article gives accounts of work on (1) the determination of the wavelength of the standard Cd line; (2) measurement of 1 m length standards; (3) the wavelength of the Cd red line for the isotopes 112, 114, and 116; and (4) a method for finding the velocity of light. Results are given in each section with diagrams of the apparatus used.

Koesters Interferometer, J. B. SAUNDERS, J Res NBS v58 n1 Jan 1957 (RP2730) p 27–31. Results of investigation of Koesters double image prism; some of results are not in harmony with those given by other investigators; modification of Koesters prism is described that forms simple interferometer that is easy to apply to testing of lenses, mirrors, and combinations of these elements; practical test given for determining maximum size of source that is usable in any interferometer.

Construction of Koesters Double-Image Prism, J. B. SAUNDERS. J Res NBS v58 n1 Jan 1957 (RP2729) p 21–6. Interferometric method for use in constructing and adjusting double image prisms of Koesters type; faces of prisms form elements of several interferometers used for testing and making adjustments during construction; prisms are cemented together and are quite stable; pre-

cision attainable in adjustments approaches interfero-metric perfection.

A New Interferometer with Three Waves, J. J. HUN-ZINGER. Rev. Opt v36 n6 June 1957 p 285–91 in French. A new type of interferometer is described using three interfering waves. This is suitable for the measurement of end-standard gauges. There are certain advantages in the system which are discussed. An arrangement for mount-ing the mirrors is described. In effect the system can be considered as a compound Michelson interferometer in which two dividing mirrors are used behind each other. The intensity distribution in the fringe system is discussed.

Latest Wave in Physical Optics, F. ZERNIKE. Opt Soc Am J v47 n6 June 1957 p 466–8. Basic principles and some little known minor subjects discussed; new concept of partial coherence treated; old relative phase shift, as in Fresnel rhomb, gives rise to new effect—destructive inter-ference between two halves issuing from roof prism; phase differences which are otherwise unobservable be-come visible on coherent background obtained in simple manner by diffraction.

Spherical Aberration in Fizeau Interferometer, W. G. A. TAYLOR. J Sci Instrum v34 n10 Oct 1957 p 399–402. Re-view of drawbacks of types of instrument in common use; primary aberration theory predicts quite accurately errors introduced even by simple collimators with large aberra-tion; advantages of using collimating lens based on mul-tiple meniscus design; comparison of performances of several lens-systems.

Interferometry—Symposium Held at National Physi-cal Laboratory June 1959. Great Britain NPL—Sympo-sium n11 1960 471 p. Contains 14 papers on absolute length measurement and light sources for interferometry, and optical testing and measurement of relative position; topics treated include accuracy of light wave sources and wavelength comparison, wavelengths of helium lines, po-larization interferometers, accurate interpretation of microinterferograms, study of optical images, possibilities of moiré fringe, and interferometry with electronic aids.

Precision Millimeter Wave Interferometry at the U.S. National Bureau of Standards, W. CULSHAW, J. M. RICHARDSON, D. M. KERNS. NPL Symposium n11 Interferometry. H.M. Stationery Office, London 1960 (Paper 4–3) p 329–53 9 figs 17 refs. Describes techniques of precision millimeter wave interferometry for purposes of determinations of wavelength, velocity of light, and length on the basis of the extreme coherence and sensi-tivity available. Develops a solution for the diffraction correction. Describes present status of experimentation.

Introduction to Interferometry, T. J. O'DONNELL. Am Mach/Metalworking mfg v104 n12 June 13 1960 p 123–46. How interferometers can be used in shop to measure and compare length, angles, parallelism, and surface condition.

Methods of Narrowing Spectral Lines for Interference Measurements of Length, A. P. KIRICHENKO. Uspekhi fiz. Nauk (USSR) v78 n3 Nov 1962 p 525–38 in Russian. English translation in Soviet Physics-Uspekhi (USA) v5 n6 May–June 1963 p 998–1005. A detailed review is given of some methods employed for the production of strictly monochromatic radiation having breadth smaller than the Doppler breadth. The methods described are inter-ference monochromatization using a spherical Fabry-Perot etalon, absorption monochromatization in which radiation is transmitted between two close-lying absorp-tion lines produced by Zeeman splitting and an interfer-ence-compensation optical scheme. Laser techniques are only briefly mentioned.

Two Interference Methods for Measuring Amplitude of Oscillations of Mechanical Systems, B. S. DAVYDOV. Instruments & Experimental Techniques (English trans-lation of Pribory i Tekhnika Eksperimenta) n1 Jan–Feb 1963 p 132–3. Principles of contactless methods are examined, for determining total amplitude of oscillations from tens of microns to several millimeters, in wide fre-quency range, with error from 0.1 to 6% or less, by using phenomenon of interference of light.

Interference Monochromator with a Spherical Fabry-Perot Standard, N. R. BATARCHUKOVA, A. P. KI-RICHENKO. Meas Techns 1962 n8 Feb 1963 p 633–6 5 figs 2 refs. See abstract under 2.4.5.

Large Aperture Interferometers with Small Beam Divid-ers, J. B. SAUNDERS. J Res NBS C Eng and Instru-mentation v67C n3 July–Sept 1963 p 201–205 7 figs 11 refs. This paper shows some practical interferometers for test-ing very large and very small specimens. This is accom-plished by using a particular type of beam divider that operates near the vertex of a convergent or divergent beam of light that permits almost unlimited size fields of view. Thus very large or very small specimens can be tested. Also, the wave front reversing properties of this beam divider permit tests to be made without the neces-sity of using standards of reference, thus eliminating the requirement for large standards that are usually expensive and require large working areas. The principles of these interferometers are so closely related to previously de-scribed instruments that very little additional explana-tion is required for an understanding of their operation. Several variations of the Kösters prism type of interferom-eter are shown schematically.

The Use of a Single Plane Parallel Plate as a Lateral Shearing Interferometer with a Visible Gas Laser Source, M. V. R. K. MURTY. App Optics (USA) v3 n4 Apr 1964 p 531–4. A high-intensity interference pattern can be ob-tained in a shearing interferometer with the use of a visible gas laser and a simple construction. The high in-tensity of the laser per unit of solid angle gives an inter-ference pattern that is visible in room light. The narrow spectral width of the source allows a simple plane parallel plate to be used to obtain the desired shear.

2.2. Interferometry Theory

2.2.1. General

Über einen Interferenzmessapparat (Regarding an Inter-ference Measurement Apparatus), O. PULFRICH. Zeit für Instrumkde v18 Sept 1898 p 261–7. Description of Pulfrich interferometer, based on the principle of the simultaneous use of monochromatic lights of different wave-lengths and micrometric measurement of the inter-ference fringes.

On a Method of Increasing the Sensitiveness of Michel-son's Interferometer, H. C. POCKLINGTON. Cambridge Phil Soc Proc v11 May 1902 p 375–9. In the modified ar-

rangement the two interfering beams consist of circularly polarised light, and a retardation of either causes rotation of plane of polarization of resultant. The incident light employed is plane polarised. Accuracy of an observation is increased nearly 200 times.

Interference of Light with Great Path Difference, O. LUMMER, E. GEHRCKE. Deutsch Phys Gesell Verh v4 Oct 17 1902 p 337–46. Method, based on multiple reflection within a plane parallel plate, by means of which interferences can be investigated for a path difference as great as 2,600,000 wave lengths.

Sensibility of Interferometers. Improved Half-shadow Instruments, A COTTON. CR Acad Sci Paris v152 Jan 16 1911 p 131–3. While instruments using polarized light will detect a difference of $\lambda/10{,}000$, ordinary interferometers will scarcely detect a difference of $\lambda/100$, due to the irregularities of surface of the media traversed, to accidental variation in temperature, and to cruder method of measurement. Tells how a more accurate half-shadow instrument may be constructed and also how Michaelson interferometer may be improved.

Resolving Power of Interferometers, H. NAGAOKA. Math Phys Soc Tokyo Proc 8 Oct 1915 p 214–20. Discusses in some detail the resolving power of various instruments having high resolving power, and advocates the employment of crossed systems in preference to making attempts to increase the resolving power of individual instruments. Attention is paid to the question of the resolution of a strong line accompanied by a much weaker satellite.

Michaelson Interferometer, G. KRAUSE. Ann der Phys v48 Feb 1 1916 p 1037–60. Abstract of dissertation, Breslau. Gives mathematical theory, with experimental verification, of the interference phenomena obtained when the compensating plate in a Michaelson interferometer is inclined to the reflection plate.

Fringe Systems in Uncompensated Interferometers, J. GUILD, Proc Phys Soc v33 Dec 15 1920 p 40–52. It is shown that the form of fringes in this case is unaffected by lack of compensation in a Michaelson interferometer, but the visibility of fringes is conditioned.

Die Anwendung der Intreferenzen in der Technik (The Application of Interference in Engineering), H. SCHULZ. Zeit für tech Phys v3 n9, 10 1922 p 284–90, 313–20. General principles, interferences of equal thickness in optics, interfences of equal thickness in mechanics, the Michaelson and Mach arrangement, interference of equal inclinations.

The Lummer-Gehrcke Parallel Plate Interferometer, F. SIMEON. J Sci Instrum v1 July 1924 p 296–304 3 figs 39 refs. Gives simple approximate expressions for order of spectrum, separation of consecutive orders, dispersion, and resolving power, together with notes on methods of use, appearances obtained and interpretation of these appearances. Precautions to be observed in order to obtain finest definition.

On the Passage of Light Through Transparent Plates, A. SCHUSTER. Phil Mag v48 Oct 1924 p 609–19. Mathematical discussion.

Grating Interferometer, B. P. RAMSAY. J Opt Soc Am v24 n9 Sept 1934 p 253–8. Discussion of Michelson interferometer indicates that fringes are formed by superposition of two approximately parallel wave fronts; wave fronts having necessary characteristics can be obtained by mounting gratings on arms of interferometer in places of customary reflecting mirrors; construction and action of such interferometer has been studied and is described.

Theory of Interference Apparatus, A. BOGROS. J de Phys et le Radium v8 Mar 1937 p 88–92. A comparison of spectroscopic instruments which depend on the interference or diffraction of radiation are geometrically similar shows, by a simple argument, that in the case where the fringes are observed at a finite distance the linear dispersion for a given radiation is proportional to the dimensions of the apparatus. In the case where the fringes are observed at infinity the angular dispersion is independent of the dimensions of the apparatus. In both cases, however, the dispersion counted in fringes and the power of resolution are proportional to the dimensions of the instruments. These remarks permit of the correlation of known results obtained with different spectroscopic instruments, and can facilitate the study of certain particular cases,

such as that of the fringes due to layers of air of different thicknesses.

Distribution of Intensity in Interference Fringes, J. ROIG. J. de Phys et le Radium v9 June 1938 p 241–4. A method is described for separating the width of the fringe due to the line width from that due to the apparatus in the case in which the former is large (line widened by the Doppler effect) and the effect of the latter is small (a large path difference).

Harmonic Analysis of Interference Fringes Produced by Multiple Reflection, P. M. DUFFIEUX. Rev d' Optique v18 p 1–19 Jan and June–July 1939 p 201–22. The intensity curve for fringes given by an infinitely narrow spectral line can be developed as a harmonic series. For a perfect optical system the amplitudes of the terms in this series are successive powers of the reflecting power; but for imperfect surfaces they need to be multiplied by factors derived from the errors of planity and parallelism, treated as curves of probability. A number of simple cases are considered, and a new intensity distribution function is calculated. By examination of effective amplitudes for various reflecting powers the range of applicability of such functions can be determined. The classical formula for a perfect system is only valid for reflecting powers less than 0.5. No general formula can be applied to very high reflecting powers. A relationship is established between the intensity curve for fringes given by a wide spectral line and the intensity distribution in the line. The cases of a simple line and of a line with satellites, with thermal broadening, are examined. In the latter, the system of equations which resolves the hyperfine structure shows that the number of resolvable components depends on the amplitude of the errors of planity.

Superposition fringes for Optical Etalons with Parallel Faces, N. CABRERA, J. TERRIEN. L'Optique (Rev Opt Theor Instrum) v20 1941 p 35–46. An extensive theoretical study is made of the superposition fringes and rings obtainable at infinity using two etalons. The effects obtained, as the path difference and thickness of etalons is changed, are discussed mathematically and the application of the results to problems such as the determination of small differences in the evaluation of the standard metre is examined.

General Interferential Method, L. STURKEY, B. P. RAMSAY, London, Dublin & Dublin Phil Mag & J Sci v31 n204 Jan 1941 p 13–23. Derivation of general intensity equation directly applicable to all instruments; special cases of resulting intensity equation are discussed; process of applying general function to specific optical problems is defined as interferential method. Bibliography.

Interferometers and the Group Index, A. C. CANDLER. Nature London v157 Apr 6 1946 p 444. The group index $G = N + \nu \delta N / \delta \nu$ where N is the refractive index and ν the wave number. Its use simplifies determination of effective range and limit of resolution for all interferometers.

Low-Order Multiple-Beam Interferometry, S. TOLANSKY. Proc Phys Soc London v58 Nov 1946 p 654–62. A discussion is given of the various factors affecting the intensity and sharpness of the multiple-beam Fizeau fringes and fringes of equal chromatic order used for the study of surface topography. The effects of absorption in the Ag film, phase condition, linear displacement of the beams, finite size of source, departure from parallelism and source line width are considered. It is shown that Fabry-Perot fringes, multiple-beam Fizeau fringes and fringes of equal chromatic order have all the same fringe shape if certain conditions are fulfilled.

Optical Conditions in the Use of Photo-electric Cells in Spectrographs and Interferometers, P. JACQUINOT, C. J. DUFOUR. Rech Cent Nat Rech Sci n6 1948 p 91–

103 in French. From considerations of the spread of the image of a slit due to diffraction and scatter in the photographic emulsion it is shown that increased resolution implies reduced luminosity, the best compromise being obtained when the diffraction image of the slit is equal to the spread in the emulsion. A photographic spectrograph must be designed either for high resolution or luminosity; a universal instrument is not possible. With a photo-electric cell, which responds to total flux (not luminosity), it is shown that a universal instrument is possible. The optimum slit-size and slit-magnification are considered. A similar treatment is applied to the case of a photo-cell used with the Fabry-Perot interferometer.

Theory of the Corner-Cube Interferometer, E. R. PECK. J Opt Soc Am v38 Dec 1948 p 1015–24. The corner-cube interferometer is analysed geometrically and analytically. When the prisms are used near their axis, the instrument is found to behave essentially like an interferometer using triple sets of front-surface mirrors. Equations are obtained describing the fringe pattern when one prism is used far off its axis, and also when both are used near their axis. These fringe patterns are discussed and illustrated.

Multiple-Beam Interferometry: Intensity Distribution in Reflected System, J. HOLDEN. Phys Soc—Proc v62 Pt 7 n355B July 1 1949 p 405–17. Investigation of reflected intensity distribution given by interferometer whose reflecting surfaces are formed by thermal deposition of silver upon optical flats, covering range of reflectivities from 4 to 92%; use of Fizeau fringes localized on zero order Feussner surface for observations; results apply to fringes of equal inclination and to fringes of equal chromatic order in reflection.

The Angle Mirror Interferometer and the New Interference Effects, J. RIENITZ. Optik v8 n12 1951 p 561–9 in German. A description of the Michelson interferometer in which the two plane mirrors are replaced by either right angle mirrors or right angle prisms. The optical properties of the system are discussed including the sideways displacements of homologous points. The adjustment of the system is simplified. Sideways displacement of a mirror leads to horizontal movement of the fringes in the field.

Measurement of Thickness of Microscopic Objects Using Three-Beam Interference, B. MENZEL. Note in Naturwissenschaften v39 n17 1952 p 398–9 in German. A microscope modification of a technique formerly described, wherein the thickness of a thin object is obtained from change in localization of fringes produced by three slits. A microscopic reduced image of the three slits is projected on to the small object on the microscope stage and by observing changes in localization of fringes with beams going through and missing the microscopic object, thicknesses can be measured as small as 100 A units.

Wide-Angle Interference from a Quadrupole Source of Light, M. V. FOK. Dokl Akad Nauk SSSR v89 n3 p 439–42 1953 in Russian. English translation, U S Nat Sci Found NSF-tr-20. A computation is made for the visibility of interference fringes in so far as they depend upon the angle between the interfering rays. Rules are given for distinguishing between the dependence of the visibility on whether dipole or quadrupole radiation is involved. Polarization effects are also calculated. The theory developed is an extension for any quadrupole of that formulated originally by Vavilov (Miterostrukturu sveta, 1950) for linear dipoles and quadrupoles.

The Geometrical Optics of Two-Beam Interferometers, H. SLEVOGT. Optik v11 n8 1954 p 366–79 in German. A survey of the optimum geometrical conditions necessary in the use of the Michelson interferometer, the Twyman-Green interferometer and the Linnik interferometer, for the testing of optical components (including a Zeiss modification of the Linnik interferometer). Discussion of the sharpness and localization of the fringes. In general the middle points of the aperture and field stops must be imaged in the two auto-collimation points of those mirrors which form the generalized Michelson interferometer.

Interference Fringes of Equal Thickness in the Measurement of Length with Light Waves, G. SCHULZ. Ann Phys (Leipzig) v14 n3–5 1954 p 177–87 in German. A theory is developed for two-beam interference in a simple wedge. On the basis of this, spatial distribution, contrast and intensity distribution are calculated. Corrections due to the aperture are introduced for apertures 0–90°. It is demonstrated that two-beam interference of equal thickness, even using strictly monochromatic radiation, should show alternations caused by the aperture and not by the source. Proposed corrections as a function of the real aperture increase from 0 up to some 6% for 30° apertures.

Determination of Order of Interference in White Light, R. C. FAUST, H. J. MARRINAN. Brit J App Phys v6 n10 Oct 1955 p 351–5. Achromatic fringe observed in white light does not necessarily correspond to position of zero path difference, since optical paths of two interfering beams do not usually have same wavelength dispersion; general theory of this effect; how it can be applied to Rayleigh interference refractometer, Babinet compensator, and interference microscope; experimental verification.

An Interference Optical Alinement Method, G. A. HARLE, B. S. THORNTON. Nature (London) v176 Oct 1 1955 p 651–52. A system is described which is applicable to the alignment of coaxial optical systems with a large number of surfaces. A spatial distribution of non-localized interference fringes is employed. Thus, the necessity of image location is eliminated and a technique combining the advantages of aperture sight and image alignment is available. Various interferometric arrangements are described. One uses a bi-prism and slit. Another uses a point source and the Michelson interferometer with mirrors parallel. A third uses a Fabry-Perot etalon and multiple-beam fringes are employed of the non-localized type described by Tolansky. The theories of the methods are similar to those of the image alignment method.

Integrated Flux from a Michelson or Corner-cube interferometer, E. R. PECK. J Opt Soc Am v45 n11 Nov 1955 p 931–4. Flux in the circular fringe pattern of a Michelson or corner-cube interferometer is integrated over a centered, circular or rectangular field stop, as is done experimentally by a photoelectric cell in fringe counting. The results are discussed in terms of fringe amplitude, modulation depth, and phase shift.

Effect of Source Size on Visibility of Fringes in Interferometer Employing Division of Amplitude, M. DE. J Assn App Physicists v3 n2 Sept 1956 p 51–60. Simplified geometrical optical treatment of problem of finding optimum size of source for interferometer employing division of amplitude; criterion, instead of being arbitrary, is chosen in relation to limiting visibility of fringes; application to almost generalized case of two beam interferometer is also given.

Interference In An Optical Wedge, U. OPPENHEIM, J. H. JAFFE. Am J Phys v24 n9 Dec 1956 p 610–15. Many standard textbooks treat interference in an optical wedge quite inadequately. Elementary treatments of this problem often leave much confusion about the exact conditions under which the fringes are formed and observed. Here a unified introductory treatment is presented both for two-beam and multiple-beam interference. Special attention is given to the localization of the fringes around the wedge. Factors governing the fringe visibility are examined.

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Uncompensated Corner-Reflector Interferometer, E. R. PECK. J Opt Soc Am v47 n3 Mar 1957 p 250-2. Analysis is made of the effect of omitting the compensating plate in a corner-reflector interferometer. It is concluded that a non-compensated instrument has disadvantages when compared to a compensated one, but when properly adjusted it may still be useable with a photoelectric detector. The flux is integrated over rectangular field stops.

A High-Sensitivity Interferometer for Measurement of Phase Shift and Other Applications, J. B. SAUNDERS. NBS Cir 581 Apr 1 1957 p 51-9 8 figs. With highly reflective surfaces, such as fresh silver, as many as 50 reflections may be used, in which case one order of interference will correspond to about 0.01λ. A method of applying this interferometer to the measurement of phase shift from metallic surfaces and for the comparison of gage blocks is described.

Applications of Coherence Theory in Microscopy and Interferometry, H. H. HOPKINS. J Opt Soc Am v47 n6 June 1957 p 508-26. General treatment of influence of size of source on visibility of fringes in two-beam interferometers; use of coherence theory in microscopy summarized; how concept of "effective source" helps study of influence of abberations under various conditions of coherence; discussion of theory of chromatic coherence.

Spherical Aberration in the Fizeau Interferometer, W. G. A. TAYLOR. J Sci Instrum v34 n10 Oct 1957 p 399-402. The drawbacks of types of instruments in common use are reviewed. It is shown that primary aberration theory predicts quite accurately the errors introduced even by simple collimators with large aberration. The advantages of using a collimating lens based on a multiple-meniscus design are indicated, and the performances of several lens-systems are compared.

Fizeau-type Interference Between Beams of Light Reflected from Three Surfaces, A. H. COOK. J Sci Instrum v34 n11 Nov 1957 p 455-8. Optical interference phenomena between beams of light reflected from three surfaces are described and analysed. The distinctive feature of the fringe system is that the field is crossed by bands of intensity equal to that of light reflected from one of the surfaces, delineating the lines of constant separation of the other two surfaces. The use of the phenomena in metrology is briefly discussed.

Photoelectric Fringe Signal Information and Range in Interferometers with Moving Mirrors, G. W. STROKE. J Opt Soc Am v47 n12 Dec 1957 p 1097-1103. Theoretical and experimental studies of conditions required for adequate information content and visibility of fringe signals on photoelectric interferometers; expressions for fringe visibility with simple isotope lines of Gaussian shape are used to estimate interferometric range; application to high precision measuring instruments.

The Setting Accuracy in Two-Beam Interferometry, M. BOTTEMA. Physica v24 n6 1958 p 519-28. The accuracy of some setting methods applicable in two-beam interferometry is investigated with regard to its dependence on the conditions of observation. Photometric methods prove to be the most advantageous. With these, an accuracy of a few thousandths of a wavelength in one setting is attainable under favourable conditions.

Effect of Natural Line Width on Resolving Power of Fabry Perot Etalon, M. S. SODHA, S. S. MITRA. Optik v15 n1 Jan 1958 p 47-50. Discussion of effect of natural line width due to Doppler effect and resonance damping on resolving power of Fabry Perot etalon; table of variations.

Photoelectric Observations with the Michelson Interferometer, J. TERRIEN. J Phys Radium, v19 n3 Mar 1958 p 360-6 in French. It is possible to improve measurements with the Michelson interferometer by a photoelectric method, which allows extension beyond the visible spectrum. The photomultiplier is the only useful detector for narrow weak lines; it is supposed that fluctuations are due to shot-noise. Optimum conditions are calculated for measurements of fractional order of interference, and wavelength comparison: the diameter of the hole isolating the central part of the interference pattern, and the order of interference. The accuracy of wavelength interferometer imperfections. The most necessary improvements are indicated. The improvements obtained justify the hope that the theoretically obtainable accuracy, of magnitude 10^{-8}, will be reached when the causes of systematic errors, more numerous and serious than was previously supposed, have been removed.

Multiple-Beam Fringe Sharpening With the Series Interferometer, D. POST. J Opt Soc Am v48 n5 May 1958 p 309-12. The parallel mirror Series Interferometer exhibits fringes that are qualitatively similar to the well-known multiple-beam fringes of two mirror interference systems. Contrary to the case of two mirror systems, however, no stringent restrictions on mirror separation or monochromatic purity of light source are involved, for the relative path lengths of interfering rays is independent of mirror separation. Thus, sharpened fringes can be employed for applications that require moderately large test zones, such as problems in fluid flow, thermal expansion, optics testing, etc. An experimental verification and analytical treatment are presented. The analysis yields an intensity-fringe order relationship that is effectively corroborated by experimental observation.

Fringe Sharpening in Divided Beam Interferometer, W. PRIMAK. J Opt Soc Am v48 n6 June 1958 p 375-9. The development of sharpened fringes in long path length interferometers (like the Twyman-Green, Mach-Zehnder, and series) by intensity and by multiple reflection is described. The cause of the extreme localization of some of the multiple-reflection fringe patterns is discussed.

Limiting Precision in Optical Interferometry, G. R. HANES. Can J Phys v37 n11 Nov 1959 p 1283-92. The fundamental limit to the precision of setting on a fringe peak due to photon noise is evaluated for a certain class of interferometric methods in terms of parameters characterizing the source, the interferometer, and the detector. It is shown that changes in path difference of 10^{-10} should be detectable with an observing time of 1 sec, using only modest equipment. Some of the experimental conditions required to attain this precision are discussed.

Measures de Longeurs par Methodes Interferometriques, et Principes d'Incertitudes en Optique a Trois Dimensions, B. VITTOZ. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 73-81 2 figs 12 refs. Influence of spectral line width upon interferometric measures of lengths. One comes to an absolute limitation of the sensibility, which is analogous to the general principle of uncertainty in quantum mechanics, and which is a complement to the optical uncertainty principle of Ingelstam. The analogy of the quantum mechanics of the photon appears in a very general way by the help of the Fourier transformation.

Photometric Setting Methods in Interferometry, M. BOTTEMA. Optics in Metrology. P. MOLLET. Pergamon Press 1960 p 42-49 2 figs 6 refs. Great precision is attainable. Two methods are compared with a common geometric method.

Discovery of Interference by Thomas Young, R. W. POHL. Am J Phys v28 n6 Sept 1960 p 530-2. Thomas Young contributed to philology and to the problems of vision, as well as to the understanding of wave motion and interference for which he is principally known. The steps by which he achieved understanding of the phenomena of interference, from his first work in 1801, through the pub-

lication of Course of Lectures on Natural Philosophy, and up to his development of the theory of the interferometer in 1817, are outlined.

Ueber den Einfluss der teildurchlaessigen Schichthen auf den Wirkungsgrad von Zweistrahlinterferometern, J. RIENITZ. Deutsche Akad der Wissenschaften zu Berlin—Klasse fuer Mathematik, Physik und Technik—Abh n2 1961 46 p. Influence of partially transparent layers on efficiency of 2-beam interferometers; analyses of Michelson and of MachZehnder type of instruments. 67 refs.

Analysis of Some New Possibilities of Interference of Electromagnetic Waves, A. H. COOK. Optica Acta (Int) v9 n1 Jan 1962 p 55–64. It is shown that with sources available now or shortly to become available, there is correlation in the radiation emitted at distances as great as 270 m at 1 A or 600 km at 7000 A. Possibilities of detecting this correlation by means of a Michelson interferometer and by means of an intensity interferometer are discussed in terms of the limits set by resolution and noise.

Adjustable Compensators for Two-Beam Interferometers, W. H. STEEL. Optica Acta (Int.) v9 n2 Apr 1962 p 111–19. When a two-beam interferometer is adjusted to satisfy particular compensation conditions, high-contrast fringes can be obtained when the light source is neither small nor highly monochromatic. In some interferometers a continuous variation of compensation is desirable. Two adjustable compensators are discussed and their application to a lens-testing interferometer is described.

Limiting Precision in Scanning Optical Interferometer, R. M. HILL, C. F. BRUCE. Austral J Phys v 15 n2 June 1962 p 194–222. Interferometer uses photoelectric detection and it is shown that principal noise sources limiting accuracy of detection are shot noise in vacuum photocell and photon noise from light source; from limiting precision of pointing on fringe, limiting precisions of measurement of small wavelength shifts and of measurement of wavelengths have been calculated.

On the Factors Contributing to the Formation of Multiple-Beam Fizeau Fringes, N. BARAKAT and S. MOKHTAR. J Opt Soc Amer v53 n2 Feb 1963 p 300–1. The approximate formula derived by Tolansky in 1948 for the phase lags and beam displacements in multiple-beam Fizeau interference fringes are now refined and extended. The earlier formulae are correct to a first approximation. Intensity effects and contribution of different numbers of beams are discussed. Numerical apertures of collecting lenses are considered. The displacement between 1st and nth beam in zero order formerly given as $2n^2\epsilon t$ is shown now to be $2n^2\epsilon t[1- \epsilon^2/3\ (1 + n^2)]$.

Theory of Frustrated Total Reflection Involving Metallic Surfaces, T. R. YOUNG, B. D. ROTHROCK. J Res NBS A. Physics and Chemistry v67A n2 Mar–Apr 1963 p 115–25 9 figs 6 refs. See abstract under 11.2.

On Order of Interference in Michelson Interferometers in Case of Circular Light Sources Central on Optical Axis, Z. ERDOEKUERTI, K. KANTOR. Optik v20 n5 May 1963 p 243–58. Changes in order of interference in Michelson-type interferometers have been determined experimentally by phase detecting method in terms of source size, interferometer geometry and spatial coordinates of point of observation for case of circular light sources centered on optical axis; measured values of order of interference are in good agreement with those predicted by theory.

Quantum Limit to Precision of Wavelength Determination, G. R. HANES. App Optics (USA) v2 n5 May 1963 p 465–70. The precision of wavelength determination is

ultimately limited by noise arising from the quantum nature of light and light detection. Expressions are derived for the limiting precision attainable by various interferometers and conventional spectrometers in terms of parameters characterizing the instruments, the source, and the detector. A comparison of five different instruments shows the superiority of the interferometers and indicates that they are divided into three classes, according to the role played by the half-width of the radiation from the source.

Frequency Spectrum of Photoelectric Signal from Oscillating Interference Fringe Pattern, J. L. GOLDBERG. Australian J App Sci v14 n3 Sept 1963 p 231–42. Conditions for optimum signal-to-noise ratio, in multiple-beam interferometer; optimum signal-to-noise ratio is determined by aperture width in relation to fringe spacing; since some bandwidth restriction is essential to limit white noise spectrum of detector, theoretical limits are derived for bandwidth required to pass acceptable amount of detail in photoelectric signal, for case where motion of fringes is oscillatory.

Forty Years of History of a Grating Interferometer, V. RONCHI. App Optics (USA) v3 n4 Apr 1964 p 437–51. Deals with the development of studies concerning the employment of diffraction gratings as interferometers, starting in 1922 when they were used to test optical systems. After reporting how a concave surface was tested by means of gratings, their elementary theory is described. The phenomenon is further studied from the interferential standpoint and a wave theory of shadows formulated which is analogous to Abbe's theory on images. A series of studies follows demonstrating that interferential theory accounts for the form of the fringes recorded when a grating is placed on the path of a wave affected by any aberration. In conclusion some simple rules are derived which allow evaluation of both the quality and the amount of the aberration of the wave under test on the basis of the form of the fringes. The sensitivity of the method is then studied, and the most recent developments and better-known applications of the gratings reported, concerning their employment as achromatic interferometers.

High-Precision Pointing Interferometer, G. H. LOVINS. App. Optics v3 n7 July 1964 p 883–7. By adjusting Koester's prism interferometer so that zero-order fringe is parallel to beam splitter and to apex, parallel-beam Michelson-type interferometer was produced which is capable of pointing with precision of 0.02 sec of arc; sensitivity is proportional directly to beam spacing and inversely to wavelength; described are schemes for using instrument for measurement of film thickness, plane mirror rotation, divided circle accuracy, refractive index differences, ball-bearing sphericity, absolute pressure, tilt, etc.

2.2.2. Method of Coincidences

Millimeter and Centimeter Standards, R. BENOIT. Bul Soc France Phys n97 1897 p 2–3. Standards, by the Bureau international des Poids et Mesures, are described, on the principle of measuring displacements by the travel of circular fringes in a Michelson's refractometer, taking the four cadmium radiations simultaneously; absolute coincidence of the limit of the standard with the plane of reference in the instrument being indicated by certain characteristic fringes.

Über einen Interferenzmessapparat. (Regarding an Interference Measurement Apparatus), C. PULFRICH. Zeit für InstrumenKde v18 Sept 1898 p 261–7. Description of Pulfrich interferometer, based on the principle of the simultaneous use of monochromatic lights of different wave-lengths and micrometric measurement of the interference fringes.

Sur un Procédé pour la Comparaison et la Mesure en Valeur Absolue des Étalons a Bouts Plans, au Moyen des Interférences Lumineuses (Absolute Measurement of Length Gages by Optical Means), A. PÉRARD. CR Acad Sci v170 Feb 16 1920 p 390–2. Describes a method for determining the dimensions of Johansson gages in terms of wave lengths of monochromatic light. It has been shown previously that the interspace between the surfaces of two gages is less than $.02\mu$ and the method of measurement proposed consists in placing the gage to be measured in contact with a plane steel surface of greater area. Upon the other surface of the gage is placed a reference plane of glass. Thus, by suitable arrangements described it is possible to deduce the thickness of the gage. Measurements up to 15 mm are possible.

Interference Methods for Standardizing and Testing Precision Gage Blocks, C. G. PETERS, H. S. BOYD. NBS Bul 17 1922 p 697–713 21 figs. (Sci Paper 436.) Interference methods are described by which the planeness and parallelism errors of precision surfaces can be measured and the length of standard gages determined by direct comparison with the standard light waves with an uncertainty of not more than a few millionths of an inch. The errors of other gages can be determined by comparison with these calibrated standards with equal precision.

Procédés Actuels pour L'Étude des Calibres Industriels au moyen des Interférences Lumineuses. (Interference Methods for Measuring Johansson Blocks), A. PÉRARD. Rev d'Optique v1 May 1922 p 209–31 14 figs. Interference method consists in placing the block between two parallel plates, the upper one being glass so that a uniform air layer remains between the glass and the upper surface of the block and proceeding as in the usual Fizeau experiment to observe the fringes due to the air layer formed by monochromatic light. By using several kinds of monochromatic illumination, 8 in all, whose values of λ vary from $640.224m\mu$ to $435.832m\mu$, the actual length required is evaluated by certain series formula quoted. An apparatus for comparing 3 blocks set up between the parallel plates is also described and sketched.

Über die Länge eines Parallel-Endmasses bei Messung in Lichtwellenlängen (Regarding the Length of a Parallel End Standard with Measurement in Light Wavelengths), H. PIETZSCH. Buch druckerei Wilhelm Volkman, Dresden 1928 30 p 6 refs. Applies Kösters interference comparator with a mean error of $\pm 3m\mu$ (omitting the wringing film). Discusses "springing on" and wringing correction.

Measuring Gauge-blocks by Light Waves, F. KONIG. Machy (London) v32 July 5 1928 p 425–8 8 figs; Machy (N Y) v34 July 1928 p 809–13 8 figs. New Zeiss interferometer is primarily intended for taking absolute measurements but is readily converted into a comparator; measurements computed to millionths of inch; two features of this new interferometer are swiveling prism for effecting spectral dispersion, and adjustable virtual plane of reference about midway between two surfaces of gage block; conditions involved when poly-chromic light is used; slide rule used in conjunction with interferometer.

Applications of Thallium and Zinc Spectral Lines in Metrology, A. PÉRARD. CR Acad Sci Paris v225 Dec 1 1947 p 1045–7 in French. In metrology the direct observation is the fractional excess of an order of interference, and the whole number is deduced by combining observations of the excess fraction given by several spectral lines. This assumes that the wavelengths of the lines are constants, independent of the path. This is only strictly true for monochromatic lines. By comparison with a sufficiently monochromatic line (e.g. Cd red), it is possible to evaluate corrections for lines less monochromatic, which can be added to the fractional excesses observed. Work-

ing in this way, with a Michelson interferometer, complex lines were studied in Cs, Tl and Zn spectra, chosen because of their brightness. In graphs, corrections are given for the green Tl line (5 350 A) and the red (6 363 A) and blue (4 811 A) Zn lines, as functions of the path difference up to 200 mm. This allows these more intense sources to be used in spite of the lines not being strictly monochromatic.

A Spectrograph Unit for Use with the N.P.L. Gauge Interferometer, C. F. BRUCE, V. R. FINDLAY. J Sci Instrum v30 Sept 1953 p 297–9. The unit enables photographic recording to be used satisfactorily in the routine determination of length in terms of cadmium light waves with this interferometer. The time taken to record and measure is no longer than that taken with the normal visual method and the photographic method has advtantages of permanent recording, reliability of measurement and lower fatigue effects on observers. The unit can also be used very effectively for improved visual observation. The present unit is primarily designed for dispersing the cadmium radiations satisfactorily and does not, for example, separate adequately the two mercury yellow 5791 Å and 5770 Å.

Abstandsmessung von Röntgeninterferenzen. Ein neues Längenmessgerat (Intervals of Röntgen interference fringes. A New Length-Measuring Instrument), C. HOFFRÖGGE, H. WEYERER. Zeit für angew. Phys v6 n9 1954 p 419–20 3 figs 1 ref. A simple measuring instrument is described consisting of a translatable scale in a frame and a dial indicator which shows the displacement. Uncertainty is 0.01 mm. Through its coincidence setting the instrument appears to be especially suitable for the measurement of faded (reflected beam) lines.

The Accuracy of Interferometric Length Measurement, R. LANDWEHR. Zeit für angew Phys v8 n11 Nov 1956 p 561–8 in German. A review article; summarizes the sources of error in the measurement of the fractional order of interference and discusses the effect of errors in the fractional order on the accuracy of the measurement of length, particularly on the use of the method of exact fractions to determine the order of interference. The results of some experimental tests are reported.

Multiple-Beam Fringes of Equal Chromatic Order. VIII. Method of Coincidence, W. F. KOEHLER. J Opt Soc Am v48 n1 Jan 1958 p 55–7. An interferometric method of coincidence for the measurement of a large step height $\triangle t$ is reported. The method is based upon the more rigorous interference equation $n=2tv+f$. The term f is a function of v and is necessary to account for phase changes upon reflection at the boundaries of the interference film when other than zero or π.

Determination of the Interference-Band Order using a "Monoprism" and a Plate, V. G. KHOMAZYUK. Optika i Spektrosk v8 n2 Feb 1960 p 261–3 in Russian. Describes a procedure for determination of the interference-band order using two plane-parallel quartz plates, one 0.9 mm thick and the other 1 mm thick (one of the faces of the latter is bevelled at an angle of 5° and is called a "monoprism").

Photoelectric Recording of Interference Fringes, Iu. P. EFREMOV. Meas. Techns 1958 n6 Mar 1960 p 630–2 3 figs 10 refs. Translated from Izmer Tekh n6 Nov–Dec 1958 p 15. Up to 1000 mm gage blocks are measured on a large VNIIM horizontal interferometer by comparing their lengths with the length of a 100 mm Fabry and Perot master gage. The accuracy of these instruments depends mainly on how precisely the length of the master gage is known at the moment when the comparison is made. The length of these master gages can be measured most accurately in wavelengths of visible light by the absolute interference method, which in essence is reduced to the

determination of the fractional part ϵ of the order of interference in the center of rings with equal slope. This paper deals with the replacement of the visual observation method by photoelectric recording, which makes the measurement of the fractional part of the order of interference ϵ more objective and accurate. Advantages of the photoelectric recording method include : its objectivity, reliability, and the speed with which the result is obtained. In addition, the use of this method offers wide possibilities for using in the interference length-measurements of spectral lines from the part of the spectrum close to the infra-red region, which makes possible the extension of the range in which absolute measurements of gage blocks in wavelengths of light can be performed.

Fractional Order Slide Rule for Interferometric Length Measurement, K. H. HART. Rev Sci Instrum v31 n4 April 1960 p 438–40 ; n10 Oct 1960 p 1166. A description is given of a slide rule of special design for use with the method of exact fractions in interferometry. The instrument computes lengths from measured fraction orders.

A New Method of Measuring Gage Blocks, J. B. SAUNDERS. J Res NBS v64C n3 July–Sept 1960 p 173. The parallel testing interferometer is quite applicable without modification, to the comparison of lengths of gauge blocks. This note describes the testing of gauge blocks of all lengths, up to several meters, without having to contact them to optical flats.

Tables for Absolute Measurements of Gage Blocks, Engineering Metrology Section, NBS Jan 12 1961. Contains 6 tables of fractional band constellations for nominal gage lengths for Cd, He, and Hg 198. Also 6 tables of length equivalents of hundredths of a band and vice versa.

The Calculation of Excess Fractions from Measurements on Optical Interference Rings, D. C. WILLIAMS. Optica Acta (Int) v9 n3 July 1962 p 269–75. An improved method is described for obtaining excess fractions from observed diameters of optical interference rings of the Haidinger type which enables the accuracy of certain interferometric length determinations to be doubled. In appropriate cases ambiguity between orders of interference can thereby be removed. The method is extended to include spectrographic recording of the fringes.

Simple Device for Measurement of Fringe Displacement in Gauge Interferometer, M. J. PUTTOCK. J Sci Instrum v39 n10 Oct 1962 p 498–9. Device for direct measurement of fractional displacement of fringes on gage relative to fringes on base plate.

Influcene de la dispersion sur les phénomènes d'interférences (Influence of dispersion on interference phenomena), D. TINAUT. Acad Sci CR v258 n25 June 22 1964 p 6110–11. When 2 beams of interferometer pass through 2 media of different dispersion, colors observed are very different from Newton scale ; colors are classified as function of dispersion difference and so facilitate interferential measurements ; this can be particularly useful for calculation of indeterminate form of entire part of interference order.

2.2.3. Aperture Correction

On the Admissible Width of Slit in Interference Experiments, J. WALKER. Phil Mag v46 1898 p 472–8. A mathematical investigation. The angle subtended by the slit at the interference apparatus must be a small proportion of that subtended by the width of the bands at the same point. When the variations of the width of the bands are due to variations of the distances of the slit and screen of observation from the apparatus, as the bands become finer the slit may be made wider without loss of distinctness. A progressive widening of the slit causes a periodic

disappearance of the bands, the system of bands at the successive reappearances being alternately bright and dark centered. Paper deals solely with visibility of bands.

Interference of the Pencils which Constitute the Remote Divergences from a Slit, C. BARUS. Nat Acad Sci Proc v4 May 15 1918 p 134–6. Describes the lay-out of the apparatus used for obtaining interference between the edge rays from a slit. The fringes are difficult to find and, when lost, are not easy to rediscover. The behavior of the images is otherwise as described in the case of achromatics obtained by the use of a cleavage prism.

Effect of Size and Spectral Purity of Source on Fringe Pattern of Mach-Zehnder Interferometer, F. D. BENNETT. J App Phys v22 n6 June 1951 p 776–9. In analysis of Mach-Zehnder interferograms of axisymmetric flows above supersonic projectiles, question arises whether errors in fringe width occur because of finite size and non-zero spectral width of source ; in order to solve problem quantitative investigation was made of intensity pattern of interferometer ; results obtained.

An Arrangement for Measuring the Angle of Incidence of the Beam in a Fizeau-Pérard Interferometer, J. HAMON. Rev Opt (Theor Instrum) v30 Aug-Sept 1951 p 366–8 in French. When length standards are required to be known to one in 10^7 a correction due to non-normal incidence is needed. A method for evaluating this is described.

Experimental Verification of Source Size Theory for Mach-Zehnder Interferometer, G. D. KAHL, F. D. BENNETT. J App Phys v23 n7 July 1952 p 763–7. Test of simplified theory ; reduction in visibility of fringes formed by interferometer due to extended area light source is shown experimentally ; effect is caused by superposition of two separate effects characteristic of two angular coordinates of unit vector pointing from center of collimating lens toward each point in plane of area-type source ; other results.

Effect of Source Size on Coherence of Illuminating Wave, L. R. BAKER. Phys Soc Proc v66 n407B Nov 1 1953 p 975–83. Study relating to image formation in optical instruments ; calculation of intensity distribution in diffraction pattern of two parallel interferometer slits illuminated by slit source of variable width ; dependence of fringe visibility on choice of slit widths ; effect of source size on coherence of wave front.

Interference Fringes of Equal Thickness in the Measurement in Length with Light Waves, G. SCHULZ. Ann Phys (Leipzig) v14 n3–5 1954 p 177–87 in German. A theory is developed for two-beam interference in a simple wedge. On the basis of this, spatial distribution, contrast and intensity distribution are calculated. Corrections due to the aperture are introduced for apertures 0–90°. It is demonstrated that two-beam interference of equal thickness, even using strictly monochromatic radiation, should show alternations caused by the aperture and not by the source. Proposed corrections as a function of the real aperture increase from 0 up to some 6% for 30° apertures.

The Effects of Collimation and Oblique Incidence in Length Interferometers. I, C. F. BRUCE. Austral J Phys v8 n2 June 1955 p 224–47 ; v10 n2 June 1957 p 324–5. An investigation has been made of the effects of position and size of diaphragm apertures on the interference fringes in length interferometry. The results indicate that, while the well-known correction formula for the effect of the oblique rays from a point source off the optic axis is always applicable, the effect of finite area of aperture is a more complex one and is not in general proportional to the length measured. This effect depends essentially on the phase differences arising from different points of the aperture and is oscillatory in character. For a narrow

slit the maximum fringe displacement arising from this effect is not greater than about 0.15 fringe.

Obliquity Correction Curves for Use in Length Interferometry, C. F. BRUCE. J Opt Soc Am v45 n12 Dec 1955 p 1084–5. In Fizeau-type interferometers the aperture is often placed slightly off-centre in order to view the returning light. The effect of the size of the apertures and their positions can introduce fringe displacement effects which are computed. The fringe displacement computed is wavelength dependent. Correction curves are presented which enable a rapid application of the correction to be made in precision interferometry. The fringe displacement is computed as a function of the phase difference between the centre and the edge of the aperture. Computations are made for a maximum path difference of 800 mm which might be attainable with isotope mercury and krypton sources. The results found are given in the form of curves.

Fringe Spacing in Interference Microscopes, J. W. GATES. J Sci Instrum v33 n12 Dec 1956 p 507. In high-power interference microscopes fringe spacing is greater than half a wavelength, depending on the numerical aperture, and this arises from obliquity of incident light, when a converging beam is used. A formula is derived, and predictions are compared with observations for N.A. values 0.30, 0.60, and 0.65. There is close agreement.

Obliquity Effects in Interference Microscopes, C. F. BRUCE, and B. S. THORNTON. J Sci Instrum v34 n5 May 1957 p 203–4. A theoretical analysis is made of the influence of oblique rays on the fringes produced with interference microscopes. The convergency of the light, which is determined by the numberical aperture of the objective, results in the fringes being displaced from the position for ideally collimated light at normal incidence. The analysis accounts fairly well for measurements of step heights with microscopes of different numerical apertures by Tolmon and Wood. The correction due to obliquity is of the order of 10% and over a limited range of step heights, a simple correction rule of $\alpha/4$ per unit is satisfactory to about 2%, where $\alpha^2 = \sin^{-1}$ (n.a.). The more rigorous formula shows a nonlinear relation between obliquity-correction and step-height.

Obliquity Effects in Interferometry, C. F. BRUCE, Optica Acta v4 n4 Dec 1957 p 127–35. The present author and Thornton have previously described the influence of oblique rays on the measurement of length by interferometry. On-center apertures were treated approximately. This paper deals with a more exact treatment of the off-center cases for circular and rectangular apertures. The treatment is adequate for all cases that may occur in practice and the expressions for on-center cases are quickly derivable. The results show that approximate formulas can give quite incorrect results at path difference and obliquity values which still allow fringes to be observed when isotope light sources are used. Fringe displacement curves are given to show the main characteristics of the obliquity effects, and these have been confirmed experimentally.

Correction Due to Aperture in Transmission Interference Microscopes, E. INGELSTAM, L. P. JOHANSSON. J Sci Instrum v35 n1 Jan 1958 p 15–17. The fringe spacing in transmission interference microscopes is shown to require a correction due to the oblique rays, with respect to the ordinary value valid for perpendicular rays. The spacing, and accordingly the measured path differences, are smaller than the normal values (opposite to the case of reflection microscopes). Calculations are made for different values of condenser N.A. and varied parameters, showing corrections up to −15%. The fringe intensities also decrease with the order of interference when it is low. Experiments confirm these findings. The effect is discussed in relation to some general ideas of (x,y)-fidelity and (z)-fidelity as obtained in a limited optical information channel.

On the Improvement of the Precision of Microinterferometry. Investigations Concerning Interference Spherometry, R. LANDWEHR. Zeit InstrumKde v66 n7 Aug 1958 p 134–8 in German. A geometrical analytical examination concerning the calculation of corrections in exact two-beam interferometry. The displacements arising both from the small angle of inclination between the surfaces and also from the finite angles of the incident cone of light are computed. Tables of corrections are given for numerical apertures up to 0.65. The application of these computations to the possibility of accurate interference spherometry is discussed.

Abhaengigkeit des Kontrastes der Fizeau-Streifen im Michelson-Interferometer vom Durchmesser der Aperturblende, G. HANSEN, W. KINDER. Optik v15 n9 Sept 1958 p 560–4. Dependence of contrast of Fizeau fringes in Michelson interferometer on diameter size of diaphragm aperture; computation of values for intensity and position of maxima and minima of Fizeau fringes; contrast of Fizeau fringes disappears completely for first time, when in Lummer-Haidinger system, phase difference between center and rim of diaphragm just amounts to one complete wavelength.

Estimation of Two Causes of Error in the Photoelectric Observation of Interference Fringes at Infinity with a Michelson Interferometer, J. TERRIEN. J Phys Radium v20 n2–3 Feb-Mar 1959 p 446–8 in Russian. In an earlier study the author assumed (1) perfect centering of the receiving aperture on the ring center, and (2) uniform illumination of this aperture in the absence of interference. The accuracy in centering and uniformity of illumination required to justify these assumptions are here estimated. To attain an accuracy of 0.001 of a fringe, the error in centering must be less than 0.05 of the aperture diameter and the illumination must not fall by more than 12% from the center of the aperture to its rim.

Some Remarks on the Question of Aperture Corrections in Interferometric Length Measurements, R. LANDWEHR. J Opt Soc Am v49 n7 July 1959 p 733–4. A summary of the computations made in particular in connection with the practical measurements of end standards. Some of the calculations of Bruce are modified. Aperture corrections are shown graphically for the cases of (1) a circular hole (2) a narrow slit (3) a square aperture.

A Correction for the Dimensions of the Exit Diaphragm in Photoelectric Recording of Equal-Inclination Interference Bands, YU. P. EFREMOV, YU. P. KANEVSKII. Optika i Spektrosk v8 n2 Feb 1960 p 266–8 in Russian. Derives a correction for the dimensions of rectangular, square and slit-shaped exit diaphragms used in photoelectric recording of the order of equal-inclination interference bands.

On the Order of Interference in Michelson Interferometers in Case of Circular Light Sources Centered on the Optical Axis, Z. ERDÖKÜRTI and K. KÁNTOR. Optik (Germany) v20 n5 May 1963 p. 243–58. Changes in the order of interference in Michelson-type interferometers have been determined experimentally by a phase-detecting method in terms of source size, interferometer geometry and the spatial coordinates of the point of observation for the case of circular light sources centered on the optical axis. The measured values of the order of interference are in good agreement with those predicted by the theory of Bakas et al. (1961).

Visibility and Order of Interference in Michelson Interferometers in the Case of Rectangular Light Sources Centered on the Optical Axis, Z. ERDÖKÜRTI and K. KÁNTOR. Optik (Germany) v20 n6 June 1963 p 304–18.

The order of interference (phase) and the visibility of the interference produced in Michelson interferometers are determined for rectangular sources centered on the optical axis. The measurements are performed in terms of the geometrical parameters of the light source and the interferometer, as well as with respect to the coordinates of the point of observation. The calculated results are listed, also separately grouped with respect to various parameters.

Visibility and Order of Interference in Michelson Interferometers in the Case of Eccentric Light Sources, Z. ERDÖKÜRTI and K. KÁNTOR. Optik (Germany) v20 n7 July 1963 p 325–32. The visibility and order of interference in Michelson interferometers are determined for the case of eccentric light sources. The results readily obtained on the basis of the theory of partial coherence were also confirmed experimentally.

2.2.4. Refractive Index of Air

Measurements on the Refractive Index of Air for Wavelengths from 2218A to 9000A, W. F. MEGGERS, C. G. PETERS. NBS Sci Paper 327 Oct 31 1918 p 697–740 7 figs 59 refs. Discusses various methods of measurement and gives summary of previous work. In this investigation a Fabry-Perot interferometer was used. Observations were made from the infra-red light through the visible spectrum and into the ultra-violet. Apparatus and experimental procedure are described. A total of 1165 index measurements for different wavelengths were made in dry air at temperatures at 0°, 15° and 30°C. Dispersion equations are derived which are a sufficiently accurate representation of the observations.

Variations in Refractive Index of CO_2-free Dry Air and a Statistical Correlation with Solar Activity, L. W. TILTON, NBS. J Res NBS v13 (RP 695) July 1934 p 111–24 2 figs 38 refs. All refractive-index data taken on air since 1857 have been examined for evidences of systematic variations, and a correlation between refractivity and annual sunspot number has been found.

Standard Conditions for Precise Prism Refractometry, L. W. TILTON. J Res NBS v14 n4 Apr 1935 (RP766) p 393–418. Air as standard reference medium for precise refractive-index measurements, discussed with respect to precision necessary in control and measurement of its temperature, pressure, humidity, and carbon-dioxide content ; preparation of accurate correction tables for reduction of refractive-index observations to standard conditions of reference described and exemplified.

Standards of Length. Optical Metrology. Refractive Index of Air. Eng v142 Aug 21 1936 p 205–6. Phase loss of light reflected from surfaces differs appreciably among apparently different surfaces. Method of measuring refractive index to 1 part in 10^8 is outlined. An accuracy of 1 part in 10^7 has been attained in measuring 10 cm, using Kr.

Refractive Indices of Water Vapor and Carbon Dioxide at Low Pressure, K. B. NEWBOUND. J Opt Soc Am v 39 n10 Oct 1949 p 835–40. Fabry-Perot interferometer used to obtain dispersion curves for water vapor and for carbon dioxide in wave length range 2500 to 8600A at pressures below 20 mm of Hg at 20 C ; results formulated to permit computation of refractive index of air containing these substances.

Apparatus for Recording Fluctuations in the Refractive Index of the Atmosphere at 3.2 Centimeters Wave-length, C. M. CRAIN. Rev Sci Instrum v21 May 1950 p 456–7. The equipment is a modification of that previously used for measuring dielectric constants of gases. The frequency of each of 2 microwave oscillators is controlled by the resonant frequency of its associated cavity resonator.

One cavity is sealed off and the other modified by drilling holes in one end plate, through which air is pulled.

The Dispersion of Air between 2500A and 6500A, H. BARRELL. J Opt Soc Am v41 n5 May 1951 p 295–9 9 refs. A new dispersion curve for air is derived from reasonably concordant refractivity data previously obtained in the visible spectrum at three different laboratories.

The Refractive Indices of Water Vapour, Air, Oxygen, Nitrogen, Hydrogen, Deuterium and Helium, L. ESSEN. Proc Phys Soc (London) B v66 Mar 1953 p 189–93. The method described by Essen and Froome has been used to measure the refractive indices at 9200 Mc/s. The value of $(n-1)10^9$ obtained for water vapour at 10 mm Hg pressure at 20°C is 60.7 which is the same as the value obtained at 24000 Mc/s, showing that the absorption line at 22 000 Mc/s, has a negligible effect on refractive index. The values obtained for air, O and N also agree with those previously obtained within the limits of error and therefore confirm the earlier results. The values of $(n-1)10^9$ obtained for H and D are higher than those calculated by Ishiguro et al. by 2% and 3% respectively. The calculated values were expected to be a few per cent lower than the true values, and they are therefore supported by the experimental results.

The Dispersion of Standard Air, B. EDLÉN. J Opt Soc Am v43 n5 May 1953 p 339–44 2 figs 17 refs. By combining Barrell's and Sears' measurements in the visible and Koch's and Traub's in the ultraviolet, a dispersion formula for standard air has been derived.

Index of Refraction of Air in the Infrared, D. H. RANK, J. N. SHEARER. Letter in J Opt Soc Am v44 July 1954 p 575. New measurements are reported for the refractive index of air at about 1.5μ. These show that the formula due to Edlen predicts values of $(\mu-1)$ too small by slightly more than one part in 1000 in the infrared region of the spectrum beyond 1μ.

Measurement of the Index of Refraction of Air At 1.74μ, F. LEGAY. CR Acad Sci (Paris) v242 m8 Feb 20 1956 p 1008–10 in French. A description is given of the determination of the refractive index of air which is dry and free of CO_2 at the wavelength 1.737μ, using a Twyman interferometer. The interferometer was simultaneously illuminated with a mercury lamp and a Nernst filament. The circular fringes were projected on to the slit of spectrograph. The value found for the refractive index is $(\mu-1) \times 10^6 = 273.13$.

Tables of Refractive Index for Standard Air and Rayleigh Scattering Coefficient for Spectral Region Between 0.2 and 20.0 μ and Their Application at Atmospheric Optics, R. PENNDORF. J Opt Soc Am v47 n2 Feb 1957 p 176–82. Refractive index tabulated for range 0.2 to 20.0 μ; for computation of Rayleigh scattering, scattering cross sections, mass and volume scattering coefficients are tabulated for same values of wavelength as for refractive index ; optical thickness and transmissivity of standard atmosphere given.

Refractivity of Air in the Near Infrared, D. J. SCHLUETER, E. R. PECK. J Opt Soc Am v48 n5 May 1958 p 313–5. Measurements are reported for the refractive index of air in the infrared up to 2 microns. These are both absolute and relative in nature, the latter being more precise. It is concluded that the measurements support the validity of Edlen's refractivity formula in this region.

Measurements of the Dispersion of Air from 3651 to 15 300 Angstroms, D. H. RANK, G. D. SAKSENA, T. K. McCUBBIN, JR. J Opt Soc Am v48 n7 July 1958 p 455–8. The difference between the index of refraction for green mercury light and 7 other mercury emission wavelengths from 15 300 A to 3651 A was measured using a Twyman-Green interferometer as a refractometer. A

photoelectric method was used for the infrared determination. A method depending upon photography of interference fringes which were caused to appear crossing the lines in the mercury spectrum was used for the visible and ultraviolet measurements. The mean observed deviation of the measurements of $(\mu-1)$ from the predictions of the Edlén formula was 1 part in 10^6.

Measurements of the Dispersion of Air for Wavelengths from 2302 to 6907 Å, K. F. SVENSSON. Arkiv Fys v16 paper 35 1960 p 361–84. Measurements of the dispersion of air have been carried out with a Jamin refractometer within the wavelength region from 2302 to 6907 Å. The investigation has confirmed Edlen's formula for the dispersion of standard air, as far as the relative values are concerned; the differences are everywhere less than $\pm 2 \times 10^{-8}$ and exceed $\pm 1 \times 10^{-8}$ only in a few cases. The measurements have been made at different temperatures from 6 °C to 23 °C. According to the observations by Meggers and Peters in 1918, the effect of the temperature on the density factor of the refractivity would depend on the wavelength. It has not been possible to confirm any such dependence in the present investigation. In any case, a possible effect of this kind is less than one per cent of the value that Meggers and Peters have stated. When the air was dried with both silica gel and P_2O_5, the dispersion curve showed a steeper course than when the drying had been done only with P_2O_5. This may be explained by assuming that silica gel absorbs proportionately more nitrogen than oxygen. If this is the case, it would also cause the refractivities for air dried with silica gel to be lower than for air of normal composition at the same temperature and pressure. The reduction to standard conditions of wavelengths measured in non-standard air is discussed, and tables to be used for this reduction are given.

Dispersion of Air in the Near-Infrared, E. R. PECK, B. N. KHANNA. J Opt Soc Am v52 n4 Apr 1962 p 416–9. Methods of computation are described for determination of the refractivity of air from measurements made with a corner-reflector Michelson interferometer. Results are given for eleven vacuum wavelengths from 703A to 20 587A. These results support Svensson's conclusion that Edlen's dispersion formula may be increased in precision by raising it slightly in the near-infrared. They indicate however an increase of $0.12 \times 10^{-3} \times (3.35 \ \mu^{-2} - \sigma^2)$ over Svensson's formula. The existence is discussed of appreciable variations, perhaps seasonal in nature, in the refractivity of out-door air.

Investigation of the Invariance of Atmospheric Dispersion with a Long-Path Refractometer, K. E. ERICKSON. J Opt Soc Am v52 n6 July 1962 p 777–80. An investigation was made of the extent to which the relative refractivity of the atmosphere is invariant under changes in pressure and humidity. To achieve the necessary precision a refractometer with double-passed chambers 14.3 m long was designed for use in the photographic region. No fiducial line is employed. The relative refractivity of dry air was found to vary by less than 3×10^{-8} over the region from 3890 to 6440 A for a change in pressure of $\frac{1}{2}$ atm. The relative refractivity of water vapour at low pressure in the region from 3610 to 6440 A was found to be

$$\delta H_2O = 0.961646 + 0.0086062 \ k^2$$
$$- 0.00010547 \ k^4 + 0.00001312 \ k^6,$$

where k is the vacuum wave-number in μ^{-1}.

An Air Refractometer for Interference Length Metrology, J. TERRIEN. Metrologia v1 n3 July 1965 p 80–3 3 figs 6 refs. A refractometer for the measurement of the refractive index of the surrounding air is described, in which interference fringes are produced between two beams, one propagated in air, the other in vacuum. The accuracy aimed at is one part in 10^8, corresponding to the accuracy of the best vacuum wavelength standards used in the length measurement of mechanical standards. The refractometer is placed with the comparator inside an airtight isothermal enclosure and is operated from outside.

2.2.5. Phase Change at Reflection

See also Section 11

Ueber die Phasenänderung des Lichtes bei der Reflexion an Metallen (Regarding the Phase Change of Light by the Reflection on Metals), P. DRUDE. Ann der Phys und Chemie 3 ser v50 n12 1893 p 595–624, v51 1894 p 77–104 6 figs, Part I, experimental: A. Phase change with reflection at the boundary air-solid silver, the method: the measurement of the relative phase shifts, measurement of the silver thickness, the results of observations. B: Phase change with reflection at the boundary glass-solid silver: the method, the significance of thickness change of the glass film, results of observations, comparison with the results of other observers, an investigation of the surface layers between the silver and glass. C: Phase change with reflection at the boundary air-thin silver. D: Phase change with reflection at the boundary glass-thin silver. Part II, theoretical: Derives general formulas for the intensity of the light reflected by two thin layers of any media. Discusses results from various material combinations. Draws 6 conclusions, including: The Fresnel light vector, with reflection by a solid silver layer in air, undergoes a phase acceleration of 0.412 wavelengths; with reflection in glass an acceleration of 0.365 wavelengths. The Neumann light vector in these two cases undergoes a retardation of 0.088 and 0.135 wavelengths.

Ueber normale und anomale Phasenänderung bei der Reflexion des Lichtes an Metallen (Regarding Normal and Anomalous Phase Changes with the Reflection of Light by Metals), W. WERNICKE. Ann der Phys und Chemie 3 ser v51 n3 1894 p 448–59 6 figs. Questions Wiener's conclusion that phase change corresponds to a retardation and not an acceleration. Describes experiments from the results of which he concludes: (1) That with a silver layer between two transparent media, of which the front one has the larger index of refraction, the phase change produced is an acceleration which constantly increases from zero to about $\frac{1}{4}$ to $\frac{3}{8}$ wavelength as the thickness of the silver increases from zero to opacity. (2) If the metal layer is not solidly bound to the front medium but lies between thin layers of a foreign substance, the phase change is a retardation of about $\frac{3}{4}$ to $\frac{5}{8}$ of a wavelength. Such apparent phase change must be called anomalous. (3) In undertaking measurements, if the applied metal layer shows anomalous phase change it is unsuitable for the determination of optical constants. A thickness of foreign substance equal to the diameter of one or a few molecules is sufficient to produce the appearance of anomalous phase change. P. DRUDE discusses Wernicke's work in v53 n13 1894 p 841–4 and credits him for having eliminated certain uncertainties. However he claims priority for developing a better method for attaining knowledge of the properties of a body of molecular dimensions and for deriving the necessary equations.

Zur Phasenänderung des Lichtes bei der Reflexion an Metallen (Change of Phase through Metallic Reflection), H. KATH. Ann Phys Chem v62 1897 p 328–52. The experiments were made with absolutely pure metallic mirrors obtained by placing glass plates next kathodes of silver or gold in a vacuum-tube. An even deposit on the glass was produced by the disintegration of the kathode in an atmosphere of hydrogen. It was found that the change of phase is an acceleration in the case of silver and gold, amounting to 0.55λ in the case of silver in air, and to about 0.25λ in the case of gold in air. The acceleration is independent of the incidence in the case of silver, but in the case of gold it increases to 0.5λ grazing incidence. For platinum the acceleration is 0.39λ.

Measurement of the Change of Phase at Reflection, A. PEROT. CR Acad Sci v142 March 5 1906 p 566–8. Describes dispersion measurement of phase change.

Variation de la Surface Optique Avec la Longeur D'Onde Dans la Réflexion sur les Couches Métalliques Minces (Variation of the Optical Surface with Wavelength in the Reflection from Thin Metallic Coatings), C. FABRY, H. BUISSON. J Phys Ser 4 v7 1908 p 417–29. Introduction, methods and measuring accessories, results.

Interferometer Method of Measuring the Phase Difference at Metallic Reflection, H. P. WORAN. Phil Mag v43 Mar 1922 p 471–7. During the experiments on the use of a thin layer of transparent liquid floated on mercury acting as a parallel plate interferometer it was suspected that the difference in the conditions at which reflection takes place at the two surfaces might be a disadvantage. When a Lummer plate was silvered along one half in the direction of the length the number of interference bands was doubled due to phase difference introduced at metallic reflection. From theory developed it is concluded that this may be an accurate method for the determination of the phase difference introduced at metallic reflections.

The Difference between the Mechanical and Optical Lengths of a Steel End-Gauge, F. H. ROLT, H. BARRELL. Roy Soc Proc. v122 Jan 1 1929 p 122–33. It is pointed out that as the ends of such a gauge have sufficient polish to observe interference rings the optical length can be found by placing the gauge between the mirrors of a Fabry-Perot etalon. The factors which make this length different from the geometrical and mechanically measured lengths are discussed, and a method of arriving at the differences by wringing a number of such gages together is worked out. The experimental realization of this is described, and results for two neon radiations are given. For visible radiations longer than 0.55 μ in wave-length the difference $(M - O)$ of the mechanical and optical lengths is found to be $0.27\lambda + 0.005\mu$ where λ is expressed in microns. The method of calculation of excess fractions by a method of least squares is appended.

Standards of Length. Optical Metrology. Refractive Index of Air. Eng v142 Aug 21 1936 p 205–6. Phase loss of light reflected from surfaces differs appreciably among apparently different surfaces. Method of measuring refractive index to 1 part in 10^8 is outlined. An accuracy of 1 part in 10^7 has been attained in measuring 10 cm, using Kr.

Graphical Method for the Rapid Determination of Phase Changes Occurring on Reflection at Compound Plates, M. PERROT, P. COTTON. Ann Phys (Paris) Ser 11 v20 Nov–Dec 1945 p 585–600 in French. The phase changes occurring on normal reflection of a light wave at the surfaces of a layer separating two transparent media are investigated theoretically. Based on the relations for the complex amplitudes for the reflected waves given by Rouard, a simple graphical method is described which permits the variation of the phase changes with thickness of the layer to be determined rapidly. The dependence of the phase changes on the optical interpretation is given for several curious results obtained in experiments by Rouard on thin metallic films deposited on a transparent support.

Some Further Applications of Multiple Beam Interferometry. I. Interferometric Method for Measuring Differential Polarization Phase Change at Metallic Reflection, S. TOLANSKY. J Phys Radium v11 July 1950 p 432–3. The differential phase change on reflection at a thin Ag film is measured from the doubling of white light fringes of equal chromatic order. Data are given for Ag using λ5461 A with a film thickness of 350 A over an angle of incidence 0–70°. The observations closely fit the values calculated from classical electromagnetic theory. The precision of measurement exceeds that reported earlier

(Tolansky, Phil Mag 35 149 1944) using Fizeau fringes. Even for a film thickness of 350 A the multiple beams lead to very sharp fringes.

Differential Phase Change at Reflexion, P. M. AITCHISON. Letter in Nature (London) v166 Sept 23 1950 p 522–3. Phase change effects are measured on polished and etched glass surfaces which have been silvered, using the multiple-beam interference technique. By measuring steps with light of two different wavelengths the differential phase change can be derived. For etched steps on glass a value of 14° is found. This is attributed to surface roughness.

Some Optical Properties of Evaporated Layers of Silver, Copper and Tin. D. G. AVERY. Phil Mag v41 Oct 1950 p 1018–3. In earlier work by Tolansky a description was given of the use of multiple-beam interferometry to determine relative phase changes on reflection at the silvered surfaces of an interferometer. This method has been extended and critically examined. It is shown that the method does not approach the accuracy of the older polarimetric methods, and that its optimum use is restricted to reflecting surfaces of fairly high reflection coefficient. Within its limitations the method has advantages. Measurements of the relative phase changes on reflection at a number of layers of Ag, Cu and Sn have been made, together with measurements of the ellipticity of the light reflected at these layers. The variation of these quantities with the thickness of some layers of Ag has been discussed in relation to the use of evaporated layers for the measurement of the optical constants of bulk materials, and the optical constants of evaporated layers of Cu and Sn have been determined and the results discussed.

The Dependence on Angle of Incidence of the Variation of Phase Change on Reflection at Silver, G. DORNENBURG, R. FLEISCHMANN. Zeit Phys v129 n3 1951 p 300–6 in German. The phase displacements are measured with a Jamin interferometer for the reflections glass-silver and air-silver over a wide angular range. The two beams are brought to equal intensity by polarization methods. The phase change is separately determined for the two directions of polarization. Some variation is found in different samples and this is attributed to surface films whose thickness and optical properties are evaluated by the method of Drude.

The Effect of Phase Changes in White Light Interferometry, L. G. SCHULZ. J Opt Soc Am v41 Apr 1951 p 261–4. The phase change accompanying the reflection of white light from metal films was studied experimentally by interferometric methods. As predicted by electromagnetic theory, the phase change was found to vary with the wavelength of light. Corrections for this variation must be made in white light multiple-beam interferometry if the full sensitivity of the method is to be used in making thickness measurements. Practical suggestions are given for making the required corrections. It is demonstrated experimentally and theoretically that these corrections are practically independent of the film thickness. Precise measurements of phase changes on Ag films gave results closely consistent with those calculated from published values of the optical constants of Ag. No agreement was found for Al.

The Correction for Dispersion of Phase Change in Fabry-Perot Interferometers, H. BARRELL, P. TEASDALE-BUCKELL. Proc Phys Soc London B v64 May 1951 p 413–8. A technique based on well-known interferometric procedures is described for determining the corrections for phase-change dispersion at reflection in Fabry-Perot interferometers. Results obtained during precise determinations of mercury-198 wavelengths are quoted to illustrate its application. A marked difference is found between the dispersion corrections for the silvered and aluminized mirrors actually used, and it is established

that the latter have negligible corrections in the region 4 047 to 6 438.A.

Multiple-Beam Fringes of Equal Chromatic Order. I. Phase-Change Considerations, W. F. KOEHLER. J Opt Soc Am v43 Sept 1953 p 738–43. An equation of the form $n\lambda=2t+f\lambda$ is necessary to represent multiple-beam fringes of equal chromatic order. Experimental values of f are reported for several silver coatings of various reflectivities and ages in the working range. The experimental values of f for new coatings are independent of λ in the range 4500 Å to 6300 Å. The experimental values of f for aged coatings with reflectivities greater than 60% agree reasonably well with a value estimated from the known optical constants of bulk silver. The systematic error inherent in the result of determining a thickness or a change in thickness when using the elementary equation $n\lambda=2t$ is of the order of 1% in the working range of age, reflectivity, and order of interference.

Some Problems Arising From the Use of Interference for the Precise Measurement of Plane-Ended Gauge Blocks. The Study of Fringes From an Air Wedge, J. TERRIEN. J Phys Radium v15 Apr 1954 p 6S–8S in French. The length of steel gauge blocks can be found by comparison of the two fringe systems formed by interference between beams reflected from a reference glass surface, the upper gauge block surface and the surface plate on which the block is resting. For large gauge blocks, an error arises from the different character of the two sets of fringes, that from the upper surface arising from multiple reflections. The error is calculated and a method of measuring it is suggested.

Remarks on the Function of the Multiple-Beam Interferometer Used for the Detection and the Measurement of Small Differences in Phase, G. NOMARSKI. J Phys Radium v15 June 1954 p S 26–S 30 in French. A theoretical analysis of the optimum conditions for best contrast when using the Fabry-Perot interferometer as an instrument for the detection of small phase differences. The paper discusses both application to large objects and to objects of very small lateral dimensions. A new expression is derived for the resultant amplitude for interference from the infinite series of diffracted waves. Attention is drawn to the modulating effect at infinity on the diffracted light. A new experimental set-up is proposed.

The Question of Phase Relationships at the Boundary of Dielectric and Metal, I. N. SHKLYAREVSKII. Zh teckh Fiz v26 n2 1956 p 333–42 in Russian. It is alleged that in the majority of published work false values are given for the magnitude and sign of the phase angle of reflection and transmission coefficients at inter-faces. Correct values are given. Measurements are made of the dispersion in the phase jump on reflection between air and silver. A calculation is made of the dispersion in the same quantity for a thin sheet. A new method is described for an interferometric method of determining the optical constants of a metal.

Phase Shift Effects in Fringes of Equal Chromatic Order, C. J. KOESTER. J Opt Soc Am v48 n4 Apr 1958 p 255–60. For the calculation of step heights or interferometer plate displacement three methods of analysis are discussed. A comprehensive expression is derived which requires knowledge of the phase shift of reflection. A simple expression, $2\Delta t=\lambda_1\lambda\Delta/(\lambda_o-\lambda_1)$, is shown to be exact under certain conditions. Here Δt is the step height, $\Delta\lambda$ the fringe shift, and λ_o, λ_1 are the wavelengths of adjacent fringes, $\lambda_o>\lambda_1$. A method is introduced which does not require prior knowledge of the phase-shift dispersion. For one set of fringes an arbitrary integer, N, is selected and the function $\tau N(\lambda)$ is found by plotting $N\lambda_o$ v. λ_o, $(N+1)\lambda_1$ v. λ_1, etc. For the set of shifted fringes the function $\tau N(\lambda)$ is found similarly by plotting $N\lambda_o'$ v. λ_o', etc. where the fringe at

λ_o' has the same order number as that at λ_o. It is shown that the vertical displacement between the two curves is a constant equal to twice the step height. Other uses of the tau function are described. If the tau function is linear with wavelength, the simple expression above can be used without error.

Developments in the Comparison of Lengths Using Fringes of Superposition in White Light, A. H. COOK, H. M. RICHARDSON. Proc Phys Soc v73 pt4 Apr 1959 p 661–70. When two Fabry-Perot etalons are placed one in front of the other, and the length of one is a small multiple of that of the other, fringes are seen in white light and have been used in the past to compare the lengths of etalons. In the study reported in this paper, these fringes have been observed photoelectrically while the optical length of one etalon is varied by changing the pressure of the air inside it. It is shown that the variation of intensity with path difference is the sum of two Fourier integrals involving an intensity function and the phase shifts at the reflecting surfaces. By forming cosine and sine Fourier transforms these quantities can be obtained separately and a correction applied for the error introduced into the comparison of lengths by the change of the phase shifts with wavelengths. It is shown that phase shifts can be measured more accurately by this method than by other interferometric means. It is possible to compare a metre length with a 20 cm length to about 1 in 10^8.

Effect of Surface Roughness on the Phase Change at Reflection in Interferometers, B. S. THORNTION. J Opt Soc Am v49 n5 May 1959 p 476–9. The effect of the phase change of light due to surface roughness on the precision measurement of length by interferometry is an important practical problem upon which only little work seems to have been done. This paper investigates the effect from a theoretical and experimental standpoint and shows that the phase loss due to surface roughness is a function of wavelength as well as a function of amplitude and waveform of the roughness.

Phase Shift Effects in Fabry-Perot Interferometry, C. J. KOESTER. J. Res NBS v64A n3 May–June 1960 p 191–200 8 figs 37 refs. A method is demonstrated for utilizing in Fabry-Perot interferometry the data on reflection phase shift dispersion obtained from fringes of equal chromatic order. Unknown wavelengths can be calculated from the Fabry-Perot patterns obtained with a large etalon spacing, even without prior knowledge of the phase shift of the reflecting surfaces. When the theoretical phase shift as a function of wavelength is known approximately, then the correct orders of interference can be determined for both the Fabry-Perot fringes and fringes of equal chromatic order. From the wavelengths of the latter the phase shift dispersion can be measured to an accuracy of about 10A. The method is especially useful for reflectors with large dispersion of phase shift, such as multilayers. Results in the visible spectrum are reported for aluminum films and a pair of dielectric 15-layer broadband reflectors.

Phase Dispersion in Interferometry, P. E. CIDDOR. Optica Acta (Int) v7 n4 Oct 1960 p 399–403. It is shown that the interference equation for interferometers exhibiting phase-change effects should take the form $M\lambda=2d-\lambda v/\pi$, where v is $(\beta-\pi)$ and β is the phase-change at reflection for one reflecting surface. Several recent treatments of the phase-change on reflection are critically examined and it is shown that the phase-dispersion deduced from them is inconsistent with generally accepted experimental results for interferometers with silver films.

Experimental Determination of Phase Change at Reflection From Glass-Metallic Layer Interface Using a Kösters Interference Comparator, N. BARAKAT, S. MOKHTAR. J Opt Soc Am v53 n10 Oct 1963 p 1153–5. Opaque films of

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copper and indium have been evaporated on a glass substrate, and the phase shift at reflection from the glass-metal interface has been determined both with white light and monochromatic fringes. Helium and krypton spectral lines with a Kösters interference comparator were used. Comparison is made between experimental results and theoretical calculations based on the electromagnetic theory for opaque copper films.

Determination of Absolute Phase Change on Reflection at Chromium Films, G. HENDERSON, C. WEAVER Opt Soc Am v54 n8 Aug 1964 p 1052–6. Determination of absolute phase change at chromium film-air interface for thickness up to 400 A at 5461 A wavelength; comparative measurements show Weaver-Hill-MacLeod method is as valid as well tried method of Rouard, although for films thinner than 100 A Rouard method is more suitable.

2.3. Wavelength Standards and Light Sources

See also Subsection 1.2.2.

2.3.1. General

Wave Length of Sodium as a Standard of Length, A. A. MICHELSON, E. W. MORLEY. J Assn Eng Soc May 1888. Read before the Civil Engineers Club of Cleveland. Gives a method for making the wavelength of sodium light the actual and practical standard of length.

Les Méthodes Interférentielles en Metrologie et l'établissement d'une Longueur d'Onde Comme Unité Absolue de Longueur (Interferometry methods in metrology and the establishment of a wavelength as the absolute unit of length), A. A. MICHELSON. J de Phys v3 n3 1894 p 5–22.

Sur les Sources de Lumière Monochromatiques (Sources of Monochromatic Light), C. FABRY, A. PEROT. J de Phys 3rd ser v9 July 1900 p 369–82. A series of descriptions of the various methods used by the authors for obtaining monochromatic lights of varying degrees of purity. The most useful cases were: (1) Simplification of white light by analysis of spectrum; (2) emission spectrum of a gas; (3) flames; (4) gases electrically excited by various sources of power; (5) electric spark; (6) electric arc in air; (7) electric arc in vacuo. The final choice was fixed on a mercury arc in vacuo, using the green line chiefly, the other radiations being suppressed by interpolated solutions of quinine, eosine, etc.

Light Waves and Their Uses, A. A. MICHELSON. Univ of Chicago Press 1903. Republished as PSS 514, Phoenix Science Series, Univ of Chicago Press, 1962. Contains a chapter on light waves as standards of length.

Die Anwendung der Interferenzen in der Spektroskopie und Metrologie. (The Application of Interference in Spectroscopy and Metrology), E. GEHRKE. Published by F. VIEWEG und SOHN, Braunschweig, 1906. Contents: General introduction; production and theory of a few chosen interference phenonema; spectral apparatus; selection of results of the spectroscopic research regarding the mechanism of light; application of interference to physical measurements in metrology. Bibliography.

Some Measurements of Wave Lengths with a Modified Apparatus, LORD RAYLEIGH. Phil Mag ser 6 May 11 1906 p 685–703. Measurements on Cd, Hg, He, Zn, Na. Mesures de Longueurs D'Onde pour l'Établissement d'un Systeme de Reprères Spectroscopiques (Measurements of Wavelengths for the establishment of a System of Spectroscopic Spectrum lines), H. BUISSON, C. FABRY. J Phys Ser 4 v7 1908 p 169–95. Introduction, sources of light, methods, description of apparatus, manipulation, measurements, corrections, results.

Width of Spectrum Lines and Interference Fringes with Large Path-Difference, C. FABRY, H. BUISSON. CR Acad Sci v154 May 6 1912 p 1224–7; J de Phys v2 Sec 5 June 1912 p 442–64. Formulas for width of line and number of the order corresponding to the limit of visibility of the fringes; order number for He, Ne, and Kr.

Nouvelle Détermination du Rapport des Longueurs, d'Onde Fondementales avec L'Unité Métrique (New Determination of the Relation of the Fundamental Wave Lengths to the Metric Unit), J. R. BENOIT, C. FABRY, A. PEROT. Trav et Mem du BIPM v15 1913 280 p 23 figs. Part 1, Interference phenomena with silver films: production and properties of fringes of silver films in monochromatic light; theory of coincidences; influence of dispersion phenomena; phenomena produced by superposition of films; influence of variations in the refractive index of air. Part 2, Methods and apparatus; construction and study of the measuring standard; interferential standards; cadmium light source. Part 3, Organization, execution, and calculation of the experiments. Part 4, Results and conclusions. Detailed observations.

Sur les Étalons de Longueur d'Onde (Wavelength Standards), C. FABRY, H. BUISSON. J Phys Ser 3 v5 Aug 1913 p 613–22. The exactitude of secondary international standards is first discussed. It is seen that many researches lead to the conclusion that the values given by interference methods are perfectly correct and identical with those found by means of a grating. The paper then deals in succession with (1) The progress of measurements of secondary standards. (2) Variability of wave lengths. (3) Tertiary standards of wave length. (4) The utility of having more numerous secondary standards measured by interference methods.

Limit of Interference in the Fabry-Perot Interferometer, M. N. SAHA. Phys Rev v10 Dec 1917 p 782–6. The theory of the Fabry-Perot interferometer has been worked out by Lippich, Rayleigh, and Schonrock. They have shown that when the pressure is small, the critical distance D, or the limit of interference, is connected by the following formula with the wave length λ of the light, the temperature T of the tube, and the mass M of the emission centers:

$$\frac{D}{\lambda} = A \sqrt{\frac{M}{T}}.$$

Paper develops an exact value for A which is 1.50×10^6.

Interference Measurements in the Spectra of Argon, Krypton, and Xenon, W. F. MEGGERS. Sci Papers NBS n414 Aug 1 1921 p 193–202. Gives values of 50 wave lengths in spectrum of argon, krypton and xenon, all of which have been compared with wave length of red radiation from cadmium which is international primary standard.

Measurement of Meter in Wavelengths of Light, C. F. SMITH. Machy (London) v28 1926 p 53.

Determination of the Yard in Wave-Lengths of Light, A. E. H. TUTTON. Roy Soc Phil Trans v230 Sept 1931 p 293–322. The British Imperial Standard Yard has been evaluated in wave-lengths of the red hydrogen line Hα, the yellow line of Ne$_c$, and the red line of cadmium Cd$_r$. The author's interferential method was employing Grayson-ruling fiducial marks of only half-wave-length thickness, the author's interferometer, and the Tutton

comparator. Results obtained are tabulated and possible errors discussed.

Determination of the Relationship between Wavelength of Light and the Fundamental Standards of Length, J. E. SEARS, Jr., H. BARRELL. Roy Soc Phil Trans v231 Sept 16 1932 p 75–145. Apparatus and methods developed at the NPL for the establishment of suitable means of realizing a wave-length standard of length and for determining the imperial standard yard and standard meter in terms of it. Measurements can be made either in air under controlled conditions or in vacuum.

Interference Measurements in the Spectra of Noble Gases, W. F. MEGGERS, C. J. HUMPHREYS. J Res NBS v13 Sept 1934 p 293–309 81 refs. Values are given for 3 lines of He, 172 of Ne, 87 of A, 55 of Kr, and 130 of Xe. Many of the lines have been found to be reproducible to 8 figures and are regarded as highly satisfactory standards in spite of objections on account of isotopic hyperfine structure.

The Primary Standard of Wavelength, W. F. MEGGERS, NBS. Rev Mod Phys v14 Apr-July 1942 p 59–63 19 refs. Discusses various spectrum lines and hyperfine structure originating in the isotopic constitution of certain chemical elements.

A Method of Cooling Hydrogen Discharge Tubes, H. CHAO-WANG. Rev Sci Instrum v14 Aug 1943 p 250–3. Experiments are described on cooling by means of rapidly evaporated liquid air. The temperatures were measured with a calibrated Cu constantan thermocouple. Special apparatus was constructed to determine the f.p. of the substances used for calibration. Cooling of the light source to 56 °K. is obtained at low cost.

Use of the Fabry-Perot Interferometer for the Study of Feeble Satellites. C. DUFOUR. Rev Opt (Theor Instrum) v24 Jan-Mar 1946 p 11–8 in French. Heavily silvered mirrors are best. Low luminosity due to reflection at the first surface is overcome by having a clear space for entry. The methods of use, and the advantages obtained, are discussed at length. Attention is also given to the use of long tube "end-on" sources.

Direct Determination of Wave-Lengths from Fabry-Perot Interferometer Patterns, G. R. HARRISON. J Opt Soc Am v36 n11 Nov 1946 p 644–54. Data on measuring and computing engine which determines wavelengths and wave numbers directly from spectrograms made by crossing dispersion of Fabry-Perot interferometer with that of concave diffraction grating; wavelength of spectrum line is determined to six figures from grating dispersion by automatic comparator, and is then converted to wave number by mechanical continuous-function computing arrangement. Bibliography.

Relations Entre les Étalons de Longueur Fondamentaux et les Longueurs d'Ondes Lumineuses. (Relations between Fundamental Length Standards and Wavelengths of Light), H. BARRELL, NPL. Rev de Métrologie v25 ser 2e n7 Feb 1947 p 33–44 7 figs 12 refs.

Recording Interferometer for Precision Wave-Length Determinations, W. R. SITTNER, E. R. PECK. J Opt Soc Am v39 n7 July 1949 p 544–6. Precise measurement of angle by means of interferometric measurement of chord length; application to problem of precise wavelength determinations; possibilities for measurement of rotation of linear displacement as small as one microinch.

Use of the Fabry-Perot Etalon for the Wavelength Calibration of Monochromators, F. DESVIGNES. CR Acad Sci Paris v229 Nov 15 1949 p 1001–3 in French. The author considers the conditions required for accurate calibration by "Edser-Butler" fringes and gives expres-

sions for the fringe width $(\delta\lambda)$, fringe separation $(\Delta\lambda)$, etalon transmission, and wavelength error (ϵ) due to variation of detector-response with wavelength, as functions of etalon thickness (e) and plate reflection (r). A flint prism monochromator is calibrated up to $\lambda=2\mu$ using an etalon with $e=18\cdot2\mu$ and $r=0\cdot7$; the receiver response varied by a factor of not more than 3 from one fringe max. to the next, giving $\epsilon<0\cdot18\Delta\lambda\cdot\delta\lambda/\Delta\lambda$ was equal to $0\cdot057$. The calibration obtained agreed with direct measurement of Hg and K lines to the experimental error of about $1m\mu$.

Electric Discharge Laboratory Lamps, N. L. HARRIS. Engr v189 n4906 Feb 3 1950 p 143–6 9 figs. Details of range of Osram laboratory lamps; thallium vapor lamp and its application to the interference microscope; other types of discharge tube; continuous ultraviolet spectrum used in absorption spectroscopy.

Light as Standard of Length. Light and Lighting v43 n7 July 1950 p 255–7 2 figs. How wavelength of light can be used as basis of specifications for standard of length; unit of length is now maintained by bar of platinum iridium of special cross section; disadvantage is that it cannot be reproduced from specification; standard based on use of monochromatic light; use of more precisely defined radiation for mercury isotope.

A Note on an Automatic Control for Maintaining Constant Intensity of a Light Source, K. C. WIGHT. J Sci Instrum v28 Sept 1951 p 276–7. An electronic arrangement for automatically maintaining constant intensity of a light source using a tungsten filament lamp is described, in which normal electrical components are used. Curves show the stability over a period of some hours and the effect of mains voltage variation. The regulation of intensity for the latter, on a percentage basis, is about 150 to 1.

Calibrating Wavelengths in Region From 0.6 to 2.6 Microns, N. ACQUISTA, E. K. PLYLER. J Res NBS v49 n1 July 1952 (RP2338) p 13–6. Wavelength of 20 absorption bands measured on grating spectrometer, several emission lines of krypton also measured in near infrared region; purpose was to make available additional calibration points for prism instruments.

Light Waves, Radio Waves Measure to Millionths, D. E. BROOKS. Can Machy v65 n1 Jan 1954 p 108–9, 174. Recent improvements in sources of monochromatic light permit lengths up to 0.5 yd and 0.5 m to be measured with accuracy corresponding to one millionth of inch in 10 in.; method to be of greatest value in measuring of reference end gages; possibility of reaching international agreement on specified wavelength to be used as ultimate standard of length.

Light Waves and Length Standards, I. C. GARDNER. J Opt Soc Am v45 n9 Sept 1955 p 685–90. A brief history of earlier standards of length and of the standards now in use is given. The plan to substitute a wavelength of light for the present international platinum-iridium prototype metre as a standard of length is now under consideration by the appropriate international committees. The advantages of the proposed plan, the different isotope sources of monochromatic radiation that have been suggested by different countries, and the present status of the proposed change are presented.

Wavelength Data and Correction Tables for Length Interferometry, C. F. BRUCE. Australia. Commonwealth Sci & Indus Res Organization-Tech Paper n8 1956 87 p. Sets of tables compiled for use in length interferometry; included are all relevant data on wavelengths, refractive indices, and correction factors; to facilitate reduction of results, additional tables are given of vapor pressures and of wavelength fractions with metric and inch equivalents.

Fine Measurements, J. R. ADAMS. J Sci Instrum v33 n10 Oct 1956 p 369–75. The limitations of the existing legal standards of linear measure are considered. The use of light waves as a universal reference of linear measure depends on the availability of a source of truly monochromatic light and considerable progress has been made using the isotope Hg^{198}. Many aspects of engineering require measurements accurate to a few micro-inches and instruments capable of meeting such demands have been designed. Several typical instruments, together with details of the principles on which they are based, are briefly reviewed.

Koesters-Type Interferometer, C. F. BRUCE. J Sci Instrum v33 n12 Dec 1956 p 478–82. Design and performance of instrument which measures lengths of up to 500 mm directly by interferometry; isotopic light sources are necessary for measurement of longer lengths, and sources containing mercury 198 and krypton 86, as well as natural krypton and cadmium, have been used; results of some length and relative wavelength measurements given to illustrate performance of instrument in air and in vacuo.

Broadening and Shift of Spectral Lines Due to the Presence of Foreign Gases, S. CH'EN, M. TAKEO. Rev Mod Phys v29 n1 Jan 1957 p 20–73. This comprehensive review is intended as a sequel to that of Margenau and Watson (1936–7) and deals with pressure-induced broadening and shifts of atomic and molecular lines in the ultraviolet, visible, infrared and microwave regions by neutral particles. The effects of electron and ion collisions and high temperature broadening are not treated. The following topics are discussed: (A) Causes producing broadening and shift of spectral lines; (B) Impact theory; (C) Statistical theory; (D) Theory at general pressures; (E) Fine structure pressure broadening of atomic lines. Experimental Observations: (A) Pressure shift and broadening of atomic lines; (B) The fine structure and pressure effect; (C) Narrow diffuse bands of various metals produced by close encounters with foreign particles; (D) Pressure boardening of molecular bands in the infrared region; (E) Pressure broadening of lines in the microwave region.

Line Shape, R. G. BREENE, Jr. Rev Mod Phys v29 n1 Jan 1957 p 94–143. This review discusses the development of the theory of line shape and broadening since Michelson's original contributions to the subject in 1895. The topics reviewed are: (i) Early line broadening theory; (ii) Stark broadening; (iii) Statistical broadening; (iv) Interruption broadening; (v) Resonance broadening; (vi) Molecular broadening.

Secondary and Tertiary Interferometric Wavelength Standards, in 1.5–2.5 Region, D. H. RANK, A. H. GUENTHER, J. N. SHEARER, T. A. WIGGINS. J Opt Soc Am v47 n2 Feb 1957 p 144–8. Results of measurement of wavelengths of three absorption lines relative to Hg 198 green line are; P (1), 002–000 band of HCN, 15,345.2887 A in vacuum; R (15), 01′1–000 band of HCN, 24,700.065 A in vacuum; R (18), 2–0 band of CO, 23,150.023 A in vacuum; 29 lines of 002–000 band of HCN have been measured relative to P (1).

Coherent Emission Light Source, R. B. GRIFFITHS, R. H. DICKE, Rev Sci Instrum v28 n8 Aug 1957 p 646–8. Sharp, intense emission line may be obtained by use of resonance radiation coherently scattered from collimated beam of atoms; coherently scattered light may be separated from exciting radiation by placing atomic beam in one arm of Mach-Zehnder interferometer or by diffraction from several parallel atomic beam pencils; technique was tested by observing hyperfine structure in light coherently scattered from beam of sodium atoms.

The Possibility of Using Absorption Lines as a Primary Length Standard, W. G. FASTIE. J Phys Radium v19 n3 Mar 1958 p 405–8 in French. It is possible to establish conditions of pressure and temperature in an absorbing gas so that its absorption lines are invariant in wavelength, whereas emission lines are subject to wavelength shifts dependent upon the condition of excitation. Experimental limitations have, however, restricted work on the primary length standard to emission lines. The development of techniques is described which make it possible to achieve comparable measurement accuracy with absorption lines of I_2 vapour at a pressure of 2 μ and at a temperature of 250° K. A Hg 198 source was viewed along a variable magnetic field. A quarter wave plate in combination with a polaroid sheet isolated one of the Hg 5461 components which illuminated a long path Fabry-Perot interferometer-monochromator which was scanned by variation of air pressure. When the I_2 absorption tube was placed in the light path, the magnetic field could be adjusted until one of several I_2 absorption lines overlapped the Hg line. The shape of the absorption line was measured photoelectrically by scanning the interferometer. Likewise photographs of the Fabry-Perot patterns in absorption were obtained. The half width of the two lines which have been carefully studied was found to be 0.030 wave numbers, about 2.5 times the theoretical Doppler width, presumably due to the nuclear spin effect of I^{127}. In spite of the width of the lines, their absolute invariance in wavelength makes them appear to be at least comparable to presently proposed emission line standards. However, the presence of the nuclear spin effect precludes the possibility of narrowing the lines by molecular beam techniques.

Fabry-Perot Fringes in White Light Used as Wavelength Standards, F. S. TOMKINS, M. FRED. J Phys Radium v19 n3 Mar 1958 p 409–14 in French. The term analysis of the complex rare earth and heavy element spectra requires highly accurate descriptions of these spectra in order to avoid the masking of real regularities with spurious ones, and wavelength accuracy approaching that obtainable interferometrically is desirable. Such accuracy can be obtained by photographing white light interference fringes as wavelength markers instead of the iron arc or other conventional standards, without the loss of light attendant on the usual methods of interferometry. The white light fringes provide equally spaced standards of uniform intensity and sharpness, whose wavelength values can be easily calibrated by comparison with a source such as Hg^{198}, thus avoiding the deficiencies of the iron lines with respect to accuracy, sharpness, and number. The spacing between fringes is determined by the etalon thickness and can be chosen at will. The wavelengths are determined as in the conventional method using a Fabry-Perot interferometer, by measuring the fractional order of the unknown by interpolation between neighbouring fringes, and the whole order number either by counting fringes from a known line or by calculation from the known etalon thickness if the wavelength is already known to approximately 0.1 A. In either case the interpolation distances actually measured are quite small and errors due to emulsion shrinkage or errors in the focal surface of the plateholder are minimized. Wavelengths accurate to ±0.0003 A can be obtained using this system in the 5th order of the Argonne 30 ft. spectrograph, and typical measurements are shown. Some applications of the method to the calibration of the spectrograph are discussed.

Interferometric Calibration of Quartz End Standards, E. ENGELHARD. Zeit Instrumkde v67 n3 Mar 1959 p 59–65 in German. See abstract under 2.3.3.

Accuracy of Lightwave Scales in Interferometry, E. ENGELHARD, PTB. NPL Symposium n11 1959, Interferometry. H. M. Stationery Office, London 1960 (Paper 2–1) p 19–47 22 figs 14 refs. Describes investigations dealing with linearity of visible radiation sources. Lightwave scales often have periodic or progressive errors caused by deficiencies depending on spectroscopical conceptions such as line width, line asymmetry, line struc-

ture, and line shift. Paper illustrates certain errors by some earlier, mostly unpublished measurements as well as by some recent observations made with different kinds of commercial cadmium lamps and with the Krypton-isotope lamp developed at the PTB. An addendum presents line profiles of various Cd and Kr lines and the pressure shift of the Kr 6056Å line. Discussion.

On the Accuracy of Wavelength Comparison, K. M. BAIRD, NRC Canada. NPL Symposium n11, 1959, Interferometry. H. M. Stationery Office, London. 1960 (Paper 2-2) p 49–66 2 figs 10 refs. Declares that an uncertainty of the order of ±0.0002Å to ±0.0003Å must be ascribed to determinations of wavelength values up to the present, but that as far as the sources themselves are concerned agreement in the fifth decimal place should be possible. Discusses pointing on interference fringes and maximum attainable precision of setting. Concludes that with refinement of techniques now being developed something approaching the limit imposed by quantum effects will be reached.

Spectral Lines of Narrow Breadth, M. BOTTEMA. Nederlands Tijdschrift voor Natuurkunde (Netherlands) v26 n6 June 1960 p 188–91 in Dutch. A survey of recent work on the production of fine spectral lines using discharge lamps containing pure isotopes. Particular mention is made of the work at the National Bureau of Standards and that of Gardner and Nefflen. The least breadth quoted (the breadth at half the height) is 0.003 cm^{-1} found for Ca^{89} by an atomic beam method and for Hg^{198} by the use of a spherical interference filter.

Grating Diffraction Spectra as Coherent Light Sources for Two- or Three-Beam Interferometry, A. LOHMANN. Optica Acta (Int) v9 n1 Jan 1962 p 1–12. It is common practice in two-beam and three-beam interferometry to obtain coherent light sources by using slits in a coherent field (division of wave-front) or by means of suitable mirror devices (division of amplitude). The purpose of this paper is to show that better coherence properties may be realized if one uses grating diffraction spectra as coherent light sources. As a result one may use a source larger than that permissible in a conventional slit-interference set-up and thereby gain in photometric efficiency. Further, it is shown that the fringes with slit interference are, in general, inhomogeneously distributed in space. The proposed method of interference between the disturbances from the different grating spectra does not suffer from these disadvantages. Also one gets achromatic fringes, and hence the grating interference technique is ideally suited for interferometry in the ultraviolet or infrared region of the spectrum. The physical reason for the achromatism of the fringes is easy to understand, if one considers the fringes as images of the grating produced by lenses which have no chromatic aberrations. Finally, other interferometric devices are also discussed in terms of coherence.

Limiting Precision in Scanning Optical Interferometer, R. M. HILL, C. F. BRUCE. Austral J Phys v15 n2 June 1962 p 194–222. Interferometer uses photoelectric detection and it is shown that principal noise sources limiting accuracy of detection are shot noise in vacuum photocell and photon noise from light source; from limiting precision of pointing on fringe, limiting precisions of measurement of small wavelength shifts and of measurement of wavelengths have been calculated.

A Thallium Beam Frequency Standard, J. BONANOMI. IRE Trans Instrum (USA) v I–11 n3–4 Dec 1962 p 212–5. Following a proposal by Kusch, a thallium atomic beam frequency standard was constructed and put into operation. The main characteristic is that frequency of 21 310 Mc/s is only very weakly affected by inhomogeneities of the C-field. The construction, which is similar to conventional caesium standards, differs from these in the following main points: a high (1000° K) oven temperature, high (14000 G) A- and B-fields, an oxidized tungsten filament detector. The interaction length is 90 cm; the Q factor of the resonance is 160 million. The measurements show that the uncertainty in the Zeeman-shift is negligible, while the error arising from an unsymmetrical cavity is the same as in the case of caesium.

Vacuum Wavelength of Kr^{86} Hg^{198} and Cd^{114}. K. M. BAIRD, D. S. SMITH, K. H. HART. J Opt Soc Am v53 n6 June 1963 p 717–20. Vacuum-wavelengths values are given for a number of visible lines, emitted by Kr^{86}, Hg^{198}, and Cd^{114}, which are useful spectroscopic and metrological standards. The wavelengths are based on a number of Fabry-Perot interferometer measurements during the past few years; some of the values have also been confirmed by independent measurements on Michelson interferometers. Perturbations to the wavelengths are discussed.

2.3.2. Cadmium

Détermination Expérimentale de la Valeur du Mètre en Longeurs d'Ondes Lumineuses (Experimental Determination of the Value of the Meter in Terms of the Wave Length of Light), A. A. MICHELSON. Trav et Mém du B.I.P.M. v11 1895 p 3–85. Appendix, 1, "Déterminations Metrologiques" by J. R. Benoit and Ch. Ed. Guillaume, p 86–111. Other appendixes p 112–237. Paper covers introduction, theory, description of apparatus, methods of observation, Cd light source, results.

Cadmium Lamp for Interference Fringes, M. HAMY. CR Acad Sci. 1897 p 749–52. Michelson's lamp (cadmium vapor in a Geissler tube with aluminum electrodes) does not last well. The author describes a form without interior electrodes, in which the tube is terminated by metal caps lined with black lead, with a sufficient condenser, in derivation, in the induced circuit for the purpose of preventing perforation of the glass by sparking.

Michelson's Reference of the Meter to certain Wavelengths of Cadmium Light, P. CULMANN. Zeit für Instrumtkde v22 Oct 1902 p 293–311. Extract from Bul Soc Enc Ind Nat v101 1902 p 146. A description of Michelson's experiments carried out at Sevres, in which, by an optical interference method, he obtained the meter in terms of certain wavelengths of the cadmium spectrum. According to Guillaume the meter has been obtained to an accuracy of .001 mm in terms of those wavelengths.

On Standards of Wave-length, H. KAYSER. Astrophys J v19 Apr 1904 p 157–61; Phil Mag v6 n8 1904 p. 568. Discusses discrepancy between Michelson's and Rowland's values.

Nouvelle Determination du Mètre en Longueurs d'Ondes Lumineuses (A New Determination of the Meter in Terms of the Wave-length of Light), R. BENOIT, C. FABRY, A. PEROT. CR Acad Sci v144 May 21 1907 p 1082–6. The authors have redetermined the length of the standard meter in terms of the wave-length of the red line of cadmium and find that 1 m=1553164.13×λ, and λ=0.6438, 4702, the measurements being reduced to 760 mm and 15° on the hydrogen scale.

Determination of Length of International Meter in Terms of the Red Cadmium Line, N. WATANABE, M. IMAIZUMI. Imperial Acad of Japan Proc v4 July 1928 p 350–3 in English. Results of author's determination coincides fairly well to that of Fabry, made 21 years earlier; change of length of international meter prototype during this time has not been detected; at same time it has been confirmed that red cadmium line of Michelson's lamp is quite reliable as standard of length.

Settling the Primary Standards Controversy. Black and White, v1 n4 Feb 1929 p 22–6. Question of selecting pri-

mary standard of measurement is discussed; wave length of red ray of cadmium light is advocated as primary standard in place of present bar standards whose lengths vary in Washington, London and Paris.

Interferential Comparison of Radiations Emitted by a New Cadmium Lamp and the Michelson Lamp, J. E. SEARS, JR., H. BARRELL. Roy Soc Proc v139 Jan 2 1933 p 202–18. Comparisons were made by means of a Fabry-Perot interferometer, of the wavelengths of the red radiation emitted by the two sources at a series of path differences. Wavelengths are the same to an accuracy of at least 1 part in 16,000,000.

Reversal of the Red Line of Cadmium, A. PÉRARD. CR Acad Sci v198 Feb 19 1934 p 727–9. Spontaneous reversal of the cadmium red line has been previously noted in the Hamy lamp, and also, under special circumstances, in the Michelson lamp. The effect is easily observable in the hot-kathode lamp excited by the normal current of 2 amperes. but the reversal is suppressed when the current is reduced to about one ampere. Using a hot-kathode lamp with a constriction at the middle of the discharge tube and a current of 1.15 amperes, the highly intense red line produced is unreversed and is capable of interference over path differences up to 280 mm.

Use of Cadmium Red Radiation as a Standard in Metrology and Spectroscopy, C. FABRY. CR Acad Sci v198 Mar 5 1934 p 861–4. Objection is raised to a statement by Pérard that the possibility of self-reversal in the red radiation of Cd disqualifies it from future use as the fundamental unit of length. All radiations are reversible, but they can be produced without reversal by suitable control of the conditions of excitation. Discusses adopting a wavelength of light as the international unit of length and possibilities of radiations of Kr and Xe as suitable additional standards.

Determinations of Fundamental Standards of Length in Terms of Wavelengths of Light, J. E. SEARS, H. BARRELL. Roy Soc London Phil Trans Ser A v233 June 22 1934 p 143–216. Definite determinations have been completed of lengths of yard and meter in terms of wavelength of cadmium-red radiation, both in air and in vacuum, results of these determinations given.

Intercomparaisons D'Étalons Métriques au Moyen des Longueurs D'Onde Lumineuses (Intercomparison of metric etalons by means of the wavelength of light), W. KÖSTERS, J. E. SEARS, JR. Comité International des Poids et Mesures. Proces-Verbaux des Séances 2d ser v17 1935 p 113–28 2 figs 3 refs. Contents: Introduction; influence of phase loss; optical comparison of etalons; reverification of national prototype meters of England and Germany Nos. 16 and 18; repetition of the determination of the wavelength of the red radiation of cadmium by NPL; correlation by PTR of the red ray of cadmium with the German prototype No. 18 by Kösters and Lampe; summary.

Cadmium Red Line as Standard of Wave-Length, C. V. JACKSON. Roy Soc Proc v155A June 2 1936 p 407–19. An investigation of the condition necessary to ensure accurate reproducibility of the wave-length of the Cd red line from various sources is described. The sources used were Michelson lamps of the original vacuum type, and as modified by Pérard containing air at a pressure of about 1 mm., Osram hot-kathode discharge lamps and a Schuler hollow-kathode lamp. Under certain specified conditions all sources give a wave-length identical and reproducible with an accuracy of about ±0.0001 A. The Michelson lamp as modified by Pérard is found to be superior to the original vacuum type, and in the Osram lamp the exciting current needs to be limited to a value of 1.1 A, to ensure reproducibility with other sources.

Interferometric Wave-Length Comparison of the Red Cadmium Radiation Emitted by Different Sources, W. E. WILLIAMS, D. V. GOGATE. Roy Soc Proc v16 7A Sept 23 1938 p 509–16. A comparison is made between the wavelengths of the red Cd line 6438 A emitted by a G.E.C. Osira Cd lamp and a Schuler hollow-kathode discharge by photographing the Fabry-Perot fringes due to the two sources side by side in the same horizontal plane by means of a specially designed plate-holder. Interferometer gaps up to 10 cm. were used, and the greatest difference recorded was less than 1 part in 100×10^6 or 0.00006 A.

Comparison of the Prototype Metre with the Wavelength of the Red Line of Cadmium, M. F. ROMANOVA, G. V. WAHRLICH, A. I. KARTASHEV, N. R. BATARCHUKOVA. CR Acad Sci URSS v37 n2 1942 p 46–51. Values previously obtained for their wavelength of the red line of Cd are set out, in their original form and corrected to apply to dry air at 15° C. and 760 mm. Hg, containing 0.03% CO_2. Technique and results obtained in a new comparison between the std. USSR metre (metre No. 28) and the wavelength of this line are described in detail. The method employed involves the use of a Fabry and Perot interferometer, measurement being made on a flat-ended steel metre bar. Mean values obtained for the red line of Cd were; normal air, $\lambda = 6440.2488$ A. The mean quadratic error was ±0.0002 A.

A Light Source for the Primary Standard of Wave-Length, C. W. HSUEH. J Opt Soc Am v36 Mar 1946 p 160–4. A light source for the red Cd line, 6438.4696 A, was developed in which the important objections against the Michelson type lamp were eliminated. It consisted of a discharge tube of two Pyrex bulbs joined by a U-shaped capillary in an electric furnace maintained at a temperature between 300° C and 320° C. The current was 2.5A. The intensity of the standard line was strong, as shown by the short exposure time (30 min) required to produce an interferometer spectrogram. The effective light-emitting area was 50x2.5 mm² which was large enough to cover most spectrograph slits. The Cd standard line was narrow, as shown by the interferometer spectrograms. The Doppler-effect broadening was reduced by observing the light in a direction perpendicular to that of the discharge current.

Effect of Change of Argon Pressure in an Electrodeless Discharge upon the Reproduction of Wavelength of the Cd[114] Red Line, N. R. BATARCHUKOVA, F. B. DUBROVSKII. Optika i Spektrosk v1 n3 1956 p 330–3 in Russian. A spectrum line used as a standard of length should be symmetrical in form and stable to ensure reproducibility and it should have no hyperfine structure. The Kr[84] line has been shown to give a shift in its maximum line under change of pressure. Present authors set out to determine the shift and broadening of the Cd[114] line, with change of argon pressure, in an electrodeless discharge. A Fabry-Perot type interferometer was used set up between the collimator and prisms of a Frish spectrograph. On a length of film photographs were taken of the Cd spectrum over a range of some 40 pressures ranging from 1 to 48 mm Hg. A graph of shift v pressure (roughly linear) is given with an expression for its calculation.

Preliminary Report on the Isotopic Structure of the Cadmium Primary Standard of Wavelength, J. F. WISE, K. L. VANDER SLUIS. J Opt Soc Am v46 n8 Aug 1956 p 587–9. With enhanced samples of the eight isotopes of cadmium in electrodeless discharge tubes, measurements of the centre of gravity line position of λ 6438 have been made to better than one part in 25 million or to about 0.0003 A. The estimated resolution, based on Doppler broadening, was 500,000. The observed shifts, compared to a similar normal cadmium source, have been treated by a least squres analysis of a matrix multiplication by the ORACLE. The preliminary results indicate a difference for the extreme masses of about 0.008 A, which is comparable with the half-width of the red line in an atomic

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beam source. With exception of mass 108, there is a regular increase in wavelength for the even mass numbers. The odd mass isotopes appear to give anomalous shifts, falling near the shift for the adjacent larger even mass. The principal source of error in the procedure is associated with apparent shifts due to differences in density of the patterns.

Interferometric Measurements in Metrology, M. F. RO-MANOVA. Optika i Spektrosk v3 n5 1957 p 457–72 in Russian. This review article gives accounts of work on (1) the determination of the wavelength of the standard Cd line; (2) measurement of 1 m length standards; (3) the wavelength of the Cd red line of the isotopes 112, 114, and 116; and (4) a method for finding the velocity of light. Results are given in each section with diagrams of the apparatus used.

Some Considerations About the Precision of the International Standard of Wavelength, S. Y. CH'EN. Am J Phys v26 n7 Oct 1958 p 464–6. The precision of the accepted value for the wavelength of the red line of Cd is discussed. The uncertainty due to the setting of the end marks by a microscope in the interferometric measurement, the correction for the refractive index of air, and the difficulty in controlling precisely the conditions of excitation of the light source are reviewed with considerations for a new standard of wavelength and a new pair of end marks.

Preparation of Hg [198] and Cd[114] Electrodeless Lamp, T. TAKO. Report of the Central Inspection Institute of Weights and Measures, Japan v8 n4 report 20 1960 in Japanese. To obtain the best data to use in the making of the lamp and its operation, several Hg[198] and Cd[114] electrodeless discharge lamps with various amounts of isotopes and argon or neon of various pressures as carrier gas are prepared. The isotope Hg[198] used is the Atomic Energy of Canada Limited's of which composition is reported to be, by mass-analysis, Hg[198] : Hg[199] : Hg[200] =98.74 : 1.19 : 0.07% and the sum of the rest is less than 0.01%. An ingenious method for taking a small definite quantity of Hg[198] : say 0.2 mg out of its reservoir is explained. The isotope Cd[114] used is Oak Ridge's and its purity is published to be 98.2%. The reduction of Cd[114] from Cd[114] O is simply carried out by the use of hydrogen. For both cases the procedures in making the lamps are thoroughly explained with figures and photographs. Some considerations for these lamps are given. The author adds that the half-value width and broadening of the spectral lines of the lamps are under observation and examination, and their results will be reported in more detail later.

Wavelengths of Krypton 86, Mercury 198, and Cadmium 114, C. F. BRUCE, R. M. HILL. Austral J Phys v14 n1 Mar 1961 p 64–88. The vacuum wavelengths and the spectral line profiles for four lines of Kr[86], four lines of Hg[198] and four lines of Cd[114] were measured. One line, the radiation $2p_{10}$–$5d_5$ of Kr[86] (6057 Å), was used as the reference standard in the wavelength measurement. A variable gap Fabry-Perot interferometer with electromagnetically controlled plate holders was used throughout under vacuum conditions. The use of photoelectric recording methods and mechanical scanning made it possible to compare wavelengths with an accuracy of better than 1 part in 10[8], and half-intensity widths of lines were measured with an accuracy of 0.5 mK (0.0005 cm^{-1}). The 6057 Å line of Kr[86] was examined under different operating conditions of the Engelhard-type and small wavelength shifts due to variation of temperature, pressure, and current density were measured. The Doppler shift and interatomic Stark shift annul each other if the lamp is viewed in the direction cathode to anode to observer, and is operated in a liquid air bath with the temperature near the capillary surface of the lamp at $63 \pm 1 °K$ and with a current density of 0.28 ± 0.05 A/cm^{2}. The Doppler shift under these conditions was found to be $+0.014 \pm 0.003$ m[-1] (-50 ± 10 μA) and the interatomic Stark shift -0.014

± 0.003 m^{-1} ($+50 \pm 10$ μA). Under these conditions also the half-intensity width is 13.4 ± 0.5 mK, and the wavelength emitted is that for the unperturbed state of the atoms to 2–3 parts in 10[9]. This line is superior to the other lines examined for sharpness and reproducibility and other wavelengths may be established in terms of it to at least 1 part in 10[9]. This is the line that has been recommended as the new primary standard of length.

2.3.3. Krypton

Eine neue Methode höchster Genauigkeit zur interferometrischen Wellenlangenmessung und ihre erstmalige Anwendung zur Vorbestimmung der für den deutschen Anschluss des Meters an Lichtwellen vorgesehenen Kryptonlinien (A New Method of Highest Precision for Interferometric Wave-Length Measurements and their Primary Application to the Predetermination of Designated Krypton Lines for the German Relation of the Meter to Light Waves), A. P. WEBER. Phys Zeit v29 Apr 15 1928 p 233–9 3 figs. (English translation is available).

The First Spectrum of Krypton, W. F. MEGGERS, T. L. DE BRUIN, C. J. HUMPHREYS. J Res NBS v3 (RP89) July 1929 p 129–62 6 figs 42 refs. About 200 lines were photographed with concave grating and quartz spectrographs. From these spectrograms a new list of estimated intensities and measured wave lengths was obtained.

Interference Measurements in the First Spectra of Krypton and Xenon, C. J. HUMPHREYS. J. Res NBS v5 Nov 1930 p 1041–57. Determinations of the stronger arc lines made with the Fabry-Perot interferometer. None of the krypton lines exhibit fine structure under the resolving power employed, and the intensities of any satellites which may exist are too small to influence the wave-lengths.

First Spectrum of Krypton, W. F. MEGGERS, T. L. DE BRUIN, C. J. HUMPHREYS. J Res NBS v7 Oct 1931 p 643–57 7 refs. Wave length and intensity data have been improved, several close pairs of lines have been resolved, and total number of lines increased to 460, as the result of a change in technique.

Au Sujet de la Recherche d'une Raie Nouvelle comme Étalon de Longueur d'onde Lumineuse (New Line Standard of Wavelength), A. PÉRARD. CR Acad Sci v194 May 9 1932 p 133–5. By means of the Michelson interferometer comparisons have been made between the provisional standard red line of Cd and four Kr lines, and reasons are given at length for adopting KrI (5562.22576 Å) as standard.

Krypton Vacuum Wavelength Measurements, T. A. LITTLEFIELD. Proc Roy Soc A v187 Oct 22 1946 p220–8. The wavelengths of 31 lines in the spectrum of Kr were compared directly with the red Cd standard using a reflecting echelon in vacuo. Uncertainties connected with dispersion in air are thus eliminated. The values are given to 8 significant figures and this accuracy is justified. For details of the optical apparatus see Abstr. 4466 (1933).

Mercury and Krypton Isotope Electric Discharge Lamps, their Applications to Interferometry, N. L. HARRIS. Engr v190 n4095 Nov 3 1950 p 409–11 5 figs 5 refs. Discusses increased sharpness of interference fringes; the artificial preparation of Hg[198] isotope; Hg[198] lamps; the use of the Kryton discharge.

Isotope Electric Discharge Lamps as Spectral Sources for the Exact Measurement of Length, R. D. KNOTT. Gen Elec Co. J v18 July 1951 p 169–75. Describes the way in which Hg[198] is made and the factors which affect the sharpness of the spectral lines given by such an isotope. The form of lamp found most suitable for interferometry

is a water-cooled cold cathode lamp with large hollow Mo cylinders as electrodes and A at 10 mm pressure as carrier gas. Lengths up to 20 cm, corresponding to an order of interference of about 350 000, can be measured with such a source. To obtain higher source intensities and minimum line width a water-cooled electrodeless lamp has been developed. Future work includes the development of a Kr 84 lamp, cooled in liquid air to reduce the Doppler broadening effect on the lines.

The Present State of a Lightwave Standard of Length, E. ENGELHARD. "Maintenance of standards" symposium PTB. Feb 1954 p 13–23 6 figs 8 refs. The proposal to establish a lightwave standard of length is reviewed. The basic problem is two-fold; the development of apparatus for the comparison of the lightwave with the metre, and the development of suitable light sources of the chosen standard wavelength. A new interferometric apparatus for the former is described, for the comparison and measurement of end gauges, in which corrections for the refraction of air can be made without the necessity for having the gauges themselves in vacuo. The establishment of a lightwave standard of the required precision and reproducibility is discussed in terms of the causes of line-broadening in spectroscopic sources. In particular, the merits of a source using the isotope Kr^{84} cooled to 63 °K are mentioned.

Spectral Profile and Causes of Broadening of Certain Highly Monochromatic Radiations of Krypton-86, J. TERRIEN, J. HAMON, T. MASUI. CR Acad Sci (Paris) v245 n11 Sept 9 1957 p 960–3 in French. Interferometric measurements were made upon the 5649A and 6056A lines of krypton. They are extremely narrow (~ 0.01A) and do not suffer from self-absorption effects. The 6056A line in particular, which arises from the $2p_{10}$–$5d_5$ transition, is suggested as a new primary standard of length. In comparison with the 6438A line of Cd, its wavelength is: $6057 \cdot 8021 \times 10^{-10}$ m $\pm 0.0001 \times 10^{-10}$m, the error being in the lack of reproducibility of the Cd radiation.

Optical Definition of the Meter, H. BARRELL. Nature (London) v180 Dec 21 1957 p 1387–8. The Comité Consultatif pour la Définition du Metre has recommended that the meter should be defined as equal to 1 650 763.73 times the wavelength in vacuo of the orange—red radiation $2p_{10}$–$5d_5$ of the Kr^{86} atom. The background to this recommendation is explained and it is stated that with a suitable source, the new definition is reproducible to within 3 parts in 10^9.

Interferometric Measurements of Vacuum Wavelengths of Radiations of Hg^{198} **and** Kr^{86}, T. TAKŌ, I MIYASATO, H. NIU, T. KANEKO. Report of the Central Inspection Institute of Weights and Measures, Japan, v17 n1 report 14 1958 in Japanese. The vacuum wavelengths of three radiations of Hg^{198} (0.456, 0.577 and 0.579μ) and three of Kr^{86} (0.565, 0.606, and 0.646μ) were measured in terms of the vacuum wavelength of the red line of Michelson type cadmium lamp, of which value is taken as 0.644024907μ deduced from Edlèn's formula. A Fabry-Perot etalon with a pair of optical glass flats separated by 62.5 mm invarspacer was used in an evacuated enclosure to obtain the interference fringes. The observations of interference patterns were made photographically with the aid of a large dispersion spectrograph. Hg^{198}: The NBS electrodeless Hg^{198} lamp (with 3 mm Hg argon) was excited by high frequency (200 MHz). The discharge column was viewed from the side through the surrounding water jacket and was maintained at temperatures between 0 and 5°C by running water. Kr^{86}: The Engelhard type Kr^{86} hot cathode lamp (with 1~2 mm Hg Kr^{86}) cooled in liquid nitrogen was viewed from the end. The results were reported to Comité Consultatif pour la Definition du Meter on the 23d Sept 1957 and are in good agreement with those of BIPM, PTB, NPL, and NRC.

Standard Wavelengths in the Visible Spectra of Krypton-86 and Mercury–198, J. TERRIEN. CR Acad Sci (Paris) v246 n16 Apr 21 1958 p 2362–4 in French. Measurements of λ5650 A in the krypton spectrum and of λλ5791, 5770, 5461 and 4358 A in the mercury spectrum by comparison with the standard λ6056 A in the krypton spectrum. The uncertainties are less than 1 in 10^8.

Preliminary Measurements of Some Wavelengths of Krypton 86 and Mercury 198 Lines, K. M. BAIRD, D. S. SMITH. J Opt Soc Am v48 n5 May 1958 p 300–1. Vacuum wavelength values for some of the lines in the spectra of Kr^{86} and Hg^{198} have been derived by comparison with a Michelson type Cadmium lamp, by using a 67.5 mm Fabry-Perot etalon as the intermediary. The same lines have been intercompared by means of a Twyman-Green interferometer, referring to the Hg^{198} green line wavelength as 5462.2704A. The half-widths of the lines were also measured.

Interferometric Calibration of Quartz End Standards, E. ENGELHARD. Zeit InstrumKde v67 n3 Mar 1959 p 59–65 in German. A review is given of the interference methods in use in different countries for the testing and preparation of end standards. The definition of the official metre is discussed. It is considered that the uncertainty in the best cases approximates to 0.1μ. It is estimated that a five times smaller uncertainty could be attained by using the red cadmium wavelength as the standard instead of the standard metre. A ten times smaller uncertainty is attainable using Kr^{86}.

Discussion of The Reproducibility of the Wavelength of the $2p_{10}$–$5d_5$ **Emission Line of** Kr^{86}, **the Proposed Standard Unit of Length,** J. TERRIEN. CR Acad Sci (Paris) v248 n15 Apr 13 1959 p 2171–2 in French. The variation of the wavelength of this line with current density and pressure has been investigated. From the results obtained the non-perturbed wavelength can be found by extrapolating the results to zero current density and pressure. It is estimated that the determination of the wavelength can be reproduced to an accuracy better than 2×10^{-9}.

Kr 86 and Hg 198 Wavelength Standards, K. M. BAIRD, D. S. SMITH. Can J Phys v37 n7 July 1959 p 832–40. New values are given for the vacuum wavelengths of six lines Kr^{86} and five lines of Hg^{198} in the visible spectrum. The wavelengths were referred to the Kr^{86} primary standard line, 6057.80211, by a series of very careful measurements over a period of several years. The accuracy with which wavelengths can be compared by present methods is discussed at some length.

Determination of the Wavelength of the $2p_{10}$–$5d_5$ **Line of** Kr^{86} **for Non-Perturbed Atoms,** E. ENGELHARD, J. TERRIEN. Rev Opt (France) v39 n1 Jan 1960 p 11–18 in French. Extrapolations from measurements on Kr^{86} lamps at varying pressure and temperature were used to obtain the wave-number for unperturbed atoms as a function of temperature correct to 3 parts in 10^9. The wave-number is given as 1650763.73±0.004 m^{-1} at zero pressure and 56° K.

Measurements of Half-Widths of Spectral Lines by Means of a Fabry-Perot Interferometer with Photoelectric Recording, Yu. P. EFREMOV. Meas Techn 1959 n10 Aug 1960 p 756–60 2 figs 9 refs. Translated from Izmer Tekh n10 Oct 1959 p 7. Concludes that the lines of the near infrared region of the spectrum of Kr^{86} can be successfully used for interference measurements of length, especially for difference rates exceeding 500 mm in cases when measurements by means of visible lines of the spectrum become difficult or altogether impossible.

World's New Standard for Length, P. A. MCKEOWN. Eng v190 n4930 Oct 14 1960 p 514–5. It was decided at 11th General Conference of Weights and Measures, in session during Oct 1960, that meter is to be redefined in terms of wavelength of light; new definition will almost

certainly be 1 m equals 1,650,763.73 wavelengths of orange-red line radiation in Krypton-86 spectrum (in vacuo); design, and advantages, of photoelectric microscope in measuring are discussed, and new comparator installed at Int Bur Weights and Measures is described.

Kr^{86} and Atomic-Beam-Emitted Hg^{198} Wavelengths, R. L. BARGER, K. G. KESSLER. J Opt Soc Am v51 n8 Aug 1961 p 827–9. The present investigation was undertaken in order to calibrate the Hg^{198} resonance line in terms of the wavelength of the 6057 A line of Kr^{86} as part of the investigation into the problem of redefining the standard of length in terms of a wavelength of light. Vacuum wavelengths are given for the Hg^{198} 2537 and 3132 A lines and the Kr^{86} 6013 and 5651 A lines, referred to the Kr^{86} primary standard line 6057 A. The light sources were an Hg^{198} atomic beam and a Kr^{86} hot-cathode lamp. A vacuum Fabry-Perot interferometer was employed for the measurements. The wavelength of the Hg^{198} 3132 A line was determined by using the Hg^{198} 2537 A line as the reference standard. The accuracy of measurement of the Hg^{198} lines is about a factor of 5 higher than that of Kr^{86} lines.

Primary Standard of Length, K. M. BAIRD, D. S. SMITH. J Opt Soc Am v52 n5 May 1962 p 507–14. The primary standard of length is defined in terms of the unperturbed $2p_{10}$–$5d_5$ radiation of Kr^{86}. This paper reports new measurements of the perturbations due to the conditions of excitation necessary for its practical realization. The results confirm that the present recommendation of the International Committee of Weights and Measures yields the defined standard to an accuracy of better than $1:10^8$ and they indicate how an improvement by about an order of magnitude may be realized by more exact specifications.

Wavenumber Reproducibility of the Radiation $2p_{10}$–$5d_5$ of Krypton 86, C. F. BRUCE, R. M. HILL. Austral J Phys v15 n2 June 1962 p 152–61. The vacuum wavenumber of the radiation $2p_{10}$–$5d_5$ (6056 A) of krypton 86 emitted by a hot cathode Engelhard-type discharge lamp was established for the temperature range $58°$–70 $°K$ and current density range 0–1.0 A/cm^2. Wavenumber relative to the value for the unperturbed state of the radiation were measured with a reliability of 1 part in 10^9 using a photoelectric recording and electromechanical scanning Fabry-Perot interferometer. However, this reproducibility is not possible for different lamps without a more exact specification for the form and operation of the lamp and for the interferometric system used. With the present international specification for the lamp, the reproducibility of this new primary standard of length is better than 1 part in 10^8.

Krypton Lamp for Reproducing the Standard Unit of Length, N. R. BATARCHUKOVA, YU. P. EFREMOV, G. S. POPOV. Meas Techns 1962 n8 Feb 1963 p 636–8 3 figs 4 refs. Translated from Izmer Tekh n8 p 14–6 Aug 1962. Describes a lamp consisting of a discharge tube with vertically placed capillaries, a Dewar flask for cooling the discharge tube, a hermetically sealed chamber made of perspex, and adjustable devices for illuminating the interferometer mounted on a table. Tests showed that there is no displacement on the orange line wavelength as compared with the Engelhard lamp. It is easy to manufacture and completely meets the requirements of the International specification.

The International Length Standard, K. M. BAIRD, L. E. HOWLETT. App Opt (USA) v2 n5 May 1963 p 455–64. Describes the characteristics of the $2p_{10}$–$5d_5$ radiation of Kr^{86} which was adopted in 1960 as the primary standard of length. After a brief history of the development leading to the adoption of this spectral line, its physical characteristics are discussed with a view to showing its merits as a standard. The relative merits of possible alternatives are also considered. It is concluded that the $2p_{10}$–$5d_5$ radiation is superior to any available alternative.

2.3.4. Mercury

Constancy of Wave-Length of a Spectral Line, G. C. OMER, JR., J. L. LAWSON. Astrophys J v84 Nov 1936 p 477–8. The Hg line $\lambda4358$ was observed with Fabry and Perot etalon from June 24 to Aug 27 1935. The wavelength of this line was found to be constant to within 2 parts in 1,000,000.

Possibility of Employment of Hg Lamp as Stable Monochromatic Source, G. BLET. Rev Opt (Theor Instrum) v21 1942 p 65–70 in French. The influence of variations of voltage and frequency on the intensity of the various radiations emitted by a Hg high pressure lamp (type, Philips H.P.–300) are studied, the radiations being isolated by means of filters and measured by Se cells. It is concluded that the lamp can be used as a stable source of monochromatic light but that for the flux to be maintained constant to 0.5% the voltage and frequency must be maintained constant to 0.1%.

Production of Hg^{198} as a Possible Source of an Improved Wavelength Standard, J. H. WIENS. Phys Rev v70 Dec 1 and 15 1946 p 910–4. The green line 5 461 A from any of the even isotopes of Hg is superior, in many respects, to the red line 6 438 A of Cd. Hg^{198} was produced by utilizing the reaction $_{79}Au^{197} + n \rightarrow _{80}Hg^{198} + \beta$ One oz of pure Au sealed into a quartz tube with pure A 4 mm Hg pressure was exposed to stray neutrons from a cyclotron for 10 months; the Hg produced was then distilled into an attached capillary and the spectrum of an h.f. discharge observed with a Fabry-Perot etalon. Hg lines in the correct position for the isotope of mass 198 were observed. The production of larger amounts should present no difficulties.

Light Wave of Artificial Mercury as Ultimate Standard of Length, W. F. MEGGERS. J Opt Soc Am v38 n1 Jan 1948 p 7–14. Efforts to use light as constant, reproducible standard of length traced back to Babinet in 1827; work of Michelson and Morley culminating in use of cadmium red light for accurate determination of meter; improved method resulting from transmutation of Au^{197} to Hg^{198} yielding material for lamps emitting superior standards of length; discussion of lamp characteristics. Bibliography.

The Ultimate Standard of Length, W. F. MEGGERS, NBS. Sci Monthly v68 n1 Jan 1949 p 3–11 7 figs. J Opt Soc Am v38 1948 p7. Suggests recognition of the wavelength in vacuo of the green light of Hg^{198} as the ultimate standard of length.

Possibility of Enhanced Hg^{202} as Source of Monochromatic Light, J. R. McNALLY, JR., P. M. GRIFFIN, L. E. BURKHART. J Opt Soc Am v39 n12 Dec 1949 p 1036–7. Discussion of electromagnetically enhanced Hg^{202} as source material for highly monochromatic radiation; relation to effects of isotopic impurities; Fabry-Perot interference pattern shows line purity in 98.06% Hg^{202}; applicability to production of monochromatic lamps of 5461A wavelength.

Lamps and Wavelengths of Mercury 198, W. F. MEGGERS, F. O. WESTFALL. J Res NBS v44 (RP2091) May 1950 p 447–55 4 figs 25 refs. The production and extraction $_{80}^{198}$ Hg from $_{79}^{197}$ Au bombarded by neutrons is described, and the procedure in making electrodeless lamps with $_{80}^{198}$ Hg is given in detail. These lamps are excited by high-frequency radio waves; they emit the mercury spectrum entirely free from isotope shifts and hyperfine structures that characterize natural mercury. Fabry-Perot interferometers and a prism spectrograph were employed for measuring relative to Cd $6438 \cdot 4696$ angstroms, the wavelengths of the stronger lines in the visible spectrum of $_{80}^{198}$ Hg. Preliminary values for $_{80}^{198}$ Hg radiations in normal air are reported $5790 \cdot 6627$, $5769 \cdot 5984$, $5460 \cdot 7532$, $4358 \cdot 3377$, $4077 \cdot 8383$, and $4046 \cdot 5717$ angstroms, with probable errors not exceeding ± 0.0001 angstrom.

Interference Measurements in the Spectra of Neon and Natural Mercury, K. BURNS, K. B. ADAMS, J. LONGWELL. J Opt Soc Am v40 June 1950 p. 339–44. Accepted Ne standards cover the region 6 929–2 852 A. The first spectrum of Ne has been observed throughout the region 8 919–3 126 A to assist in establishing secondary standards in the part of this range where none exist. The first spectrum of natural Hg was observed from 7 020 to 2 200 A to discover in what part of this range standards of suitable intensity will be available when lines emitted by Hg^{198} have been measured; and to find out which lines (if any) of the natural element may serve as standards when Hg is accidentally or unavoidably present in a low pressure source. It is shown that some lines of natural Hg are suitable for secondary standards, and nearly all may be useful when an accuracy of no more than a part per million is required.

Interferometric Measurements of Wave-Lengths in the Spectrum of Mercury Isotope 198, J. M. BLANK. J Opt Soc Am v49 June 1950 p 345–6. Six lines in the spectrum of Hg^{198} in the range 5 790 to 3 650 A have been measured with Fabry-Perot etalons. The wavelengths obtained were 5 790·6627, 5 769·5984, 5 460·7531, 4 358·3376, 4 046·5715 and 3 650·1569 A. These results are compared with those previously reported.

First Observations on the Metrological Qualities of the Rays Emitted by a Non-isotopic Mercury [Hg^{198}] Produced by Transmutation of Gold; and Comments on the Standard of Length, A PÉRARD, J. TERRIEN. J Phys Radium v11 June 1950 p 249–54 in French. The use of the wavelengths of certain spectra lines as secondary standards of length, and the essential qualities of such lines for that purpose are discussed. The radiation emitted by a Meggers Hg^{198} electrodeless discharge lamp has been examined with a Michelson interferometer and the radiation compared with that of other elements. The lamp used, shown photographically, was excited by an external 100 Mc/s alternating field and was water-cooled. By rotating the lamp it could be viewed either end-on or broadside. The results showed that the lamp should be used at a temperature <30 °C and in the broadside position. The Hg^{198} green and two yellow lines (5 460·7532, 5 769·5984 and 5 790·6330 A) were compared with the red cadmium line (6 438·4696 A). The view is expressed that one of the wavelengths of the spectral lines emitted by say a Kr^{84}, Kr^{86} or Hg^{198} lamp could now be considered by the International Conference on Weights and Measures as a primary standard of length.

Wave-Lengths of Mercury 198, W. F. MEGGERS, K. G. KESSLER. J Opt Soc Am v40 Nov 1950 p 737–41. The wavelengths of 26 visible and U.V. radiations from Hg^{198} have been measured to 8 figures relative to 5460·7532 A, provisionally adopted for the green line. A water-cooled electrodeless lamp containing 2 mg of artificial Hg^{198} served as a light source when excited with radio waves of 100 Mc/s frequency. This lamp illuminated a Fabry-Perot interferometer and a large quartz spectrograph with which the interference patterns were photographed. Measurements of these patterns yielded relative wave-lengths with probable errors usually less than 0·0001 A. In addition to demonstrating that Hg^{198} 5460·7532 A provides a practically perfect primary standard of length, this paper presents preliminary values of 27 superior spectroscopic standards which show that differences among vacuum wave numbers recur within the accuracy of the measurements, and that all the existing dispersion curves for air are incorrect.

The Fundamental Standard of Wavelength, W. F. MEGGERS. Astron J v56 Oct 1951 p 116–8. Lists are given of measures of the red Cd line and, relative to this, of the more accurate and practical artificial Hg^{188} isotope line whose mean λ is found to be 5460·75318±.00006. Applications of the robust Hg^{198} lamp are mentioned, and it

is suggested that this standard should be used in future astrophysical work.

Comparisons of Wave-Length Standards Emitted by Mercury-198 Lamps, H. BARRELL. Proc Roy Soc A v209 Oct 8 1951 p 132–41. The reproducibility of high-quality wavelength standards emitted from water-cooled mercury-198 discharge lamps of the electrodeless and cold-cathode (Geissler) types has been investigated by means of a Fabry-Perot interferometer. These lamps contain a small quantity of the isotope Hg^{198} with argon, as carrier gas, at a nominal pressure of 3 or 5 mm in electrodeless and 10 mm in cold-cathode lamps; electrodeless lamps containing only the isotope and its vapour are also available. Employing for excitation a 100 Mc/s oscillator with electrodeless lamps and a transformer delivering 750 V at 25 mA and 50 c/s with cold-cathode lamps, the wavelengths of six Hg^{198} lines between 4046 and 5791 A, emitted from a sample of each kind of argon-filled lamp, have been measured in terms of the Cd red line at retardations of 5 to 25 cm. These measurements, supplemented by intercomparisons of argon-filled and argon-free electrodeless lamps at a retardation of 20 cm, reveal that Hg^{198} lines are probably subject to an asymmetrical pressure-broadening effect, producing a red shift of about 0·0001 A ($-0·0004$ cm^{-1}) per mm of argon. Wavelength reproducibility among different samples of the same kind of lamp with the same filling is of the order of $\pm 0·00005$ A, or ± 1 part in 10^8, for electrodeless lamps and $\pm 0·0001$ A for cold-cathode lamps.

Atomic Standard of Length. Gen Elec Rev v54 n11 Nov 1951 p 12–3. Note on availability of ultimate standard of length announced by National Bureau of Standards, based upon wavelength of green light emitted by lamp; wavelength, near 21 millionths of inch, is consistently emitted with reproducibility greater than one part in billion; length measurements can readily be made with accuracy of one part in 100 million. From NBS Tech News Bul v35 n3 Mar 1951.

Simple 500 Mc/s Oscillator for Use with Electrodeless Mercury-198 Lamps, A. THULIN. J Sci Instrum v32 n7 July 1955 p 257–8. Mercury-198 discharge tubes for interferometry have restricted life owing to clean-up of mercury, although they can be regenerated by heating; clean-up diminishes rapidly with increasing frequency of excitation; for such excitation, oscillator was developed which is simple, adjustable in frequency from 300 to 500 Mc, and consists of parallel line resonator associated with Philips double tetrode type QQE 06/40.

Excitation of Mercury-198 in a Liquid Nitrogen Cooled Hollow Cathode Lamp, K. M. BAIRD, K. H. HART, J. Opt Soc Am v46 n4 Apr 1956 p 304–5. Reduction in Doppler broadening is investigated qualitatively by comparative tests using a Michelson interferometer. Fringes may be observed for path differences of up to 65 cm.

Fine Measurements, J. R. ADAMS. J Sci Instrum v33 n10 Oct 1956 p 369–75. See abstract under 2.3.1.

Measurement By Photoelectric Fringe Scanning of the Pressure Shift of Hg 198 Emission Lines, K. M. BAIRD, D. S. SMITH. Can J Phys v35 n4 Apr 1957 p 455–61. Photoelectric fringe scanning apparatus has been developed for the measurement of very small wavelength changes (of the order of 5×10^{-6} A). This paper describes its application to a direct measurement of the shift of some of the visible lines of Hg^{198} caused by the presence of the various rare gases used as a carrier. The values found for the shift in wave-number are all of the order of 2×10^{-4} cm^{-1} per mm (Torr) pressure and to the red, except for He, for which it is somewhat less than 1×10^{-4} cm^{-1} per mm and to the blue.

Spectral Profile and Causes of Broadening of Certain Highly Monochromatic Radiations of Mercury-198, J.

TERRIEN, J. HAMON, T. MASUI. CR Acad Sci (Paris) v245 n10 Sept 2 1957 p 926-9 in French. The yellow and green radiations of Hg^{198} from an electrodeless lamp with the external temperature maintained at 2 °C were studied with a Fabry-Perot etalon and by the visibility of two-beam interference fringes with a view to their use as a fundamental standard of length. The half-width of the green line is about 20 mK. Analysis of the visibility curve shows that the Doppler half-width is 16 mK, corresponding to a temperature of 38 °C; the additional broadening is mainly collision broadening and increases with the pressure of the argon carrier gas. If the external temperature of the lamp is allowed to rise, self-absorption is observed. Excellent agreement between the theoretical and calculated visibilities was found for a lamp at 22 °C assuming the effective temperature to be 60 °C.

Interferometric Measurements of Vacuum Wavelengths of Radiations of Hg^{198} and Kr^{86}, T. TAKO, I. MIYASATO, H. NIU, T. KANEKO. Report of the Central Inspection Institute of Weights and Measures, Japan v7 n1 report 14 1958 in Japanese. See abstract under 2.3.3.

Standard Wavelengths in the Visible Spectra of Krypton-86 and Mercury-198, J. TERRIEN. CR Acad Sci (Paris) v246 n16 Apr 21 1958 p 2362-4 in French. See abstract under 2.3.3.

Kr 86 and Hg 198 Wavelength Standards, K. M. BAIRD, D. S. SMITH. Can J Phys v37 n7 July 1959 p 832-40. See abstract under 2.3.3

Preparation of Hg^{198} and Cd^{114} Electrodeless Lamps, T. TAKO. Report of the Central Inspection Institute of Weights and Measures, Japan, v8 n4 report 20 1960 in Japanese. See abstract under 2.3.2.

Wavelength Shifts in Hg^{198} as a Function of Temperature, S. H. EMARA. J Res NBS v65A n6 Nov-Dec 1961 p 473-4. The wavelength shifts for the green (5460 A) and blue (4358 A) lines emitted from an electrodeless discharge lamp of Hg^{198} were studied as a function of the temperature of the water jacket of the source. The values of the wavelength shifts observed for the green and the blue lines are (8.5 ± 3) 10^{-6} A/°C and (2 ± 1) 10^{-6} A/°C, respectively.

Wavelengths, Energy Levels, and Pressure Shifts in Mercury 198, V. KAUFMAN. J Opt Soc Am v52 n8 Aug 1962 p 866-70. The vacuum wavelengths of 27 lines of Hg^{198} and 6 lines of Kr^{86} have been measured relative to the international standard of length, the Kr^{86} line at 6057·80211 A, by photographic Fabry-Perot interferometry. These measurements were made with Hg^{198} electrodeless lamps containing argon at pressures of $\frac{1}{4}$, 3 and 10 mm Hg and a Kr^{86} hot-cathode lamp operated according to the conditions prescribed by the International Conference on Weights and Measures in 1960. Energy-level values have been derived from the wavelengths of each of the Hg^{198} sources, and on the basis of these values, the energy level and wavelength shifts per unit pressure of argon have been calculated. The suitability of the Hg^{198} electrodeless lamp as a source of wavelength standards for interferometric measurement of length and wavelength is discussed.

Measurement of the Isotopic Displacement of Mercury[198], C. CASSIGNOL, R. LENNUIER. J. Phys. (France) v24 n5 May 1963 p 348-9 in French. The profile and isotopic displacement of the Hg^{198} line at 2537 A was observed in absorption using the magnetic sweep method with an Hg^{198} discharge as the source. The transmitted intensity is plotted as a function of the magnetic field and gives a shift of 0.138 cm^{-1}. Using natural mercury in the same apparatus, the displacement for Hg^{198} to Hg^{200} was 0.161 cm^{-1} and for Hg^{200} to Hg^{202} was 0.178 cm^{-1}.

2.3.5. Helium

Über die Verwendung von Heliumlicht zur Messung optischer Konstanten (The Application of Helium Light to Optical Measurements), H. HARTING. Archiv Optik v1 1907 p 97; Zeit für InstrumKde v28 Sept 1908 p 273-5. In spectral measurements the employment of the sodium flame is subject to certain disadvantages, and the use of the helium tube and the bright helium line λ 587.7 is recommended in place of the D line. An interpolation formula is given for the change of refractive index with change of color, and the change of index is calculated for all the glasses given in Schott's catalog; it varies from 5 to 23 in the fifth decimal place.

Further Measurement of Wave Lengths, and Miscellaneous Notes on Fabry and Perot's Apparatus, LORD RAYLEIGH. Phil Mag v15 Apr 1908 p 548-58. In a previous paper the author described a modified Fabry and Perot apparatus and gave some wave-length determinations made with it. In the present paper is described an interference standard with 5 mm invar distance pieces so that the temperature coefficient is as small as possible. The value obtained previously for the Zn line λ 6362.350, is now confirmed, and the wave lengths of the helium lines are now given as 7065.200, 6678.120, 5875.625, 5015.680, 4921.920, 4713.144, and 4471.482. A 30 mm standard is also described with a glass tube having three protuberances at each end as distance piece.

Wave Lengths of the Stronger Lines in the Helium Spectrum, P. W. MERRILL, NBS. Sci Papers NBS n302 June 18 1917 p 159-66 8 refs. Helium spectrum consists of a comparatively small number of lines well distributed from the ultraviolet to the red. Precise measurements of the stronger lines were made.

The Fine Structure of the Helium Arc Spectrum, W. V. HOUSTON. Proc Nat Acad Sci v13 Mar 15 1927 p 91-4 1 fig 6 refs. It has been shown that helium lines have a structure similar to that predicted by Heisenberg. Energy level designations and wavelengths are tabulated. Scheme of energy levels which will produce the observed lines is illustrated.

The Wavelength of the Helium Line 5016Å, G. W. SERIES. J. C. FIELD. NPL Symposium n11, 1959, Interferometry. Stationery Office, London 1960 (Paper 2-4) p 93-107 20 refs. Has obtained the value 5015.6775 ±0.0004Å in standard air. Discusses previous work, experimental details and technique, comparison of the helium and cadmium lines in the hollow cathode source, dispersion of phase change, comparison of the wavelength of the cadmium red line from the hollow cathode source with other standards, gives conclusions. Further results are presented by W. C. MARTIN and J. TERRIEN. Discussion.

New Wavelengths for Some Helium (He I) Lines, W. C. MARTIN. J Opt Soc Am v50 n2 Feb 1960 p 174-6. New vacuum wavelengths for nine lines of He I in the near ultraviolet and visible regions are given. They were obtained by measurement relative to 5462.2707 A and 4359.5625 A of Hg^{198} I with an evacuated Fabry-Perot interferometer. Liquid-nitrogen cooled helium lamps were used. Interference fringes were obtained for the helium line 5017 A with spacers up to 50 mm in length. The wavelength of this line, which was used as a reference wavelength in some previous work on the Rydberg constant, is found to be 5017.0772±0.0003 A(vac.) relative to the stated values for the two standards.

2.3.6. Atomic Beam

Mercury Atomic-Beam Lamp, R. L. BARGER, K. W. MEISSNER. J Opt Soc Am v84 n7 Jan 1958 p 22-7. The construction and operation of a simple atomic-beam source employing natural mercury is described. Lines of great

sharpness are obtained when the emitting beam is viewed perpendicularly to the direction of the flight of the atoms. The Hg[198] component of the line 2537 A is isolated from the other components by proper selection of the interferometer spacer so that is can be compared with the same line of the Hg[198] Meggers lamp. This comparison shows that the atomic-beam line is much sharper and that it is feasible to construct an atomic-beam lamp employing a single even isotope of mercury.

Atomic Beam Sources and the Standard of Length, K. G. KESSLER, R. L. BARGER, W. G. SCHWEITZER. IRE Trans Instrumentation vl–7 n3–4 Dec 1958 p 181–4. Three devices which utilize the wavelength of optical transitions in an atomic beam of mercury as a standard of length are described : (1) a beam of atoms excited by electron impact ; (2) a beam in absorption which utilizes a Michelson interferometer to produce a narrow line in emission ; and (3) a beam in absorption utilized as a narrow band detector. The half-width of the 2537 A line, observed in both emission and absorption, is 0.002 cm^{-1} and is equivalent to a coherence limit of 500 cm. The comparable half-widths for the 5462 A mercury and the 6058 Akrypton lines produced in cooler discharge tubes are 0.018 cm^{-1} and 0.011 cm^{-1}. See also NPL Symposium n11, 1959, interferometry, H.M. Stationery Office, London 1960 (paper 2–3) p 67–91 12 figs 8 refs.

Interference at Great Retardations Obtained with a Calcium Atomic Beam Source, K. W. MEISSNER, V. KAUFMAN. J Opt Soc Am v49 n5 May 1959 p 434–8. By employing a calcium atomic beam source in emission and by using a beam of high collimation very clear Fabry-Perot patterns of the resonance line of calcium, λ4226 A, were obtained with retardations of 60, 78, 94, 108, 120, and 130 cm. The corresponding order numbers are about 1.42, 1.85, 2.22, 2.56, 2.84, and 3.08 million and greatly surpass those obtainable with the best conventional cooled source available at present. The good definition of the fringes obtained with the retardation of 130 cm suggests that the limit of interference is considerably higher.

Calcium Atomic Beam Source and Interference Beyond Two Meter Retardation, K. W. MEISSNER, V. KAUFMAN. J. Opt Soc Am v49 n10 Oct 1959 p 942–3 Fabry-Perot interference patterns of the resonance line of calcium, λ4226 A, have now been obtained at retardations of 153 and 204 cm by employing a highly collimated calcium atomic beam source in emission. The correspondence order numbers are 3.62 and 4.82 million. The appearance of these fringes suggests that the half-width of the line is less than 3×10^{-3} cm^{-1} which is one-fourth that of the proposed primary standard of length and one-tenth that of the present primary standard of wavelength. The use of an atomic beam source for the production of the length standard is discussed.

Correction for Systematic Wavelength Shifts in Atomic Beam Devices, R. L. BARGER, K. G. KESSLER. J Opt Soc Am v50 n4 Apr 1960 p 352–6. Light emitted or absorbed by atoms in an atomic beam is shifted in frequency relative to the frequency for a stationary atom if the light ray is not normal to the trajectory of the atom. The magnitude of this shift is calculated and several devices which correct for this effect are described. For photoelectric recording of interference fringes, complete compensation can be achieved. In the case of photographic recording, it is shown that the residual error is negligible.

Sealed-Off Hg[198] Atomic-Beam Light Source, R. L. BARGER, K. G. KESSLER. J Opt Soc Am v50 n7 July 1960 p 651–6. A sealed-off atomic-beam light source which utilizes the single isotope Hg[198] is described. The emitted 2537 A line was investigated interferometrically with Fabry-Perot interferometers. Interferograms are shown for retardations of 0.4, 1.53, and 2.04 m with order numbers 1.6, 6.0, and 8.1 million, respectively. For each retardation, the theoretical contour of the observed fringes

is shown. Theoretically predicted fringe contours are shown for retardations up to 6 m, the approximate limit of interference. It is concluded from the interferograms that the Hg[198] 2537 A line has a half-width of 0.0016 cm^{-1}, as compared to 0.012 cm^{-1} for the Kr[86] 6056 A line proposed as the new primary standard of length. Owing to the small half-width and the extremely low level of perturbation in the atomic beam, this Hg[198] line would be suitable for the primary standard of length.

Operation and Improvements of a Cesium Beam Standard Having 4-meter Interaction Length, P. KARTASCHOFF. IRE Trans Instrumentation (USA) vI–11 n3–4 Dec 1962 p 224–30. Some factors affecting the accuracy of a long caesium beam standard are discussed and the results of operation over 2 years are given. Increasing the interaction length reduces the linewidth and thus the errors in measuring the line center, as long as the s/n ratio is sufficient. Errors due to nonlinearity of f.m. used in servo locking a crystal oscillator to the resonance are below 1×10^{-11}; other servo errors are smaller. The described variable C-field measuring technique and demagnetizable Armco iron shields reduce errors due to C-field uncertainty to 1.2×10^{-12}. Cavity phase shift effects are below 1.5×10^{-11}. Standard deviation of single measurements with 4.6 sec averaging time is 2.7×10^{-11} under good conditions. Considering all effects, including those of microwave power and of cavity tuning, the stated figure of accuracy is $\pm 3 \times 10^{-11}$, V.l.f. comparisons over 2 years show agreement to about $\pm 10^{-10}$ with respect to US Frequency Standard. 12 figs refs.

2.3.7. Lasers

Resonant Modes in a Maser Interferometer, A. G. FOX, T. LI. Bell System Tech J (USA) v40 n2 Mar 1961 p 453–88. A theoretical study is made of the diffraction electromagnetic waves in Fabry-Perot interferometers when they are used as resonators in optical masers. An electronic digital computer was programmed to compute the electromagnetic field across the mirrors of the interferometer where an initially launched wave is reflected back and forth between the mirrors. It was found that after many reflections a state is reached in which the relative field decays at an exponential rate. This steady-state field distribution is regarded as a normal mode of the interferometer. Many such normal modes are possible depending upon the initial wave distribution. The lowest-order mode, which has the lowest diffraction loss, has a high intensity at the middle of the mirror and rather low intensities at the edges. Therefore, the diffraction loss is much lower than would be predicted for a uniform plane wave. Curves for field distribution and diffraction loss are given for different mirror geometries and different modes. Since each mode has a characteristic loss and phase shift per transit, a uniform plane wave which can be resolved into many modes cannot be resonated in an interferometer. In the usual optical interferometers, the resolution is too poor to resolve the individual mode resonances and the uniform plane wave distribution may be maintained approximately. However, in an oscillating maser, the lowest-order mode should dominate if the mirror spacing is correct for resonance. A confocal spherical system is also investigated and the losses are shown to be orders of magnitude less than for plane mirrors.

Atoms Inside a Perot-Fabry Interferometer, A. KASTLER. App Optics (USA) Supp v1 1962 p 67–74 in French. In the optical masers realized so far a Perot-Fabry device is used as a multimode cavity. It may be interesting to investigate the general properties of such a device when the emitting or the absorbing atoms are put inside the reflecting mirrors. Even in the case when this device works below the threshold of maser action it shows remarkable properties which are worthwhile studying experimentally. The following aspects are considered in

the paper. In the case of external illumination, the distribution of light intensity inside a Perot-Fabry interferometer is calculated. It is shown that the local light intensity in the stationary waves inside can be much higher than the intensity of the incident light beam. The properties of light emitted by atoms inside the Perot-Fabry and emerging from it are investigated. Narrow fringes of very strong intensity can be obtained. If the emitting atoms are located in an atomic beam the central fringe has natural line width, the Doppler broadening being suppressed. The realization of a fluorescent medium of lamellar structure is discussed. This structure favours one special mode of emission fringes. Finally, the absorption of atoms inside the interferometer is studied. It is shown that this device is equivalent to a long absorption path in an ordinary light beam.

Gaseous Optical Maser with External Concave Mirrors, W. W. RIGROD, H. KOGELNIK, D. J. BRANGACCIO, D. R. HERRIOTT. App Optics (USA) Supp v1 1962 p 125–6. A helium-neon optical maser was operated successfully with concave mirrors external to the gas-discharge tube. The latter is sealed at both ends with optically flat windows at the Brewster angle to the beam axis. This arrangement simplifies the tube construction and enhances its versatility. The alignment of concave mirrors is considerably less critical than that of plane mirrors. Measured beat frequencies between several pairs of concave resonator modes agree closely with computed values.

Bibliography on Lasers, P. W. BECKER, S. E. BECKER 1962 51 p. Becker and Warren, Oak Ridge, Tenn.

Optical Properties of a Continuous Helium-Neon Optical Maser, D. R. HERRIOTT. App Optics (USA) Supp v1 1962 p 118–24. A continuous optical maser was operated at five wavelengths in the near infrared. Such a maser oscillator consists of a medium having optical amplification at the wavelength of interest and a Fabry-Perot interferometer as a resonant cavity. The optical amplification is provided by maser action in a discharge through a mixture of helium and neon gas. The Fabry-Perot interferometer is constructed within the gas volume using two very flat, and highly reflecting, parallel silica plates. The transmission of the Fabry-Perot plates, although small, allows a beam to pass through each end window, with four milliwatts of continuous output power in the strongest transition at 1.153μ wavelength. Examination of the beam shows that it is almost diffraction limited for its one-centimeter diameter. The spectral line shape at each transition is made up of three or more components each less than a few hundred cycles in width separated by the spacing of orders in the interferometer.

Optical Properties of a Continuous Helium-Neon Optical Maser, D. R. HERRIOTT. J. Opt Soc Am v52 n1 Jan 1962 p 31–7 15 figs 8 refs. A continuous optical maser was operated at five wavelengths in the near infrared. Consists of a medium having optical amplification at the wavelength of interest and a Fabry-Perot interferometer as a resonant cavity. Fringes have been observed out to a path difference of 48 in.

Gaseous Optical Maser with External Concave Mirrors, W. W. RIGROD, H. KOGELNIK, D. J. BRANGACCIO, D. R. HERRIOTT. J App Phys v33 n2 Feb 1962 p 743–4. Helium-neon optical maser operating with concave mirrors external to gas discharge tube; alignment of concave mirrors is considerably less critical than that of plane mirrors; measured beat frequencies between several pairs of concave resonator modes agree closely with computed values.

Measurement Units Used with Lasers, B. F. LUDOVICI. Electronics v35 n16 Apr 20 1962 p 54 56. Nomograph determines relationships between units that express characteristics of lasers and other optical and infrared devices;

among these units are Angstroms, electron volts, tera-cycles/sec. and wave numbers.

Zeeman Effect in Gaseous Helium-Neon Optical Maser, H. STATZ, R. PAANANEN, G. F. KOSTER. J App Phys v33 n7 July 1962 p 2319–21. Strongest emission in helium-neon gas maser corresponds to transitions between $2s_2$ and $2p_4$ states of neon which have angular momenta of 1 and 2, respectively; these levels split up in a magnetic field and maser output contains differently polarized radiations of slightly different frequencies; interesting effects may be observed when various Zeeman components resonate in different cavity modes of Fabry-Perot interferometer.

Construction of Gaseous Optical Maser Using Brewster Angle Windows, D. J. BRANGACCIO. Rev Sci Instrum v33 n9 Sept 1962 p 921–2. Materials, tools and techniques used to make successful gaseous optical maser; details of gas discharge tube that consists of two optical quality glass windows, held at Brewster angle, mounted in hemispherical bulbs and connected together with quartz tube through appropriate graded seals; other design features.

Frequency Stabilized Lasers, J. LaTOURRETTE, P. RABINOWITZ, G. GOULD. IEEE Nat Aerospace Electronics Conference—Proc 1963 p 99–101. Theoretical advantages of optical heterodyne detection and its experimental verification; application of automatic frequency control (afc) to laser which has successfully traced frequency of 2nd free-running laser; using 10.7 Mc IF, spread in beat-frequency spectrum was plus or minus 3 kc with afc feedback, 100-to-1 improvement over short-term frequency stability without feedback, giving tracking accuracy of plus or minus 1 part in 10^{11} of oscillator frequency; beam splitter makes output of transmitter and local-oscillator lasers spatially coherent, impinging them into photodetector.

Modes in Maser Interferometer With Curved and Tilted Mirrors, A. G. FOX, T. LI. IEEE Proc v51 n1 Jan 1963 p 80–9. Two simple forms of aberrations in Fabry-Perot interferometer are studied; first is represented by tilted plane mirrors and second by curved mirrors; tilting mirror causes mode patterns to become asymmetric and diffraction loss to become greater; in case of interferometers with mirrors of arbitrary radii of curvature, there exist regions of low loss and high loss as mirror spacing is varied; loss function can be represented by contour map of 3-dimensional model; model is useful in choosing proper mirror spacing for low loss operation of optical masers.

Isolation of Axi-Symmetrical Optical-Resonator Modes, W. W. RIGROD. App Phys Letters v2 n3 Feb 1 1963 p 51–3. Photographs of 15 isolated TEM modes of concave mirror interferometer used as external cavity of gaseous He-Ne maser tube with Brewster angle windows; isolation mechanism appears to depend on physical processes in maser medium, rather than on purely optical phenomena.

Lasers, T. R. LAWRENCE, NBS. J Washington Acad Sci v53 Feb 1963 2 figs 13 refs. Discusses atomic processes and coherent light amplification, oscillators using coherent light amplifiers, solid state lasers, gas lasers, research and applications.

Interference Fringes With Long Path Difference Using He-Ne Laser, T. MOROKUMA, K. F. NEFFLEN, T. R. LAWRENCE, T. M. KLUCHER. J Opt Soc Am v53 n3 Mar 1963 p 394–5 3 figs 3 refs. Interference fringes produced by coherent light from a He-Ne gas laser have been observed at optical path difference up to 9 m (mirror separation=4.5 m) on a Michelson interferometer.

Frequency Stability of He-Ne Masers and Measurements of Length, T. S. JASEJA, A. JAVAN, C. H. TOWNES. Phys Rev Letters (USA) v10 n5 Mar 1 1963 p 165–7. Experiments to determine the frequency stability of He-Ne

optical masers under carefully controlled conditions are described; measurements were taken on the laser transition at 1.153μ. The technique of photoelectric mixing between two similar lasers was employed. A frequency stability of about eight parts in 10^{14} and a frequency resettability of 10^8 are claimed. A frequency drift of a few tens of cycles per second was measured. The short term stability is within one order of magnitude of the theoretical limit of the device. This frequency stability is discussed in relation to accurate measurements of length and preliminary measurements, repeating the Michelson-Morley experiment, confirm the Lorentz-Fitzgerald contraction due to the earth's orbital velocity to one part in 10^5.

Optical Maser Frequency Stabilisation and Precise Wavelength Measurements, E. A. BALLIK. Phys Letters (Netherlands) v4 n3 Apr 1963 p 173–6. The output from a photomultiplier, illuminated by maser light travelling via 2 corner reflector mirrors in a Michelson interferometer, is used to control (a) an external "cavity" (the difference in length between the two interferometer paths) or (b) the maser wavelength. The control voltage is obtained by sinusoidal variation of the position of one of the mirrors. Control of the "cavity" to 1 part in 10^8 is possible. Block diagrams are shown of the system as applied to precise measurement of lengths and wavelengths.

Interference Fringes Produced by Superposition of Two Independent Maser Light Beams, G. MAGYAR, L. MANDEL. Nature (GB) v198 Apr 20 1963 p 255–6. The interference of light from two slits has been observed when the slits are illuminated with two ruby lasers, which emit light with a photon degeneracy parameter much greater than unity. The output from each laser is coherent for only about ½ microsecond, and the emission is in the form of random spikes. Photographs showing fringes were obtained by the use of a gated image tube; the interfering beams fell on the photocathode and the grid of the tube was normally biassed off except when two coincident spikes were emitted from the lasers. Photographs of the screen of the image tube occasionally show fringes of the expected spacing and visibility. Fringes are not always obtained because of the variations in frequency from the two lasers due to thermal effects. The observed effects are describable in completely classical terms.

Construction of a Gaseous Optical Maser Using Brewster Angle Windows, K. M. BAIRD, M. J. TAYLOR, R. TURNER. Rev Sci Instrum (USA) v34 n6 June 1963 p 697. A technique is described for sealing the windows to an all-quartz discharge tube for use in an external reflector He-Ne optical maser. The ends of the tube are ground at the Brewster angle and the windows are fused on by localized heating, followed by annealing. No dimensions are given.

Wave-Length Stabilization of Optical Maser, W. R. C. ROWLEY, D. C. WILSON. Nature (London) v200 n4908 Nov 23 1963 p 745–7. Use of 6328 A line of helium-neon maser for interferometric length measurements is hindered because, in spite of its narrow bandwidth at any instant, wavelength of light can vary; simple way of improving wavelength or frequency stability is to adjust length of cavity; servo-control system does it continuously by simple electromechanical coupling.

Sur des interférences avec grande différence de marche obgenues avec un laser à gaz, R. GRUDZINSKI, M. PAILLETTE. CR Acad Sci v257 n25 Dec 16 1963 p 3842–3. Interferences with large differences of modes obtained with gaseous laser; Michelson-type interferometer was constructed for determination of limitations in duration of temporal coherence caused by conditions of practical use of gas laser, i.e., fluctuations of air indices and mechanical vibrations of soil; photographs of fringes presented.

Coherent Light and Abbe's Sine Law, P. W. WEBER. Int Sci and Techno n25 Jan 1964 p 13. Discusses angular spread in the far field for a laser oscillating in a single mode.

A Laser With a Multihole Diaphragm, T. MOROKUMA. J Res NBS v68C n1 Jan–Mar 1964 p 25–34 20 figs 6 refs. The properties of a laser with a multihole diaphragm were both theoretically and experimentally examined. This laser may be called a multibeam laser. Laser action was observed in the optical paths which were defined by the position of the holes and the cavity configuration. Interference fringes were observed on one of the cavity mirrors. A wavelength dependent interaction among the beams was observed. It is believed that the wavelength of a beam can be stabilized by the intensities of the other beams. A possible method will be proposed for the stabilization.

Helium-Neon Laser and its Potentiality for Length Measurement, D. C. WILSON. Machy (London) v104 n2683 Apr 15 1964 p 875–8. Functioning of helium-neon laser is described in simple terms and nature of its light discussed; laser offers considerable advantages over normal light sources for application to precise length measurement.

Lasers for Length Measurement, A. G. McNISH. Science v146 n3641 Oct 9 1964 p 177–82 6 figs 8 refs. Lasers are useful in metrology because of the high coherence and intensity of the light they produce. Discusses the laser principle, measuring with light waves, wavelength of laser light, measurement applications, lasers as length standards.

Laser Interferometer, F. H. LONDON. Instrum Control Syst (USA) v37 n11 Nov 1964 p 87–9. A single-mode laser with special optical and digital techniques has been designed for accurate industrial gaging, termed an absolute interferometric laser (AIL). It is of the double-beam type with a reflector on the travelling part of the machine using a gas laser at 6328 AU; the operating length is 100 in. and accuracy is either 0.00003 in., or 0.0001 in. per ft. The problems involved are stated with their solutions in tabular form. A block diagram and an outline specification are given.

Accurate Length Measurement of Meter Bar With Helium-Neon Laser, K. D. MIELENZ, H. D. COOK, K. E. GILLILLAND, R. B. STEPHENS. Sci v146 n3652 Dec 25 1964 p 1672–3 1 fig 4 refs. A helium-neon gas laser has been successfully used in conjunction with an automatic fringe-counting interferometer to measure the length of a meter bar. The agreement obtained was 7 parts in 100 million with respect to the assigned length of the bar.

2.4. Length and Diameter Measurements

2.4.1. General

Sur la Mesure en Longueurs d'Onde des Dimensions d'un Cube de Quartz de 4 cm de Côté (On the Measurement in Wave-lengths of the Dimensions of a Quartz Cube 4 cm on a Side), C. FABRY, J. M. DE LÉPINAY, A. PEROT. CR Acad Sci v128 1899 p 1317–9. The solid to be measured

is placed between two planes of silvered glass, AA', so that the faces a, a' of the solid are parallel to the planes. Results are accurate to 0.1μ in 4 cm.

Optical Measurements of Thickness, J. M. DE LÉPINAY. CR Acad Sci v134 Apr 21 1902 p 898–900. A differential fringe method is described which obviates the necessity

of knowing the refractive index of the lamina to be measured.

Optical Measurements of Thickness, J. M. DE LÉPINAY, H. BUISSON. CR Acad Sci v135 Aug 4 1902 p 283–6. The method of carrying out the principle given in a former paper is briefly described, and results are given of the measurement of the thickness and refractive index of a plate of quartz, cut parallel to the axes, for the ordinary ray. The method is considered accurate to 0.02–0.01μ for the thickness, and to the sixth decimal place for the refractive index.

Errors of Micrometer Screws, E. KEIL. Zeit für Instrumkde v28 Aug 1908 p 243–5. Determination of micrometer screw errors by mounting them in conjunction with a standard Michelson interferometer.

La Mesure de Petits Étalons Industriels à Faces Planes par une Méthode Interférentielle (Measurement of Small Gages by Interference), A. PÉRARD. CR Acad Sci v154 June 24 1912 p 1798–1800. Small Johansson gages from 5 mm downwards are measured by interference bands formed between glass slabs and the gage surfaces. The errors for 5 mm gages average 0.11μ and for 1 mm gages 0.04μ.

Sur un Procédé Pour la Comparaison et la Mesure en Valeur Absolue des Étalons à Bouts Plans, au Moyen des Interferences Lumineuses (Absolute Measurement of Length Gages by Optical Means), A. PÉRARD. CR Acad Interférences Lumineuses (Absolute Measurement of Sci v170 Feb 16 1920 p 390–2. Describes a method for determining the dimensions of Johansson gages in terms of wave lengths of monochromatic light. It has been shown previously that the interspace between the surfaces of two gages is less than $.02\mu$ and the method of measurement proposed consists in placing the gage to be measured in contact with a plane steel surface of greater area. Upon the other surface of the gage is placed a reference plane of glass. Thus, by suitable arrangements described it is possible to deduce the thickness of the gage. Measurements up to 15 mm are possible.

The Calibration and Dimensional Changes of Precision Gage Blocks, C. G. PETERS, H. S. BOYD. Am Mach v53 Sept 30 and Oct 7 1920 p 627–32 and 674–9 20 figs. Sept. 30 : How planeness and parallelism errors of precision surfaces in gage blocks are determined ; and Oct. 7 : Comparison of gages by means of light waves. Tables and charts showing results of experiments. Force required to separate optically plane surfaces (precision gage blocks). Thickness of oil film on precision gage blocks.

Prüfung von Johansson Endmassen mit Lichtinterferenz (Testing of Johansson End Measures by Light Interference), W. KÖSTERS. Feinmechanik v1 Jan 7 14 21 1922 p 2–5 19–20 39–41.

Interference Methods for Measuring Johansson Blocks, A. PÉRARD. Rev d'Optique v1 May 1922 p 209–31. Interference method consists in placing the block between two parallel plates, the upper one being glass so that a uniform air layer remains between the glass and the upper surface of the block and proceeding as in the usual Fizeau experiment to observe the fringes due to the air layer formed by monochromatic light. By using several kinds of monochromatic illumination, 8 in all, whose values of λ vary from 640.224 mμ to 435.832 mμ, the actual length required is evaluated by certain series formula quoted. An apparatus for comparing 3 blocks set up between the parallel plates is also described and sketched.

Interference Methods for Standardizing and Testing Precision Gage Blocks, C. G. PETERS, H. S. BOYD. Sci Papers NBS n436 May 2 1922 p 677–713 21 figs. Use of interference of light waves makes possible detection of errors within a few millionths of an inch.

Measurement of Primary Standards by the Interferometer Method. Machy (London) v20 May 18 1922 p 189–93 6 figs. Checking gage blocks by NPL comparator : an extremely sensitive mechanical apparatus for testing accuracy of precision slip-gages.

Metodi Attuali per lo Studio dei Calibri Industriali per Mezzo Delle Interferenze Luminose (Present Methods of Testing Industrial Standard Measures by Means of Optical Interferences). Rivista d'Ottica e Meccanica di Precisione v2 Dec 1922 p 60–73 5 figs. Application of optical method to Johansson's standards for extreme precision.

Precise Length Measurements, J. E. SEARS. Roy Soc Arts J v71 Oct 5, 12, 19 1923 p 775–91, 793–818, 819–41. Cantor lectures. Describes in outline the methods used for maintenance of the fundamental standards of length, the yard and the meter, and their mutual comparison. Describes principles underlying the use of wave lengths as absolute units, and determining legal standards in terms of wavelengths. Methods used for comparison of substandards are described in detail, with precautions to eliminate errors. Whole paper forms a useful summary of the theory and practice of length measurements to the highest accuracy attainable at present.

Die Anwendung der Interferenz des Lichtes im Lehrenbau (Application of Interference of Light in the Construction of Gages), G. BERNDT. Deutsche Optische Wochenschrift v10 June 1 8 and 15 1924 p 265–9 and 282–5 302–8 14 figs. Discusses use of light waves as constant length measure and application of its property of interference for testing accuracy of gages ; particulars of Kösters interference comparator.

Interferometers for Calibrating Standards of Length. Eng v118 Oct 3 1924 p 491–2 2 figs. Describes apparatus made by Adam Hilger, Ltd., by which accurate standards of length can be originated ; apparatus was ordered by Japanese Government because meter has been adopted as sole legal standard of length, and authorities wished to have apparatus by which residual error in existing international standard could be accurately measured, and other standards produced. Gives exact method of halving lengths of 20 in., etc.

Ein neuer Interferenzkomparator für unmittelbaren Wellenlängenanschluss (A New Interference Comparator for Directly Measuring by Light Waves), W. KÖSTERS. Zeit für Feinmechanik und Präzision v34 Apr 5 1926 p 55–9 5 figs ; Deutsche Optische Wochenschrift v12 3 figs 5 refs. Describes the Kösters absolute interferometer and auxiliary slide rules.

Über die Längenmessung mit Hilfe der Lichtinterferenz (Measuring Length by Means of Light Interference), Y. VÄISALA. Zeit für Instrumkde Aug 1927 p 398–402 2 figs. Description of quartz-meter apparatus and methods used at the University of Turku, Finland, in measuring a distance of about 24 m with error not exceeding 1 in 10,000,000.

Calibration of an End-Gage Comparator by the Interference Method. Eng v124 Nov 4 1927 p 577 4 figs. Design by J. E. Sears for measurement between flat faces which must be maintained in perfect parallelism.

Measuring Standards of Length With Light, H. SIMON. Eng Progr v9 Oct 1928 p 265–9 10 figs. How reference standards and other parts are measured directly by means of light interference within limits of less than millionth of inch ; new instrument, absolute interference comparator, designed by W. Kösters and built by firm of Carl Zeiss, Jena ; measurements are made by direct comparison with wavelengths of light, yet as rapidly as measuring with such extreme precision will probably ever be ; comparator

or "Inko" is mainly intended to check size blocks and gages of size-block type; light used is derived from helium lamp.

Applications Pratiques des Intérférences Lumineuses, a L'Étude des Calibres Industriels et Autres Longueurs a Bouts (Practical Applications of the Interference of Light, a Study of Industrial Gages and other End Length Standards), A. PÉRARD. Trav et Mém du BIPM v18 1930 85 p 32 figs 4 appendixes. Describes a new industrial interferometer for comparative and absolute measurements. Research on the whole number of the order of interference. Simultaneous determination of several gages. Influence of the quality of surfaces.

Optical Measurement of Thickness. Interference Micrometer, H. KREUSLER. Zeit für techn Physik v13 1932 p 241–3. A wedge-shaped air film of constant length (10 cm) is formed between two glass plates which are in contact at one end and separated at the other by the object whose thickness is required. Parallel interference fringes are obtained when the film is illuminated normally with parallel monochromatic light, and the thickness of the object can be deduced simply from the fringe width, measured by means of a low-power traveling microscope. For thicknesses less than 0.02 mm the accuracy obtainable is about 0.1μ.

Axial Arrangement for the Measurement of Length by the Interference of Light, J. STULLA-GOETZ. Zeit fuer Instrumkde v52 Dec 1932 p 521–4. A Michelson interferometer, illuminated with parallel white light, carries a half-silvered plane-parallel glass plate in one path. The multiple reflections arising in this path enable optical multiplication of length to be performed by a simple process in which the mirror in the other path is used as an auxiliary to increase by 3 times the original separation of the mirrors in the first path, using the central white-light fringe as an indicator.

Interferometer for Testing Gauges, C. F. SMITH. Machy (London) v42 n1082 July 6 1933 p 393–5. Apparatus designed primarily for use in connection with manufacture of silica plates employed in Williams echelon; extreme accuracy required in order that requisite optical effect should be produced made it necessary to design means for testing, and double interferometer developed by F. Twyman and J. H. Dowell enabled this to be done; apparatus suitable for examination and testing of gages.

Note sur la Détermination D'Étalons Millimétriques et Centimétriques en Longueurs D'Onde Lumineuses (Note on the Determination of Millimeter and Centimeter Standards in Wavelengths of Light), J. R. BENOIT, A. PÉRARD. Trav et Mém du BIPM v19 1934 54 p 9 figs. Interferometric comparison of Michelson etalon and small scales. Reduction of observation including correction for the refractive index of air.

Interference-Type Indicator for Precision Micrometer. Eng v148 n3835 July 14 1939 p 57–8. Description of instrument known as Van Keuren light wave micrometer, used in production of numerous types of Galex precision gages, made by G. H. Alexander Machinery, Ltd.

Étude des Étalons en Quartz, Témoins de L'Unité Métrique Internationale. Valeurs. Di'latabilites. Indices. (Study of Quartz Etalons, Embodiment of the International Metric Unit. Values. Expansions. Indices.) A. PÉRARD. Trav et Mém du BIPM v20 1944 176 p 26 figs 13 appendixes. Principles of the methods of measurement by interferometry; instruments; execution of the measurements—calculation of the excess fractions; form and relative position of the end faces; indices of refraction of quartz.

Hilger Gauge-Measuring Interfermoters. Machy (London) v69 n1770 Sept 12 1946 p 340–3; see also British

Patent 555, 672 23 Feb 1942. Operating details of gage comparing interferometer, and gage interferometer for measurement of absolute length, developed by Adam Hilger, Ltd.

Interferometers. Automobile Engr v37 n487 Apr 1947 p 137–8. Illustrated description of Hilger instruments for comparative or absolute measurements in wavelengths of light.

Measurement of Thickness of Infra-Red Absorption Cells. J. H. JAFFE, H. JAFFE. J Opt Soc Am v40 Jan 1950 p 53–4. A new interferometric method is described. An accuracy of 0.2μ is obtained independently of the thickness. The advantages over methods previously described are that the cell plates need not be parallel and the wedge angle between them is determined with the thickness. The thickness measured is not an average value. It is possible to map out the profile of the cell. The method may be used even when the cell plates are very irregular.

Interference Methods for Producing and Calibrating End Standards, C. G. PETERS, W. B. EMERSON. J Res NBS v44 n4 Apr 1950 (RP2089) p 419–42. To compare results of interferometric methods of measurement used at Bureau with those of other national laboratories, etalons of fused quartz were made and calibrated; they were then sent to Bureau International des Poids et Mesures, Physikalisch-Technische Bundesanstalt, and National Physical Laboratory for calibration; lengths of etalons as determined by various laboratories are given. Bibliography.

Interference Method for Measurement of Microscopic Spheres, B. W. WILSON. Austral J App Sci v1 n3 Sept 1950 p 235–41. Measurement of size of glass spheres ranging from 0.5–25 microns in diam; interference method was used, consisting essentially of packing spheres into very shallow wedge shaped cell for size classification and for viewing against background of interference fringes; results given for two types of cell.

Length-Determination, L. E. GLOVER. Aircraft Prod v13 n154 Aug 1951 p 230–3. Principle and application of direct measurement interferometer; instrument designed by National Physical Laboratory and manufactured by Pitter Gauge and Precision Tool Co., requires light of several colors to be available in order to determine any given length and for this purpose, hot cathode cadmium lamp radiation is used to provide red, green, blue and violet colors.

Interferometers for Measurement of Gauges. Engr v192 n4989 Sept 7 1951 p 300–2. Two forms of instrument developed by Hilger and Watts; comparison interferometer used in toolroom for comparative measurements on gages up to 10 in. long and interferometer for measuring absolute length of gages up to 12 in. long; illustrations.

Interferometer for Measuring Slip Gauges, D. C. BARNES, M. J. PUTTOCK. Eng v176 n4585 Dec 11 1953 p 757–9; Engineer v196 n5107 Dec 11 1953 p 763–6; Machy (London) v83 n2143 Dec 11 1953 p 1170–5, 1178; Machine Shop Mag Dec 1953 11 p 5 figs 4 refs. New interferometer, intended for routine measurement of length dimension of high quality slip gages up to 4 in. in terms of light waves, developed by National Physical Laboratory; optical principle.

Use of Light Waves for Controlling the Accuracy of Block Gauges (Gauge Blocks), F. H. ROLT. Hilger and Watts, Ltd. London Jan. 1955 19 p 19 figs. All requirements for flatness, parallelism, surface finish, smoothness of edges of faces, and absolute size lend themselves to checking by interferometry.

On the Principal Errors of Measurement in Schlieren and Interference Methods, H. WOLTER. Ann Phys (Leipzig)

v19 n1-2 1956 p 1-9 in German. The limits of sensitivity are roughly the same for both methods, but the experimental limits of error are higher for schlieren methods. The scatter of the measured values (e.g. of refractive index) is equal to the geometric mean of the limit of sensitivity and the experimental limit of error.

The Measurement of the Thickness of Thin Objects with an Incident-Light Interference Microscope, G. SCHULZ. Naturwissenschaften v43 n2 1956 p 31-2 in German. A description is given of a Michelson-type interferometer with a microscope object in the aperture which enables the thickness of opaque thin bodies to be measured. In essence the arrangement measures the location successively of the planes from the front and back of the object with respect to a reference mirror in the Michelson interferometer system. The separation between the front and back surface is thus secured even for completely opaque bodies.

On the Interferometric Measurement of Length with a Photoelectric Method of Observation, J. TERRIEN, J. HAMON. CR Acad Sci (Paris) v243 n9 Aug 13 1956 p 740-2 in French. The real image of the interference rings formed at infinity in a Michelson interferometer is focused on an aperture behind which there is a photoelectric cell. By adjusting a compensating plane, the phase of the centre of the ring pattern may be set to a standard value and thus lengths may be measured in terms of light wavelengths. The method is more sensitive than visual or photographic measurements and with it a number of systematic errors should be avoided; it has been checked by re-determining certain wavelengths in the Hg198 spectrum in terms of that of the green line 5461 A, the results agreeing to $\pm 1 \times 10^{-8} \mu$.

Measurement of a Profile in Coherent Light, J. C. VIÉNOT. Rev Opt v35 n10 Oct 1956 p 517-25 in French. The measurement of the diameter of a small object, such as a thread, is difficult with incoherent light because of the out of focus images of the third dimension. The diameter can be measured more precisely from the diffraction fringes formed with coherent light. Conditions are obtained for best definition and most accurate measurement. Sample results are quoted.

Modified Method of Fizeau Fringes for Thickness Measurements, H. OSTERBERG, D. LaMARRE. J Opt Soc Am v 46 n10 Oct 1956 p 777-8. The exit slit of a monochromator is focused upon a pinhole located in the first focal plane of an objective utilized for viewing the multiple-beam fringes formed by interreflections between two inclined surfaces, one of which is stepped. The step is focused into the plane of an eyepiece whose reticule contains a pair of parallel lines between which successive fringes are set and measured by rotation of the wavelength drum. The preferred, and possibly novel, method of interpreting the observations is discussed.

Precision Measurement, I. C. GARDNER. Ordnance v41 n222 May–June 1957 p 1099–1100. Reports good progress in producing an interferometric system which gives a precision of 10^{-7} in. as a standard for measuring gage blocks.

New Techniques in Interferometric Metrology at the National Research Council of Canada, K. M. BAIRD. J Phys Radium v19 n3 Mar 1958 p 384-9 in French. Deals with some of the new techniques which are being used to assist in the redefinition of the international meter. The first of these is a method of cyclical scanning of the interference fringes formed by the Fabry-Perot etalon. The scanning is done by pressure changes in the atmosphere surrounding the etalon. This method has been applied to the measurement of small wavelength shifts. A modification of this technique, using a photographic record, enables a great many spectral lines to be recorded simultaneously. An interferometer, based on Michelson's type,

makes use of a technique whereby precise determination of the order of interference can be made conveniently; it enables line standards of length to be calibrated as easily as end standards.

New Gauge Interferometer, P. HARIHARAN, D. SEN. J Opt Soc Am v49 n3 Mar 1959 p 232-4. An interferometer for the absolute measurement of the length of end standards is described in which the optical path difference introduced between the interfering beams is only half the length of the gage. This permits the direct measurement of gage blocks up to 1 m long with the isotope sources currently available. Other advantages of the instrument are its relatively compact layout and simplicity of operation.

Application of Interferometry to the Routine Measurement of Block Gauges, S. P. POOLE, J. H. DOWELL, NPL. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 405-19 8 figs 2 refs. An interferometer designed at NPL in 1937 deals with twenty gages in one operation. Methods employed are given with a brief survey of sources of error. Interferometer is illustrated with details of improvements.

Introduction to Interferometry, T. J. O'DONNELL. Am Mach/Metalworking Mfg v104 n12 June 13 1960 p 123-46. How interferometers can be used in shop to measure and compare lengths, angles, parallelism, and surface condition.

Interferometric Instrument for the Rapid Measurement of Small Diameters, D. H. BLACKBURN. Rev Sci Instrum (USA) v32 n2 Feb 1961 p 137-9. The test fibre is placed between two optically flat surfaces and, using the fibre as a fulcrum, the upper flat is adjusted until the surfaces are parallel; the absence of interference fringes between the surfaces is used to indicate parallelism. Controlled tilting of the upper flat is obtained by adjusting, with a micrometer screw, a sliding wedge under a lever attached to the upper flat. The fibre diameter is a linear function of wedge position as indicated by micrometer screw setting.

Spectrophotometric Studies on Inorganic Crystals. II. Measurement of Thickness of Thin Crystals by Interferometry, Y. KONDO. Sci of Light Japan v10 n3 Dec 1961 p 167–75. Two-beam and multiple-beam interference methods are applied to the measurement of thickness of some inorganic monocrystals and the advantages of the two methods are compared with each other. Although the multiple-beam method has greater accuracy than the two-beam one, the latter is more suitable than the former for microspectrophotometry of rather thick and coloured crystals. Use of monochromatic light from a monochromator is advisable, for continuous varying of wavelength simplifies the measurement. In some instances, use of continuous variation of refractive index of medium is advantageous. The relation between interference fringes due to monochromatic light is experimentally investigated.

Certain Changes in the Regulations for Checking and Using Block Gauges, L. K. KAYAK. Meas Techn 1961 n6 Dec 1961 p 427–31 1 fig 4 refs. Translated from Izmer Tekh n6 p 1–5 June 1961. Evaluates measurement errors of interferometric methods of measuring gage blocks.

Causes of Errors in Interference Metrology, M. CONSTANS. Rev Opt (France) v40 n12 Dec 1961 p 601–48 in French. The universal use of interference methods in aerodynamics makes evident the need for a systematic study of the errors associated with such methods. These errors are classified into four different types: (1) errors due to the refraction, i.e. to the curvature of the rays owing to the refractive index gradient; (2) errors altering the gradients themselves (draught, vibrations, change in temperature . . .) ; (3) errors due to the instrument itself and to the adjustment conditions; (4) errors due to the

interpretation of results. The first errors due to refraction are theoretically studied for a two-dimensional medium where the refractive index is varied continuously. The calculation was carried out in the second order approximation. Two types of errors may occur ; (a) errors affecting all real objects placed into the jet or up-stream ; (b) errors affecting only the interferogram fringes. It is shown that the last ones can be cancelled out, provided that the focusing plane is situated at the second third down-stream of the jet. Formulae for an evaluation and correction of errors are given. The values obtained are compared with the accuracy yielded by the measuring instrument. It is concluded that those errors are very often negligible both in interferometry and in strioscopy. For the experimental checking, the gradients are obtained by diffusion of a hyposulphite crystal into distilled water or by diffusion of a concentrated solution of hyposulphite salt into distilled water. The results obtained concern a zero incidence angle : (1) The errors affecting the interferograms appear to be very small as compared with those resulting from the instrument imperfections, wherever the focusing plane may be inside the jet and whatever the thickness of the jet may be (100 or 10 mm), provided the gradients remain smaller than 5×10^{-5} mm^{-1}. The formulae giving the deformation of a real object are checked for several positions of the object and for several gradient values. Very often the checking corresponds to an accuracy of about 6 or 8%. It is always better than 15%. Errors not resulting from refraction are studied experimentally : the equipment described makes it possible to get rid of them. It consists of a horizontal Mach-Zehnder interferometer realized in silica. Over the whole field (60 x 60 mm) the residual defect is smaller than $\lambda/13$. By an isothermal jacket the temperature is kept constant to better than 0.03°C in the course of 12 hours. Vibrations are eliminated by means of an elastic suspension.

A Method of Measuring Very Small Optical Paths, A. MARÉCHAL, O. DUPUY, M. RENAULT. Optica Acta (Int) v9 n1 Jan 1962 p 47–54 in French. Describes a method, derived from the three-slit method of Zernike, which permits the measurement of differences of optical path length of the order of 10 A, while giving a much higher luminous flux than the original method. It can be used, for example, for the measurement of phase plates, of very small refractive index differences (in glass, liquids or gases) and it can be used on very small samples.

Interferometry in Length Measurement, J. L. GOLDBERG, R. H. BROCKMAN. Electronic Technol v39 n4 5 6 Apr 1962 p 140–4, May p 186–91, June p 238–43. Electronic counting of interference fringes enables automatic and accurate measurement to be made ; problem of extracting useful signal from moving 2-beam interference fringe pattern is discussed ; circuit for amplification of small photoelectric currents encountered in transduction of light output of interferometer by photomultiplier, and subsequent generation of counting waveform by trigger circuit ; application of circuit to reversible counting.

Inspection Time Slashed on Parts Adaptable to Coordinate Measuring Techniques, C. H. WICK. Machy (NY) v69 n2 Oct 1962 p 107–9. Inspection time was reduced by about 80% (on applicable parts) and quality control greatly improved by means of Sheffield-Ferranti coordinate measuring machine at Plymouth (Mich) Div of Burroughs Corp ; hole and surface locations can be quickly and accurately measured on this machine, with dimensions of both X and Y coordinates being displayed simultaneously on direct readout panel ; lengthy and laborious bench checks with gage blocks, surface plates, and height gages are no longer required.

Methods of Narrowing Spectral Lines for Interference Measurements of Length, A. P. KIRICHENKO. Uspekhi fiz Nauk (USSR) v78 n3 Nov 1962 p 525–38 in Russian.

English translation in : Soviet Physics-Uspekhi (USA) v5 n6 p 998–1005 May–June 1963. A detailed review is given of some methods employed for the production of strictly monochromatic radiation having breadth smaller than the Doppler breadth. The methods described are interference monochromatization using a spherical Fabry-Perot etalon, absorption monochromatization in which radiation is transmitted between two close-lying absorption lines produced by Zeeman splitting and an interference-compensation optical scheme. Laser techniques are only briefly mentioned.

Application of Microwave Techniques to Noncontact Precision Measurement, D. H. PARKES. ASME–Paper 63–WA–346 for meeting Nov 17–22 1963 5 p. Developments in application of microwave interferometry in cases where standard gaging equipment is limited either by contact characteristics, or frequency response, or peculiarities of material or gaging situation.

Method for Precise Evaluation of Interferograms, G. D. DEW. J Sci Instrum v41 n3 Mar 1964 p 160–2. Photoelectric scanning device is described, capable of evaluating interferograms of 2-beam interference systems to 1/100 fringe or better ; precision is attained with barest minimum of equipment.

Fringe Pattern of Oscillating Fabry-Perot Interferometer, K. D. MIELENZ. J Res NBS Eng & Instrum v68C n2 Apr–June 1964 p 73–81. Experiments and theory of dependence of fringe pattern upon vibration amplitude ; if fringes of stationary interferometer are wide, fringe pattern tends to disappear at certain values of amplitude ; if stationary fringes are narrow, splitting of fringes occurs at certain amplitudes ; in both cases, stationary pattern reappears, with reduced contrast, at intermediate amplitudes ; applicability for measurement of vibration amplitudes is discussed.

Measurement of Fringe Displacement in a Gauge Interferometer, M. J. PUTTOCK. J Sci Instrum (GB) v42 n4 Apr 1965 p 298–9. A description is given of a second device for the measurement of fringe displacements in a gauge interferometer. This device is located in the parallel beam of the interferometer whereas the original device was located in a plane conjugate with the lapped surface of the baseplate.

2.4.2. Fringe Count Interferometers and Dilatometers

Über die Ausdehnung starrer Körper durch die Wärme (Regarding the Expansion of Rigid Bodies by Heat), H. FIZEAU. Ann der Phys v128 Oct 3 1866 p 564–89. Includes a brief review of the methods of observation applying fringe count methods. These had been previously described in CR Acad Sci May 1864 and Ann Chim Phys Ser IV T II v123 p 515.

Millimeter and Centimeter Standards, R. BENOIT. Bul Soc Franc Phys n97 1897 p 2–3. Standards, by the Bureau International des Poids et Mesures are described, on the principle of measuring displacements by the travel of circular fringes in a Michelson's refractometer, taking the four cadmium radiations simultaneously ; absolute coincidence of the limit of the standard with the plane of reference in the instrument being indicated by certain characteristic fringes.

Interferential Calibration of Screws, M. HAMY. CR Acad Sci 126 1898 p 1772–4. A plane mirror, thickly silvered, is placed on the carriage of a micrometer or dividing engine, and opposite to it, but attached to the micrometer screw, is placed a lens of very slight curvature, the side nearest the plane mirror being half silvered. Circular interference fringes are seen and screw is calibrated by

determining variation in number of bands produced as lens is advanced.

Application des Phénomenes d'Interférence a des Déterminations Métrologiques (Determinations of Length by Interference), R. BENOIT. J Phys v7 1898 p 57–68. Arrangement used by Michelson to express the length of the meter in terms of wave-lengths of cadmium radiation is used by Benoit for standardizing mm and cm.

A Compensated Interference Dilatometer, A. E. TUTTON. Phil Trans Roy Soc A v191 1898 p 313–64. A form of Fizeau interference dilatometer of increased sensitiveness. Illuminating and observing apparatus is described, p 324–32.

Extensometers, Calibration of an Interference Apparatus for the Calibration of Extensometers, J. MORROW, E. L. WATKIN. Phys Soc Proc v19 April 1905 p 365–70 2 figs; Phil Mag v9 Jan 1905 p 129–35 2 figs. An interference apparatus is described by which extensometers may be accurately calibrated. Specimen tests are given.

Interference Extensometer, E. GRUNEISEN. Zeit InstrumKde v27 Feb 1907 p 38–51. Communication from the Phys. Tech. Reichsanstalt. Describes, with illustrations, an instrument by which elastic extension of test pieces of metals is measured, using the principle of Haidinger's rings. The elastic modulus is given for about 25 various metals and alloys, together with the chemical composition and density, and modulus as observed by transverse vibrations, and in a few cases the modulus found by longitudinal vibrations.

A Wave-Length Comparator for Standards of Length: An Instrument for Fine Measurement in Wave-Lengths of Light. With an Appendix on the Use of Wave-Length Rulings as Defining Lines on Standards of Length, A. E. H. TUTTON. Phil Trans Roy Soc A v210 1910 p 1–34 13 figs. Interference comparator constructed for the Standards Dept. of the Board of Trade. Microscope cross-hairs are set on graduations. Differences are measured by counting interference bands as screw is turned.

Interferential Contact Lever Experiments Relating to the Elastics of Small Bodies, C. BARUS. Proc Nat Acad Sci v5 Feb 1919 p 44–9 9 figs. Apparatus designed by writer in which interferential contact lever measures strain corresponding to stress imparted by pushing springs.

The Use of the Interferometer in the Measurement of Small Dilatations or Differential Dilatations, C. G. PETERS. J Washington Acad Sci v9 May 19 1919 p 281–4. Equations for determining changes in length observable with dilatometer originated by Fizeau. An improved form of Fizeau's interferometer consists of three coned pins, 4 mm across the base, 10 mm long. Three conical holes 0.5 mm diam., 0.2 mm deep, 15 mm apart are drilled in the lower surface of the cover-glass plate. The pins rest on the lower glass plate. These holes keep the pins in place and stop any creep of the cover glass, and also serve as reference marks in determinations of the change of length of the pins. The fringes formed by interference are viewed by a Pulfrich interferometer. Simple theory given and uses for small samples.

A New Interferential Dilatometer, I. G. PRIEST. Sci Papers NBS v15 Feb 28 1920 p 667–78 2 figs. Apparatus is designed to measure small changes in length by "change in width" of interference fringes, instead of measuring them by displacement of fringes. The substance whose thermal expansibility is required is used as a pillar to support a glass pillar. The other side of the plate is supported by some standard substance, such as glass, quartz, or metal, of known expansibility.

A Universal Interferometer, A. E. H. TUTTON. Roy Soc Proc v104 Aug 1 1923 p 47–62 6 figs. Describes apparatus constructed for author by Troughton & Simms for measurement of small amounts of motion, slight deformations, short distances, and minute objects, of any nature whatsoever. Instrument provides steadiness and perfect control of the movement of the interference bands obtained. The interval between two interference bands is readily divisible into 0.01 parts by a micrometer.

An Optical Method of Measuring Small Vibrations, H. A. THOMAS, G. W. WARREN. Phil Mag v5 May 1928 p 1125–30. An interferometer method of measuring small mechanical vibrations is described and its application to the measurement of the vibration of a stiff reed is considered.

Interferometer for the Investigation of the Processes of Growth, K. W. MEISSNER. Phys Zeit v30 Dec 15 1929 p 965–71. Paper read before the Deut. Physikertag, Prague, Sept 1929. An interferometer of the Michelson type is described having the following features : (1) Instead of the usual horizontal mounting the movement is vertical. (2) The one interferometer mirror is movable horizontally by means of a slot and screw, while the second may be moved vertically or by a sensitive Roberval balance arrangement so that it may be moved by very small forces (20–40 mgm. weight), such as those involved in plant physiological problems. (3) In place of the plane interferometer mirror a combination of curved mirrors (concave and convex) with a plane mirror is employed. The interference fringes are then concentric Newton's rings. By simple adjustment straight line interference bands may be obtained. (4) With the help of an auxiliary scale achromatic interference fringes may easily be obtained, so that an objective demonstration by projection with white light is easily possible.

Quelques Études Particulières au Dilatomètre Fizeau (Some Special Studies in Dilatometry), A. PÉRARD. Trav et mem BIPM v19 1932 127 p 17 figs. Contents : Introduction ; Principles of the Fizeau dilatometer (and illustrated description) ; execution of the experiments for the determination of those due to the tripod ; determination of the relative expansions of the prototype meters ; refractive index of air ; tables of observations and calculations.

Amplifying Lever for Measurement of Small Displacements, G. A. FINK, G. W. FOX. Rev Sci Instrum v4 May 1933 p 276–9. System used for measuring piezo-electric deformations of quartz and tourmaline plates, involving use of interference fringes. Arm ratio is 1864 to 1.

Der Interferenzmessapparat als Hifsmittel der Keramischen Forschung (The Interference Measuring Apparatus as an Aid in Ceramic Research), H. LEHMAN, M. T. SCHULZE. Zeiss Nachr n10 Jan 1936 p 6–13 6 figs. Contains description of Pulfrich viewing device. Contents : The principle of the Fizeau method ; optical path and arrangement of the viewing apparatus ; heating arrangement ; measuring process ; test pieces ; computation of air layer thickness.

New Type of Interferometer, A. HOYT. J Opt Soc Am June 1936 p 262–6. A description is given of an extremely simple interferometer which is easy to construct and adjust. It is admirably suited to the measurement of small displacements. It can be adjusted and used with either monochromatic or white light. Each of the small, light mirrors used needs only one optical surface. The sensitivity can be increased by using multiple reflections without unnecessary loss of intensity, since the surfaces are all fully aluminised. Tests on the interferometer have shown that it is capable of detecting displacements of $\lambda/2n$ where λ is the average wave-length of the light used and n is the number of reflections from the moving mirror (nearly normal incidence). Under best (easily attainable) conditions 14 reflections can be obtained, whence a shift of 1 fringe would correspond to $\lambda/28$. Extreme

care in the preparation of optical parts might yield 20 reflections and a displacement sensitivity of $\lambda/40$ for each fringe shift. A compound multiple reflection interferometer is also described which gives twice the sensitivity mentioned above.

Improved Interferometric Procedure with Application to Expansion Measurements, J. B. SAUNDERS. J Res NBS v23 July 1939 p 179–95. The Fizeau interferometric method, as applied to thermal expansion measurements, has been studied in order to determine the source of some very serious errors and to find means of reducing such errors. Two types of errors were found to predominate. These may be termed (1) error caused by tilting of the spacers under mechanical forces, and (2) error caused by variations in air-film thickness at the contact points. Such errors often amount to 10% and may, under certain conditions, exceed in magnitude 50% of the value sought. In this paper the two types of errors are considered in detail, and a modified procedure is given whereby the errors are reduced to a magnitude comparable to other unavoidable errors, such as those in reading the fringes and in determining the actual temperature of the specimen.

Characteristics of Tuckerman Strain Gage, B. L. WILSON. ASTM Preprint n94 for meeting June 26–30 1944 10 p. By means of interferometric calibration device used at National Bureau of Standards for calibrating gages and autocollimators, experimental results are secured which indicate variations of calibration factor with different conditions of use ; description of autocollimator and strain gage ; calibration device ; behavior of gage.

Interferometer Measurements on the Expansion of Iron, J. B. SAUNDERS, J Res NBS v38 Aug 1944 p 75–86. Several sets of data, taken on relatively pure Fe by different observers and different procedures, are compared. The results show agreement between data taken with those interferometer methods that are free from tilting of spacers and air-film errors, whereas the failure to eliminate these two errors produces data that cannot be duplicated except by chance. The interferometer data that are free from these errors agree with data obtained by other precision methods. Some investigators claim to have found indications of a characteristic temperature effect in the expansivity curve of iron in the temperature range from 0° to 250° C. When the expansion data are freed from errors of tilting and changes in air films, the indications of such effects do not appear.

Apparatus for Photographing Interference Phenomena, J. B. SAUNDERS. J Res NBS v3 n35 Sept 1945 (RP 1668) p 157–86, 4 supp plates. Description of photographic instrument designed for recording changes produced in order of interference fringes over long periods and for recording large changes in order of interference ; when this instrument is used with interferometric system for studying changes caused in transparent solids by heating, it can be made to yield continuous record of simultaneous changes in temperature, time, index, strain, and density. Bibliography.

Optical Method of Determining Thickness of Geiger Tube Windows. F. W. BROWN III, A. B. WILLOUGHBY, Rev Sci Instrum v19 Nov 1948 p 820–1. The banded spectrum of white light formed by reflection from the mica window with an angle of incidence (r) of 10°, is compared in a direct-vision pocket spectroscope with the Hg spectrum (of white fluorescent light) and the number (n) of interference fringes between the yellow ($\lambda_1 = 577$ mμ) and blue ($\lambda_2 = 436$ mμ) Hg lines is counted. Then the surface density of the window,

$$W = \left[\frac{p\lambda_1\lambda_2 10^{-4}}{2\mu \cos r (\lambda_1 - \lambda_2)} \right] n$$

$n = 0.163 \, n$ m/cm², where p = density of mica (2.85 g/cm³), μ = index of refraction (1.58).

Multiple-beam Interferometry, S. TOLANSKY. Endeavour v9 Oct 1950 p 196–202. An account is given of the application of multiple-beam interferometry to the study of metals, surface polish, hardness testing, and formation of slipbands in stressed metallic crystals. The technique is also used in studying the mechanism of crystal growth in certain minerals, the hardness anisotropy of diamond undergoing abrasion test, and the modes of oscillation of quartz. A new method of obtaining sharp fringes and the adaptation of an older method for examining defects in mica are described.

A Photoelectric Interferometer for Measurement of Dimensional Changes, R. N. WORK. NBS Tech Rept n5 Oct 30 1950 5 figs 8 refs. Several applications are cited.

Photoelectric Recording Interferometer for Measurement of Dimensional Changes, R. N. WORK. J Res NBS v47 n2 Aug 1951 (RP2230) p 80–6. Method for recording of light intensity at reference point in image of interference pattern for automatic plotting of fringe count vs. thermocouple electromotive force in interferometric dilatometry ; application of technique to measurement of coefficients of expansion and to determination of transition temperature of coefficients of expansion and to determination of transition temperatures in rubber-like materials.

Wavelength or Length Measurement by Reversible Fringe Counting, E. R. PECK, S. W. OBETZ. J Opt Soc Am v43 n6 June 1953 p 505–9. Optical and electronic methods for reversible counting of fringes from corner-cube or Michelson interferometer ; counter operates in either direction at least as fast as 1000 per sec.

Electronic Location of Interference Fringes, J. PETERS, G. STROKE. J Opt Soc Am v43 Aug 1953 p 668–72. A device is described which determines a zero reference position in terms of interference fringes and measures any shift to a small fraction of a fringe. It can be used with static or slowly moving fringes, and is based on the principle of superposition of two images of the fringe pattern in polarized light on the single slit of a photomultiplier tube. By means of a rotating Polaroid as optical shutter an alternating signal is produced of which the amplitude and phase are a function of the displacement.

A Bidirectional Electronic Counter for Use in Optical Interferometry, F. H. BRANIN, JR. J Opt Soc Am v43 Oct 1953 p 839–48. A bidirectional electronic counter has been developed for both additive and subtractive counting of electrical impulses in either binary or decimal notation. Using two coherent syncopated sine-wave input signals, such as may be derived from a Twyman-Green interferometer with a stepped mirror and two phototubes, direction sensing is obtained by pulse forming and selecting circuits which feed pulses to either the "add" or "subtract" channel, depending on the phase relation between the two input signals. In the binary counting circuit, the add and subtract channels each operate separate coincidence amplifiers which select the proper phase for transferring the trigger pulses from one binary stage to the next. In the decimal counting circuit, which consists of binary stage followed by a reversible ring-of-five additional coincidence amplifiers determine the direction in which the trigger pulses transfer the count around the ring. Counting rates in excess of 150 kc have been achieved with both circuits and higher rates are possible with proper design. Although the best directional counting circuit was designed primarily for the purpose of eliminating the tedium of counting interference fringes visually, it can also be used for differential counting with two separate (incoherent) pulse inputs. A review of contemporary development in this field is given, along with a discussion on applications of the circuit in interferometry and analogue-to-digital conversion devices.

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Electronic Fringe Interpolator for an Optical Interferometer, R. D. HUNTOON, A. WEISS, W. SMITH. J Opt Soc Am v44 n4 Apr 1954 p 264–9. Electronic fringe counter for use with interferometers; provisions for automatic counting of integral fringes, interpolation to within 1/200 wavelength, and indication of motion direction of interferometer plates.

An Optical Dilatometer, J. TERPSTRA. App Sci Res B v4 n6 1955 p 434–46. An instrument is described which enables displacements of 2×10^{-6} cm to be determined by means of interference phenomena of monochromatic light. The measuring pin is pushed against the specimen with a force of 4000 dynes. The instrument setting remains stable for a period of several hours.

Interferometric Control of Grating Ruling with Continuous Carriage Advance, G. R. HARRISON, G. W. STROKE. J Opt Soc Am v45 n2 Feb 1955 p 112–21. Control method for manufacture of optical gratings; phase of low frequency a-c signal produced by interference fringes passing across photoelectric pickup is continuously compared with that of standard signal indicating periodic diamond motion involved in ruling stroke; blank positioning is controlled within $\frac{1}{40}$ of fringe.

A Machine for Measuring Interference Fringes, Y. GRIMOD. Rev. Opt v34 n10 Oct 1955 p 509–11 in French. An automatic photoelectric device is described which computes the positions of interference fringes automatically, by means of a photocell. The fringes are then counted on an automatic computing machine. The system has a capacity for counting up to lengths of 100 mm.

Fractional-Fringe Measurements with Corner-Cube Interferometer, E. R. PECK. J Opt Soc Am v45 n10 Oct 1955 p 795–7. Extension of fringe counting by interpolation to about 0.01 fringe; photoelectric method for providing reference reading of position of interferometer carriage to same accuracy as that of interpolation.

An Interference Comparator for Evaluating the Difference Between End-Standards, M. DUHMKE. Zeit Instrumkde v65 n1 Jan 1957 p 5–17 in German. By employing a difference method against a standard, lengths of slip-gauges (up to 100 mm) can be evaluated to within 0.01μ. The method described enhances the Fizeau-fringe sharpness by multiple reflection.

Plucking Millionths Out of Thin Air, J. RITCHIE. Tooling & Prod v22 n12 Mar 1957 p 83–7. Fringe count micrometer described employs interferometry in combination with electronic digital counting; instrument is intended to further extend lineal measurement accuracy by referencing dimensions to wavelength of light; gage blocks or other secondary standards are not needed to set up or calibrate instrument as built-in light source is itself standard.

An Algebraic Electronic Counter for Interference Fringes, G. RUFFINO. R. C. Accad. Naz. Lincei v22 v5 May 1957 p 602–5 in Italian. A simple direction-sensitive counter is described, using dekatron tubes to give an immediate display of the fringe count. Details of the electronic circuit are given.

Photoelectric Fringe Signal Information and Range in Interferometers With Moving Mirrors, G. W. STROKE. J Opt Soc Am v47 n12 Dec 1957 p 1097-103. Photoelectric receptors and electronics have greatly increased the accuracy and simplicity of interferometric measurements. Theoretical and experimental investigation of instrumental and light source conditions required to ensure adequate information content and "visibility" of fringe signals were made. Mirror parallelism requirements needed to maintain maximum signal modulation and to reduce apparent local displacement errors, for use with equal inclination interferometers, are expressed by the fractional number of equal thickness fringes within the

mirror traverse being reducible by decreasing this aperture and ensuring best local parallelism. The "effective" length per fringe, determined by photoelectric flux integration over an angular range within the source angular radius a, is approximately $(\lambda/n)2(1-a_s^2/4)$. Theoretical expressions obtained for the fringe "visibility" with simple single isotope lines of Gaussian shape are in good accord with experiments, showing that the fringe amplitude with perfectly adjusted continuously moving interferometers is governed by an expression usable for estimating interferometric range with such sources as the green Hg^{198} line with an effective Gaussian width of about two Doppler widths at room temperatures. The further extension of interferometric range with measurement precision of 1 part in 10^8 over traverses exceeding 300 mm appears feasible.

Length Measurement by Fringe Counting (II), Y. SAKURAI. Report of the Central Inspection Institute of Weights and Measures, Japan, v7 n2 report 15 1958 in Japanese. The operating principle and the error of an interferometer of which reflecting mirrors are made of a pair of front-surface mirrors so mounted as to form a right angle, were discussed analytically. It was found that when the interferometer was used for the measurements of length by the fringe counting method, the following adjustments were most important: (1) the positions and dimensions of entrance apertures of phototubes, (2) the linearity of the locus of the moving mirror pair, (3) the angle between the intersection line of the moving mirror pair and the direction of incident parallel light.

Interferometric Systems of Continuously Moving Mirrors and Photoelectric Detection, G. W. STROKE. J Phys Radium v19 n3 Mar 1958 p 415–23 in French. Interferometric measurements over the large path distances of several hundreds of millimetres have been recently considerably improved and simplified by the use of photoelectric receptors and electronics. Theoretical investigations of the conditions required to ensure adequate information content in the centrifringe range and visibility of the fringe signals in two-beam equal-inclination interferometers permits the examination and separate verification of (1) mirror parallelism requirements needed to maintain maximum fringe signals and to reduce apparent local displacement errors by minimizing the fraction number of equal-thickness fringes within the mirror aperture and (2) inherent interferometric conditions having to do with the interferometer geometry, the source line shape and photoelectric noise characteristics. Integration of the photoelectric flux within an angular range determined by the source radius and collimator focal length leads in practice to an "effective length" per fringe different from half a wavelength by parts in 10^7. Theoretical fringe signal amplitude curves corresponding to simple single lines of Gaussian shape, such as the green Hg^{198} line, are in good accord with experiments performed over path distances of ±320 mm and serve to estimate range and accuracy in measurements with machines where the causes of improper or variable mirror adjustments have been overcome to a large extent by mechanical perfection and servomechanical control.

Reversible Photoelectric Fringe Counting, R. L. EISNER. Rev Sci Instrum v29 n6 June 1958 p 521–3. Simple modifications of a Fizeau interferometer are shown which give a sense of direction to the passing fringes, enabling a suitable counting system to operate reversibly. Very fast counts can be made accurately using an electronic circuit actuated by four phototubes sighted on four points in the fringe pattern. An oscilloscope display can be used for fractional fringe interpolation.

Calibration of Mirror Extensometers by Optical Interferometry, A. F. C. BROWN. Eng v186 n4822 Aug 8 1958 p 180–2. Types of mirror extensometer; typical results of calibrations; factors governing behavior of Rhomb type

extensometers. Communication from Nat. Physical Laboratory.

Measurement of Small Displacement by Using Newton's Rings and an Objective Micrometer, I. IKEDA. Mem. Faculty Eng Hokkaido Univ. v10 n46 Oct 1958 p 491–503. Some details are given of the application of Newton's rings methods to the measurement of small displacements. Possible sources of error are examined in detail and a number of examples are illustrated. The method described is applied to the investigation of the aging of pieces of concrete.

Length Measurement by Fringe Counting (3rd Report), Y. SAKURAI. Report of the Central Inspection Institute of Weights and Measures, Japan, v8 n2 report 18 1959 in Japanese. The characteristics of interferometers of which reflecting mirrors are a right angle prism or a pair of front-surface mirrors mounted to form a right angle, are discussed as a continuation of the 2nd report. When the length is measured by means of fringe counting method with those interferometers, it is confirmed quantitatively that the measured values have the errors essentially in following cases, what has been expected to some extent. (i) The angle between the reflecting surfaces deviates from the right angle. (ii) The hypotenuse of right angle prism is not parallel to the intersection of its reflecting surfaces.

Length Measurement by Fringe Counting (4th Report), Y. SAKURAI, S. TAKAHASHI, K. OTA, T. YOSHIDA. Report of the Central Inspection Institute of Weights and Measures, Japan, v8 n3 report 19 1959 in Japanese. The experimental apparatus to research the method for calibrating the graduated scales with wavelength of light is shown in this report. The graduated scale to be measured is set on the moving carriage on which one of the reflectors of the corner-cube interferometer is fixed and the lines of this scale are viewed by a photoelectric microscope. The comparisons of mechanical displacement of moving reflector with wavelength are carried out by counting the number of interference fringes passing through the field of the interferometer during transference of the moving reflector. To distinguish the direction in which fringes move, two photo-tubes are arranged to view two parts of a fringe pattern where the variations of light intensity resulting from movement of fringes are different in phase by approximately 90°. The outputs of the photo-tubes are transmitted to a reversible electronic and mechanical counter, and a fraction indicator. The number of fringes is given by the indications of these instruments. The accuracy of this experimental apparatus was 0.03μ in the length of 20 mm.

High-Temperature Rotor Bore Dilatometer Unit, J. WEST. J Sci Instrum v36 n1 Jan 1959 p 1–3. The instrument measures optically the dilation due to centrifugal stresses of the bore of a steam turbine rotor under running conditions. The measurements are independent of vibration of the rotor. Light from an illuminated pinhole within an autocollimator is collimated on to a system of three mirrors supported kinematically inside a cylindrical cartridge, which is pushed into the rotor bore of the turbine. Two of the mirrors are fixed to the cartridge, and the third is hinged and connected to a feeler which is spring loaded against the rotor bore. With all three mirrors mutually at right angles, the light is reflected back to the autocollimator in exactly its own path, independent of any relative movement between the dilatometer and the autocollimator. On expansion of the rotor bore, the third mirror is displaced, tilting the returned beam of light. Since the turbine rotor is rotating, the image seen in the autocollimator appears as a circle, the diameter of which gives a measure of the dilation. The preparation of the mirror surfaces enabling them to withstand the conditions inside the turbine is discussed. (Not interferometric.)

Photoelectric Setting Methods for a Three-Beam Interferometer, P. HARIHARAN, D. SEN, M. S. BHALLA. J Sci Instrum v36 n2 Feb 1959 p 72–5. Some of the photoelectric methods which can be applied to estimate the fractional fringe order in the three-beam interferometer, previously described, are outlined, and their comparative merits are discussed. Experimental measurements show that with the help of such methods settings can be repeated to better than $\lambda/1000$, provided care is taken to minimize temperature fluctuations.

Estimation of Two Causes of Error in the Photoelectric Observation of Interference Fringes at Infinity with a Michelson Interferometer, J. TERRIEN. J Phys Radium v20 n2–3 Feb–Mar 1959 p 446–8 in French. In an earlier study the author assumed, (1) perfect centering of the receiving aperture on the ring center, and (2) uniform illumination of this aperture in the absence of interference. The accuracy in centring and uniformity of illumination required to justify these assumptions are here estimated. To attain an accuracy of 0.001 of a fringe, the error in centring must be less than 0.05 of the aperture diameter and the illumination must not fall by more than 12% from the center of the aperture to its rim.

Length Measurement by Fringe Counting, K. HARA, D. S. SMITH. Rev Sci Instrum v30 n8 Aug 1959 p 707–10. Construction and performance of reversible fringe counter with counting rate of 100 fringes per sec over path difference exceeding 20 cm: fringe excess fraction at zero path difference could be determined to 0.001 fringe, and relative precision of about $1:10^6$ was achieved at path difference of 6.4 cm.

Some More Aspects of the Michelson Interferometer With Cube Corners, M. V. R. K. MURTY. J Opt Soc Am v50 n1 Jan 1960 p 7–10. In the application of the Michelson interferometer for measurement of length by photoelectric methods there is a choice of either plane mirrors or cube-corners as the end reflectors. In the present paper it is shown that the guide on which the moving cube-corner moves needs to be only of moderate accuracy whereas it is known that the guide must be made very accurately when plane mirrors are used.

Gage Thin Strip Accurately, J. A. BUZA. Iron Age v185 n7 Feb 18 1960 p 120–1. Operation and performance of Fringecount Micrometer manufactured by Link Aviation Inc. which compares thickness of metal strip sample with wavelength of krypton light source; strip sample used as standard for maintaining gage tolerance on 26 in. wide foil of variety of alloy steels within 30 millionths of an inch at Wallingford Steel Co; photographs and sketch.

Photoelectric Method of Recording Interference Fringes in White Light, T. S. KOLOMITSOVA, I. V. NOVIKOVA. Optics & Spectroscopy (English translation of Optika i Spektrosk) v8 n3 Mar 1960 p 189–92. Photoelectric methods of isolation and recording of central white fringe in system of white light interference fringes were examined; results of calculations of magnitude of photocurrents are presented, and experimental arrangements and investigations are described; it is shown that, in principle, automation of measurements on white light interferometers is possible.

An Interferometric Measuring Apparatus, P. LEINWEBER. Mach Tool Eng and Prod News v93 n6 June 1960 p 140–5 10 figs. Translation from Werkstatt und Betrieb v93 June 1960 p 305–10. Describes an interferometer of the author's design for testing length measuring devices such as mechanical indicating gauges. Discusses "uncertainty of measurement" at some length. Presents novel fringe-count system.

Metodi Electrronici per la Misura Interferometrica delle Lunghezze, G. RUFFINO. Alta Frequenza v29 n3–4 July–Aug 1960 p 278–300. Electronic methods for inter-

ferometric length measurement; photoelectric transducer is described transforming illumination of interference pattern into electric signals; photoelectric interferometric devices classified; advantages of photoelectric method stressed.

A Method of Precise Fringe Pointing, D. S. SMITH. Can J Phys v38 n8 Aug 1960 p 983–90. Three methods of photoelectric pointing on an interference fringe are examined theoretically and the expected precision of setting is derived for each. An apparatus is described which yielded a precision of 1.2×10^9 compared to the predicted value of 5.8×10^9. The reason for this discrepancy is discussed, and modification of the apparatus which would reduce the discrepancy is suggested. Also Oct 1960 p 450.

Interference-Fringe Counter for Measuring Small Lengths, V. P. KORONKEVICH, YU. I. TRULEV. Meas Techn 1959 n10 Aug 1960 p 581–4 2 figs 3 refs. Translated from Izmer Tekh n10 Oct 1959. For measuring small lengths (1–2 mm) it was found expedient to construct an interferometer with a fringe counter by using standard instruments. The mean-square error of such an interferometer does not exceed 0.22μ, which is perfectly satisfactory for the majority of measurements in the engineering industry. The interferometer can be easily adapted for measuring micron indicator gages, screws of eyepiece micrometers, for determining coefficients of linear expansion and similar operations.

Apparecchi Electronici per la Misura Interferometrica delle Lunghezze, G. RUFFINO. Alta Frequenza v29 n5 Oct 1960 p 450–82. Electronic apparatus for interferometric measurement of lengths; performance principles of irreversible and reversible (differential) counters, interference fringes interpolators and automatic interferometric control; two methods of interpolation described; block diagrams of two automatic interferometric control devices which enhance ability of photoelectronic procedures.

An Automatic Fringe Counting Interferometer for Use in the Calibration of Line Scales, H. D. COOK, L. A. MARZETTA. J Res NBS v65C n2 Apr–June 1961 p 129–40. A reversible fringe counting interferometer is described in which mechanical, optical, and electronic adjustments are maintained stable by servomechanism control or by balancing. Mirror parallelism is achieved by detecting the angular error electronically and correcting by means of barium titanate actuators. An electronic interpolator permits recording of the count in digital form to 0.01 fringe without ambiguity. A rate of more than 1200 fringes/sec was achieved over a range of 14 cm. Higher counting rates are possible over shorter ranges. Design factors and details are discussed. A correction factor is derived for the error introduced by finite collimation of the interferometer beam.

Interference Comparator for Routine Measurement of Length. T. MOROKUMA. Oyo Buturi v31 n3 1962 p 192 22 figs 21 refs in Japanese. English translation available. Theoretical investigation is made on electronic fringe comparator for the purpose of routine measurement of length. (1) A lens and mirror system is introduced as the movable reflector system of the interferometer. This catadioptric system plays the same role as that of a corner cube reflector system when a concave mirror is situated at the focal point of a convex lens. (2) Effects of temperature and atmospheric pressure can be automatically corrected if suitable Fabry-Perot etalons are assembled tandem to the interferometer and the spacer material of the etalons has the same thermal expansion coefficient as that of the part to be measured. Equal inclination fringes are different from those formed with an ordinary interferometer. (3) Effects are calculated on the visibility of fringes due to optical arrangement of reflector systems and spectral distribution of the light which passed through the etalon. An interference comparator has been constructed on the basis of theoretical investigation, some

results of the investigation were already described in the first part of this paper and the rest are here presented. A pair of interference fringes, having uniform brightness and phase difference of $\pi/2$ rad. is formed in the same field of view by means of a quarter wave length prism analogous to a Fresnel rhomb and they are separated by a Wollaston prism. The direction in which the measuring head moves can be electronically detected from the phase relation between them. Measurement can be performed within the accuracy of 0.03μ with this instrument.

An Apparatus for the Determination of the Thermal Expansion of Solids in the Temperature Range 20–1000° C. V. E. MIKRYUKOV, I. K. KAMILOV. Pribory i Tekh Eksper (USSR) 1962 n3 p 173–5 May–June in Russian. English translation in Instrum. Exper. Tech. (USA). Describes a compact quartz dilatometer which may be used to measure the expansion coefficient to an accuracy of about 2%. It was used to determine the temperature variation of the expansion coefficient of pure Ni. A discontinuity was found to occur at the Curie point.

Interferometry in Length Measurement—1. Electronic Counting of Interference Fringes, J. L. GOLDBERG, R. H. BROCKMAN. Electronic Technol v39 n4 Apr 1962 p 140–4 6 figs 7 refs. A study of the photoelectric detection process applied to a steadily moving two-beam interference fringe pattern. Discusses photomultiplier noise, effect of the aperture in front of the photo-deflector, effect of bandwidth, and experimental details.

Interferometry in Length Measurement—2. Practical Considerations, J. L. GOLDBERG, R. H. BROCKMAN. Electronic Technol v39 n5 May 1962 p 186–91 10 figs 5 refs. Experimental results are discussed and the effects of imperfections in the transducing system are analysed together with a means of overcoming them. Considers the effects of tilt in the case of straight fringes viewed through a rectangular aperture, straight fringes viewed with a circular aperture, effects of variation of photomultiplier supply voltage, application to the absolute measurement of a meter line standard, and conclusions.

Interferometry in Length Measurement—3. Waveform Generator Suitable for Reversible Counting, J. L. GOLDBERG. Electronic Technol v39 n6 June 1962 p 238–43 11 figs 4 refs. Deals with the design of a suitable type of trigger circuit which produces a counting waveform from a noisy fringe signal. Discusses current amplifier, trigger circuit, application to counting, reversible counting.

A Versatile Silica Dilatometer, G. G. MATTHEWS, I. H. R. SATTERTHWAITE, C. CAMERON. J Sci Instrum (GB) v40 n1 Jan 1963 p 42–3. The dilatometer described here was constructed to make routine measurements of the coefficients of linear expansion of uranium specimens. The dilatometer can be used up to 1000° C or down to liquid air temperatures if required, with suitable dimensional modifications.

Interference Dilatometer, A. N. KOROLEVA. Meas Techn 1963 n8 Feb 1963 p 655 1 fig. Translated from Izmer Tekh n8 p 20 Aug 1963. Consists of a telescope with an autocollimation attachment, an interferometer, an electric oven for temperatures to 800° C, and temperature regulators. Applies method of coincidences.

Fabry-Perot Interferometer Used as a Dilatometer. NBS Tech News Bul v47 n8 Aug 1963 p 131 1 fig. Measures linear displacement as small as 10^{-7} cm.

An Automatic Recording Differential Dilatometer, J. BARFORD. J Sci Instrum (GB) v40 n9 Sept 1963 p 444–5. The apparatus is suitable for the study of the kinetics of phase transformations and precipitation processes in the solid state. Relative length changes between a specimen and a control are measured by means of a variable inductance transducer. The differential system

works to better than 1%, over temperature ranges of up to 1000°C.

Automatic Measuring Interferometers for the Determination of Length and Angle, A. K. CHITAYAT. ASME Paper n64–Prod–23 Apr 1964 8 p 8 figs. Discusses basic principles, typical utilizations of linear and angular interferometers, establishing zero reference, stability of interferometers, monochromaticity and coherence, effect of environmental conditions, utilization of lasers as light sources, high-order laser modes, selection of laser, traceability to international standard of length.

2.4.3. Fabry-Perot Interferometer

Interference Applied to Metrology, A. PEROT, C. FABRY. Astrophys J v9 1899 p 87–115. The paper is a translation from the original article in Bull Astron v16, p 5, January 1899 and describes the author's well-known methods of measuring lengths and thicknesses of observing the interference fringes produced between silvered surfaces. See also Ann Chim Phys v12 (7th series) 1897 p 459–501.

Sur la Mesure en Longueurs d'Onde des Dimensions d'un Cube de Quartz de 4 cm Côté (On the Measurement in Wave-Lengths of the Dimensions of a Quartz Cube 4 cm on a Side), C. FABRY, J. M. de LÉPINAY, A. PEROT. CR Acad Sci v128 1899 p 1317–19. The solid to be measured is placed between two planes of silvered glass, AA', so that the faces a.a' of the solid are parallel to the planes. Results are accurate to 0.1_μ in 4 cm.

Sur un Nouveau Modèle d'Interféromètre (New Model Interferometer), C. FABRY, A. PEROT. Ann Chim Phys v22 Apr 1901 p 564–74. Instrument made embodying the improvements suggested by experience. Article contains details of the new instrument.

Optical Measurement of Length Standards, A. PEROT, C. FABRY. Ann Chim Phys v24 Sept 1901 p 119–39. Details of special means for applying the interferential method to the determination of the absolute length of standard bars, the system adopted depending on the form of the end of the bar. Sketches of the modifications utilized and for the maintenance of uniform temperature are given.

Interference Rings Observable by Plates Whose Surfaces Are Absolutely Parallel, LORD RAYLEIGH. Phil Mag v12 Nov 1906 p 489–93. History of discovery. Distinction between contact rings and plate rings. Effects of double refraction of mica.

Quasi-etalon Fabry-Perot Interferometer, H. NAGAOKA. Math Phys Soc Tokyo Proc v9 Feb 1917 p 49–54. Describes arrangement for swift adjustment of mirrors to parallelism and not easily deranged. Fine adjustment is provided.

Interference Methods for Standardization and Testing Precision Gage Blocks, C. G. PETERS, H. S. BOYD. Sci Papers NBS May 2 1922 p 677–713 21 figs. Use of interference of light waves makes possible detection of errors within a few millionths of an inch. Fabry-Perot interferometer is applied.

The Fabry and Perot Parallel Plate Etalon, W. H. J. CHILDS. J Sci Instrum v3 Jan Feb 1926 p 97–103 129–35 4 figs. A concise account is given of the theory and use of the instrument, together with descriptions of the customary arrangements and the methods of etalon adjustment. Applications are: Wave-length measurement and detection of small shifts; investigation of resolution and structure; as a standard of length; investigation of absorption lines; determinations of refractive index. Bibliography.

Photography of Fabry and Perot Interferometer Fringes by Using a Simple Optical System, S. E. GREEN. Phys Soc Proc v42 Apr 15 1930 p 153–5; discussion Apr 15 1930 p 155–6. A simple method of photographing Fabry and Perot interferometer fringes is outlined, and some examples of the results obtained with mercury radiation are given.

Nomogram for Calculation of Fractional Values of Interference Fringes, A. I. KARTACHEFF. Rev Opt v14 Sept 1935 p 328–31. A nomogram is described for the graphical determination of the value of the expression $(d_2{}^2 - d_1{}^2)/d_3{}^2$, where d_2, d_1 are the diameters of successive rings for the fractional part of the order of interference of rings in the pattern produced by a pair of parallel semi-transparent reflecting surfaces illuminated by a convergent beam of monochromatic light.

A Vacuum Interferometer for Precise Measurements, R. M. ELLIOTT. Rev Sci Instrum v11 July 1940 p 235–6. The serious effect of pressure and temperature variations in the use of a Fabry-Perot interferometer is outlined together with a method successfully employed to reduce these variations to a reasonable limit.

Fabry-Perot Interferometers in Parallel Arrangement, L. STURKEY. J Opt Soc Am v30 n8 Aug 1940 p 351–4. Intensity equation of two Fabry-Perot interferometers operated in parallel is obtained and discussed; it is observed that distribution complementary to that of single Fabry-Perot instrument has very significant properties and may be obtained by such arrangement.

Interference Spectroscopy, II. K. W. MEISSNER, J Opt Soc Am v32 Apr 1942 p 185–210. The compound Fabry-Perot interferometer and the multiple-interference spectroscope are described and expressions for their resolving powers and instrumental half-widths evaluated. Applications of the Fabry-Perot interferometer to absorption-line working and to the plotting of line profiles are discussed, and recent work using high resolving power on atomic beams is described. Finally the theory of the reflection echelon and the methods employed in crossing it with auxiliary dispersion are given.

New Contribution to Interferometry. Pt I—New Non-Localized Interference Fringes, S. TOLANSKY. London, Edinburgh & Dublin Phil Mag & J Sci v34 n235 Aug 1943 p 555–65. Interference fringes, produced with small source of Fabry-Perot Interferometer, are described; these extend into space in form of cones, producing sharp rings when allowed to fall upon screen; properties of rings examined; striking characteristic is that without lenses sharp rings of great diameter can be produced; possible applications of new fringes.

On the Fabry-Perot Interferometer. Importance of Surface Defects, C. DUFOUR, R. PICCA. Rev Opt (Theor Instrum) v24 Jan–Mar 1946 p 19–34 in French. A study is made of the effects produced by various instrumental defects—diffusion, plate curvature, surface irregularities. A mathematical treatment is developed and is shown to account fully for the observations. A simple method is indicated for distinguishing between effects due to instrumental causes (surface defects, diffusion) and spectral causes (nonresolved satellites, continuous background).

The Effect of Finite Aperture on the Fringe Intensity Distribution of Fabry-Perot Interferometer. F. E. GEIGER, Jr. J Opt Soc Am v39 Mar 1949 p 249–51. An equation is derived for a square etalon which illustrates clearly the decrease in fringe intensity for increasing angles of incidence. The computations show that this effect becomes significant only for high reflecting powers and comparatively large plate separations.

The Resolving Power and Intensity Relationships of the Fabry Perot Interferometer with Silvered Reflecting

Surfaces, R. J. BRIGHT, D. A. JACKSON, H. KUHN, Proc Phys Soc London A v62 Apr 1949 p 225–36. By the use of a Fabry Perot etalon with very small spacing, the widths of the interference fringes were measured under conditions where the light could be considered as practically monochromatic. In this way, the resolving power which can be achieved with Ag deposits of known optical density was determined for light of 5 different wavelengths between 6 438 and 3 610 A. The results can be used for selecting the most favourable thickness of silvering of etalon plates, namely that which gives the resolving power required for a given purpose without unnecessary loss of intensity. The application of the results to multiple etalons is discussed.

A Mount for a Perot-Fabry Interferometer Without Etalon Ring, H. HABER. Letter in J Opt Soc Am v39 Dec 1949 p 1050–1.

The Functioning of the Fabry-Perot Interferometer; Improvement in Contrast and Luminosity, C. DUFOUR. J Rech Cent Nat Rech Sci n10 1950 p 1–16 in French. A discussion of the factors affecting contrast visibility and intensity in various interferometers, particularly the Fabry-Perot. By the deposition of alternate layers of cryolite and ZnS on the silvered surface, considerable increase in resolving power and contrast is obtained. Measurements are given and applied also to the thin film interferometric filter. It is concluded that the performance of an etalon is not so much limited by the properties of the thin film but by the surface imperfections. In the F.P. interferometer a practical contrast of 200, permitting the detection of a weak satellite of relative strength 1/1000, represents the present limit with a single interferometer. The theory is applied to combinations of etalons in series both with and without intermediate "focalization." It is considered that the F.P. interferometer presents important advantages over other instruments. Combinations of multiple etalons are discussed and it is suggested that the usual semi-transparent mirrors should be replaced by multiple films.

Accurate Thickness Measurements With a Fabry-Perot Interferometer, L. G. SCHULZ. Letter in J Opt Soc Am v40 Mar 1950 p 177–8.

The Reflectivity of Thin Silver Films and the Performance of the Fabry-Perot Interferometer, H. KUHN. J Phys Radium v11 July 1950 p 442–4. By measuring fringe widths in a Fabry-Perot etalon the reflecting coefficient R of the silvered surfaces can be derived. The transmission factors T of the films are measured directly with a photomultiplier tube. The sum $R+T$ is not markedly different for different film thicknesses but increases from $0 \cdot 84$ at $\lambda 3900$ to $0 \cdot 97$ at $\lambda 6400$. Direct measurements of R are in agreement with those derived from fringe widths. The data permit selection of the most suitable film thickness to give reasonable intensity of fringes.

A Note on the Resolving Power of the Fabry-Perot Interferometer, J. H. JAFFE. Letter in Bul Res Coun Israel v1 Mar 1951 p 113–14. It is established experimentally with a small-gap Fabry-Perot interferometer that the prediction made by Tolansky as to the dependence of resolution on polarization is correct.

Direct Method of Measurement of the Characteristics of a Fabry-Perot Interference System, P. GIACOMO. CR Acad Sci (Paris) v235 Dec 22 1952 p 1627–9 in French. The mean transmission factor of an interferometer is a function of $1-R$. where R is the coeff. of reflection of one surface. This factor is measured directly by comparing the illumination on a photocell with and without the interferometer interposed. Results obtained for layers of cryolite and ZnS, each $\lambda/4$ thick, are in good agreement with those calculated from classical Fresnel theory.

Resolving Power of the Fabry-Perot Etalon, M. S. SODHA. Letter in Current Sci v 22 May 1953 p 139–40. The Rayleigh, Sparrow and Abbe criteria for resolution are applied respectively to the case of the prism, the line grating and the Fabry-Perot interferometer. In the case of the Fabry-Perot instrument there is a large difference between the calculated resolution criteria. The three different assumptions lead to resolution separations in the ratios $1 \cdot 49 : 2 \cdot 72 : 2 \cdot 08$. Thus this interferometer is ideally suited for deciding between the validity of the three different criteria.

Influence of the Wavelength on the Sharpness and Brilliance of the Maxima of the Rings Formed by a Semi-Silvered Fabry-Perot Etalon, J. ROIG, E. COLLET. CR Acad Sci (Paris) v236 May 11 1953 p 1866–8 in French. Measurements are reported for fringe sharpness and intensity. Although internally consistent, the absorptions for Ag films appear to be higher than those of other investigators. This is attributed to insufficient pumping speed. Data are reported for eight wavelengths over the range $\lambda\lambda 4500$–6800. Some results for Al films are briefly indicated.

Selection of Optimal Spacers in Perot-Fabry Interferometry, G. V. DEVERALL, K. W. MEISSNER, G. J. ZISSIS. J Opt Soc Am v43 Aug 1953 p 673–80. Contains a general discussion of the conditions for optimal separation of Perot-Fabry patterns. A convenient graphical method is given which permits the selection of the proper spacer thicknesses for the clear resolution of the components of a pattern even in complicated cases.

New Method in Optical Interferometry, K. M. BAIRD. J Opt Soc Am v44 n1 Jan 1954 p 11–2. Rapid, accurate method for obtaining order of interference in Fabry-Perot etalon; apparatus for using method in calibrating end standards; application to wavelength determinations.

Fabry-Perot Interferometer Mirrors with Di-electric Multilayers, S, PENSELIN, A. STEUDEL. Zeit Phys v142 n1 1955 p 21–41 in German. A description is given of the production of multi-layer mirror for Fabry-Perot interferometers using vacuum evaporation. The mirrors are quarter wavelength thick and consist alternatively of the following materials. For 3000 to 4000 Å materials are PbCl and MgF_2C. For wavelengths greater than 4000 Å zinc sulphide and cryolite are employed. When freshly prepared films are used reflecting coefficients exceeding 97% are secured with a mean absorption of 0.9% for the zinc sulphide and cryolite combination. Absorption of 1.9% obtains for the lead chloride and the magnesium fluoride combination. Reflectivities are such that the fringe width is determined primarily by errors in the optical flats and not by reflectivity characteristics. Lead chloride layers are protected against the activity of dampness with a half-wavelength layer of magnesium fluoride. In the ultraviolet interferometric effects obtained with the multilayers are much superior to those of aluminum mirrors.

A Ney Type of Interference Etalon, K. I. TARASOV. Optika i Spektrosk v1 n1 1956 p 103–4 in Russian. The apparatus is a modification of the Fabry-Perot etalon in which the plane parallel reflector plates are covered on both sides with interference films of dielectric so that these reflectors individually form Fabry-Perot etalons. The plane parallel layer of air between the plates forms a third intermediate interference space. The interference picture observed in such a triple etalon is substantially different from the simple fringe system of a normal Fabry-Perot instrument recalling somewhat what is seen with the multiplex version. The reflection coefficient of each of the glass plates has its maximum value for definite angles of inclination of the incident rays and for other angles it is close to zero. With change of angle incidence there is a complementary change of phase of the reflected

ray and this, added to the phase difference of the interfering rays (determined by the air inter-layer), leads to much sharper interference rings and greater resolving power than in the normal Fabry-Perot instrument. Subsidiary maxima may be readily distinguished from line components for a change of pressure of the air inter-layer causes subsidiary maxima to remain in place while line components will move over the field of view.

High-Speed, Direct Recording Fabry-Perot Interferometer, M. A. BIONDI. Rev Sci Instrum v27 n1 Jan 1956 p 36–9. An interferometer is described which has a high optical speed and provides a direct tracing of spectral line shapes on a linear scale. A photomultiplier views the centre spot of the interference pattern. The output of the photomultiplier goes to a vibrating-reed electrometer and then to a pen recorder. The wavelength of the light at the centre of the interference pattern is made to vary with time by changing the index of refraction between the interferometer plates. This is accomplished by enclosing the plates in a gas-tight housing and admitting an inert gas such as argon or helium to the housing. By the proper choice of gas and of the rate of pressure change one obtains the desired rate of tracing the line shape. Orders of magnitude reduction in "exposure" time are achieved by eliminating the use of photographic plates.

Fabry-Perot Interferometer with Finite Apertures, K. L. VANDER SLUIS, J. R. McNALLY, JR. J Opt Soc Am v46 n1 Jan 1956 p 39–46. Closed mathematical expressions are developed for the Fabry-Perot interferometer with finite apertures for both noncoherent and coherent illumination. For most practical cases these expressions are substantially equivalent but reveal more serious aperture effects than the approximate theoretical treatment of Geiger. The effects expected are of particular importance in problems involving either compound interferometers or high reflection coatings. However, even at low reflectivities significant reductions in peak intensity and resolution are to be expected. The conditions for obtaining a 99% efficient interferometer are expressed in terms of the reflectivity and aperture parameters. These expressions still limited by the assumptions of smooth, plane parallel films, suggest modifications to the usual applications of the interferometer.

Advances in Performance and Applications of the Fabry-Perot Interferometer, A. STEUDEL. Naturwiss v44 n8 1957 p 249–55 in German. This is a general survey of recent improvements which have been published elsewhere. The importance of absorption of the reflecting film is discussed. Dielectric multilayers are surveyed and their reflectivity as a function of wavelength is discussed. Materials discussed include single sulphide-cryolite and $PbCl_2MgF_2$. Registering photoelectric Fabry-Perot spectrometers are surveyed. A comprehensive literature is reviewed.

Properties of a Fabry-Perot Interferometer Whose Mirrors Consist of Interference Filters, R. DUPEYRAT. CR Acad Sci (Paris) v244 n18 Apr 29 1957 p 2299–302 in French. The device is recommended for the interferometric analysis of Raman spectra where troublesome scattering of the exciting radiation takes place, the mirrors of the interferometer being constructed to have a reflectivity very low at the excitation wavelength but high for the Raman rays.

A Description of the Fabry-Perot Spectrometer Installed at Bellevue, J. BLAISE. J Phys Radium v19 n3 Mar 1958 p 335–7 in French. The optical system consists of a Pellin-Broca prism used as pre-monochromator, a Littrow-type spectrograph with a Bausch and Lomb grating, a Fabry-Perot etalon coated with ZnS-cryolite multilayers and a photomultiplier which is liquid nitrogen cooled. The exit slit and the collimating lens of the monochromator are focused respectively on the etalon plates and on the scanning hole. The photocell is coupled to an electronic recorder through an impedance transformer of the

cathode follower type (consisting of one tube fed by a dry cell and accumulator). The interferometer mounting allows any spacing of the etalon plates with only a few fused silica spacers. Two different devices for scanning the interference fringe system by changing the air pressure in the etalon chamber are described.

A Device Permitting the Mechanical Displacement of a Fabry-Perot Flat, R. CHABBAL, M. SOULET. J Phys Radium v19 n3 Mar 1958 p 274–7 in French. A mechanical device giving a parallel displacement to one of the flats of a Fabry-Perot etalon, which is suspended in a flexible scanning which is linear in cm^{-1}, during which the flats remain parallel to a high degree of precision over one order of the etalon. This device is thus useful for saw-tooth scanning, and yields a "definiance" some five times higher than the resolving power.

L'Étalon de Fabry-Perot Sphérique (Fabry-Perot Spherical Etalon), P. CONNES. J Phys Radium v19 Mar 1958 p 262–9 7 figs 7 refs discussion. English translation available. A Fabry-Perot interferometer can be made with two spherical surfaces, forming an afocal system. This interferometer can be used in a photoelectric spectrometer; it has the same transmission, contrast, sharpness free spectral range and theoretical resolving power as a plane Fabry-Perot of double thickness. But the "étendue" (product of surface by solid angle) of the beam is proportional to the resolving power instead of being inversely proportional, and the luminosity of the system becomes greater than that of the plane Fabry-Perot for very high values (several millions) of the resolving power. The spherical Fabry-Perot seems to be useful for studying lines whose width is only a few millikaisers. It could equally be used as a generator of artificial lines narrower than natural ones. See also Rev d'Optique v35 n1 1956 p 37–43 8 figs 3 refs.

Developments in the Comparison of Lengths Using Fringes of Superposition in White Light, A. H. COOK, H. M. RICHARDSON. Proc Phys Soc v73 pt 4 Apr 1959 p 661–70. When two Fabry-Perot etalons are placed one in front of the other, and the length of one is a small multiple of that of the other, fringes are seen in white light and have been used in the past to compare the lengths of etalons. In the study reported in this paper, these fringes have been observed photoelectrically while the optical length of one etalon is varied by changing the pressure of the air inside it. It is shown that the variation of intensity with path difference is the sum of two Fourier integrals involving an intensity function and the phase shifts at the reflecting surfaces. By forming cosine and sine Fourier transforms these quantities can be obtained separately and a correction applied for the error introduced into the comparison of lengths by the change of the phase shifts with wavelengths. It is shown that phase shifts can be measured more accurately by this method than by other interferometric means. It is possible to compare a metre length with a 20 cm length to about 1 in 10^8.

A Vacuum Contact Dilatometer, V. S. GUMENYUK. Pribory i Tekh Eksper (USSR) 1961 n4 p 101–3 July-Aug in Russian. A vacuum dilatometer for work in the region of high temperatures (500–1500°C) is described. An electrical contact device, which is connected to the mobile stage of an IZA–2 comparator, is used for measuring the length of specimens at room temperatures as well as high temperatures. The thermal expansion of tungsten was determined, and it was shown that the accuracy of the temperature-dependent elongation values that were obtained by means of this dilatometer was in good agreement with data from the literature. [English translation in: Instrum. Exper. Tech. (USA) n4 p 723–5 July–Aug 1961; publ Feb 1962.]

Double-passed Fabry-Perot Interferometer, P. HARIHARAN, D. SEN. J Opt Soc Am v51 n4 Apr 1961 p

398–9. Increased contrast and resolution can be obtained with the Fabry-Perot interferometer by reflecting the transmitted beams back through the instrument. An arrangement for this purpose is described in which the double-passed interference pattern is isolated by means of a simple polarizing system.

Zur Technologie des Perot-Fabry-Interferometers, G. KOPPELMANN, K. KREBS. Optik v18 n8 Aug 1961 p 358–72. Technology of Fabry-Perot interferometers; device is limited by departures from perfect flatness of reflecting surfaces and by imperfect parallel adjustment; photoelectric method is used to investigate these defects and ascertain possibilities for improvement.

Cube-Corner Fabry-Perot Interferometer, P. RABINO-WITZ, S. F. JACOBS, T. SCHULTZ, G. GOULD. J Opt Soc Am v52 n4 Apr 1962 p 452–3. Polarized Haidinger fringes were observed in a Fabry-Perot interferometer with one flat replaced by a cube-corner prism. Orientation of the polarization planes of the fringes and their relative phase shifts were measured. Some applications are suggested.

Construction of a High-Precision Dilatometer. The Dilatation of Copper, J. L. VERHAEGHE, G. G. ROBBRECHT, E. VAN OUTRYVE. J Phys Radium (France) v23 Suppl n6 June 1962 p 109A–110A in French. A precision direct reading dilatometer for the temperature range from −190 to 700 °C was constructed. The characteristics of the apparatus are described and its possibilities are illustrated by results obtained on copper.

Barium Titanate Ceramics for Fine-Movement Control, J. V. RAMSAY, E. G. V. MUGRIDGE. J Sci Instrum v39 n12 Dec 1962 p 636–9. Barium titanate transducers are described for use in automatic control of Fabry-Perot interferometer, to achieve parallel displacements of plate to accuracy required in interferometry.

Fabry-Perot Mirrors from Dielectric Multilayers for the Spectral Region 2350–20000 A, K. HEFFT, R. KERN, G. NÖLDEKE, A. STEUDEL. Zeit Phys (Germany) v175 n4 1963 p 391–404 in German. The production and the performance of dielectric multilayer mirrors for Fabry-Perot interferometers from 20,000 to 2350A are described. Details of the evaporation apparatus and techniques are given. The optical data, reflection factor, absorption factor and flatness, are represented graphically and discussed. For all wavelengths cryolite served as low refractive material. The high refractive materials used were ZnS for wavelengths from the infrared to $\lambda > 4120$ A, Sb_2O_3 for λ between 4200 and 3200 A and PbF_2 for the shorter wavelengths to $\lambda = 2350$ A. For PbF_2 an excitation band at 2190 A was found.

Fabry-Perot Electroptic Modulator, E. I. GORDON, J. D. RIGDEN. Bell System Tech J v42 n1 Jan 1963 p 155–79. Analysis of modulation properties of electroptic material placed in Fabry-Perot etalon; power requirements, heating and bandwidth; microwave phase velocity must be matched to that of light in electroptic medium.

Some Fringe-Broadening Defects in a Fabry-Perot Etalon, R. M. HILL. Optica Acta (Int) v10 n2 Apr 1963 p 141–52. Three forms of defect in the surface finish or alignment of the plates of a Fabry-Perot etalon are considered, and tolerances are assessed where the etalon is used as the resonant chamber of an optical maser, and as a spectrometer of high resolving power. The defects are a regular polishing error of sinusoidal form, a random polishing error of gaussian distribution of amplitude, and a small tilt error between otherwise perfect plates. It is shown that for both uses the plates have to be parallel to about a second of arc, and that if the amplitudes of the error functions are small compared to the wavelength of the emitted or incident radiation the regular sinusoidal

function gives the greatest loss in efficiency. Asymmetric line profiles can be obtained if the error in the plates is not symmetrically distributed about the mean planes of the plates.

Resolving Power in Near Infrared of Fabry-Perot Interferometer with Gold and with Silver Coatings, D. A. JACKSON, K. NARAHARI RAO. J Opt Soc Am v53 n5 May 1963 p 558–67. Experiments showing how use of Fabry-Perot interferometer with reflecting surfaces of either gold or silver can increase resolving power of spectrometer in region 0.6 to 2.4μ, or can increase luminosity without decreasing resolving power; optical systems described for these applications of interferometer.

Servo-Techiques in Fabry-Perot Interferometry, H. KOBLER. Instn Radio Engrs, Australia—Proc v24 n9 Sept 1963 p 677–84. Servo-system for position control of reflecting surfaces of Fabry-Perot interferometer is described; position errors are sensed optically with accuracy of 5×10^{-6} mm; equipment can compensate for steady errors of 4×10^{-3} mm and also reduces amplitude of induced vibrations.

Eine magnetische Feinjustierung fuer ein Perot-Fabry-Interferometer (magnetic fine adjustment for Perot-Fabry interferometer), G. KOPPELMANN, H. KRAUSE. Optik v20 n9–10 Sept–Oct 1963 p 475–80. Extremely small (0.001 of light wave length or less) but reproducible changes can be made in relative position of interferometer's mirror plates by means of device that uses small permanent magnets; efficacy of adjustment is discussed.

Remote Controlled Fabry-Perot Interferometer, Z. ERDO-KUERTI. Optik v21 n4 Apr 1964 p 167–71. Fabry-Perot type interferometer is described in which both mirror inclination and distance between mirrors can be varied in small intervals by means of electromagnets; design; calibration; testing.

Use of Dielectric Coatings in Absolute Wavelength Measurements with Fabry-Perot Interferometer, R. W. STANLEY, K. L. ANDREW. Opt Soc Am v54 n5 May 1964 p 625–7. Discussion showing how absolute wavelength measurements can be made with Fabry-Perot interferometer having dielectric coatings in manner that no errors attributable to phase change effects can enter into final results; wavelength corrections are due to dispersion of optical path rather than dispersion of phase change.

2.4.4. Interference Comparators

Optical Measurements of Length, A. PEROT, C. FABRY. CR Acad Sci v126 1898 p 1779–82. Method utilizes interference fringes produced between two lightly silvered glass plates. By having a standard pair of plates which have been accurately calibrated, the fringes produced by them can be matched with those produced in another system the distance between which may be some multiple of the standard.

Über einen Interferenzmessapparat (Regarding an Interference Measurement Apparatus), C. PULFRICH. Zeit für Instrumtkde v18 Sept 1898 p 261–7. See also "The K & E Interference Viewing Instrument, 1926." Description of Pulfrich interferometer, based on the principle of the simultaneous use of monochromatic lights of different wave-lengths and micrometric measurement of the interference fringes.

Sur l'Application de la Chambre Claire de Govi à la Construction d'un Comparateur pour Règles Étalons à Bouts (On the Application of the Camera Lucida of Govi to the Construction of a Comparator for End Standards), A. LAFAY. CR Acad Sci v133 Nov 25 1901 p 867–9. Newton's rings are used as indicators for micrometer settings which are made optically on the ends of the bars.

Compensation of Interference and Measurement of Small Thicknesses, G. MESLIN. CR Acad Sci v138 Apr 18 1904 p 957–9. A ray of light is passed through a thin plate, polarized, received on a plate of crystal (quartz cut parallel to the axis), and analyzed. The retardation in the thin, isotropic plate is compensated by that due to double refraction in the crystal, and the method is applied to the measurement of small thicknesses by using plates of quartz, 1, 2, 5, etc. mm. thick for a kind of optical balancing analogous to the use of a box of weights. Advantage lies in being able to compensate the effect of a thin plate by means of a quartz plate some hundreds of times thicker. See also MESNAGER, CR Acad Sci v138 Jan 11 1904 p 76–7.

Interferenzkomparator für Endmasze (Interference Comparator for End Measures), F. GÖPEL. Werkstattstechnik Nov 1919 7 p 12 figs. Comparator developed at the Reichsanstalt.

Measuring Balls and Plugs by Light-Wave Method, H. L. VAN KEUREN. Machy (NY) v27 Sept 1920 p 14–6 8 figs. Fundamental facts on which method of measuring plain cylindrical plug gages by interference bands produced by light waves is based.

Interferenzmethoden zur Untersuchung von Endmassen (Interference Methods for the Investigation of Gage Blocks), G. BERNDT. Betrieb v3 Apr 10 1921 p 389–96 20 figs. Notes on origin of interferences of equal thickness and their use in investigation of smoothness of surfaces and for measurement of differences in length (methods of Bureau of Standards, of Köster, and Göpel); absolute determination of length with interferences of equal thickness; interferences of equal inclination and their use in measurement technique. Definition of length of gage blocks.

L'Etude des Calibres Industriels au Bureau International des Poids et Mesures (Study of Industrial Gages at Int Bur of Weights and Measures), A. PÉRARD. Genie Civ v78 June 4 and 11 1921 p 477–80 and 500–3 20 figs. June 4: Types of gages and comparators employed. June 11: Calibration of standard gages of Johansson type by means of an interferometer. Gaging by light-interference method.

Die Anwendung der Interferenz des Lichtes im Lehrenbau (The Application of Interference of Light in Gage Work), G. BERNDT. Deutsche Optische Wochenschrift v10 n22, 23, 24 June 1, 8, 15 1924 p 265–9, 282–5, 302–8 14 figs. Describes Zeiss interference comparator and its application in the comparison of lengths of gage blocks.

Light-Wave Interference Comparator. Am Mach v62 1925 p 124.

A New Interference Apparatus for Testing Haemacytometers, C. G. PETERS, B. L. PAGE. Sci Papers NBS v20 n507 June 3 1925 p 221–36. Includes description of an interference comparator by means of which the difference from nominal of the depth of the chamber is indicated by the spacing of the fringes.

Method and Device for Examining End Gages, W. KÖSTERS. U.S. Patent 1 561 173 Nov 10 1925. Interference fringes show the difference in length of two gages.

An Interference Appliance for the Accurate Comparison of Length Gauges, F. H. ROLT, C. H. KNOYLE. J Sci Instrum v4 Nov 1926 p 42–45 2 figs. Describes an apparatus for intercomparing two or more length gages, of nominally equal length, by interference methods. It consists of a tilting lever, resting on three ball feet, two of which are supported from the base of the apparatus, while the third rests in turn on the various gages to be compared. The lever carries at the top a polished flat steel surface,

over which an optical proof plane can be adjusted to give the desired pitch and direction to the interference fringes which appear when the apparatus is suitably illuminated with monochromatic light. The number of fringes which occur within a given space is counted.

La Vérification des Calibres par les Interferences Lumineuses (Standardization of Gages by Light Interference), E. MARCOTTE. Arts et Metiers v81 July 1928 p 248–9 21 figs. Describes principles which are derived from Fizeau fringes and applied by several constructors to interference measurement of gages; study of useful rays; practical operations.

Interferometer for Gage Comparison. Am Mach (European ed) v75 p 265. This double-ended interferometer is for comparison of lengths, such as master slip gages. It consists essentially of two Michelson interferometers arranged to observe two ends of the gage and measure by wave length of light to avoid mechanical contact with the end faces. By means of this unit lengths can be compared to 0.000001 in.

Gauge Comparing and Absolute Length Measuring Interferometers. J Sci Instrum v16 n5 May 1939 p 163–5 4 figs. Describes two forms, one for comparing gages and the other for measuring absolute length. See also publication by Hilger & Watts Ltd. and British Patent 555,672 Feb 23 1942.

Method for Comparing an End-gauge and a Slip-gauge, J. TERRIEN. CR Acad Sci (Paris) v235 Nov 24 1952 p 1288–90 in French. The use of transparent parallel-plane glass or silica end-blocks, the thicknesses of which are determined by interference, is proposed and the advantages are detailed.

Interference Comparator of the Test Laboratory of the Conservatoire National Des Arts et Métiers, J. J. HUNZINGER. Rev Opt v34 n10 Oct 1955 p 512–19 in French. An interferometric circuit is described which is a polygonal variant of the Michelson interferometer. With it two length standards can be compared. The method of adjustment is described in detail, and the manipulation and performance surveyed. Standard gages are examined with this system and comparisons are made.

Novel Interferometer Construction, N. O. YOUNG. J Opt Soc Am v46 n11 Nov 1956 p 996. An interferometer related to the system of Väisälä is described. A simplified construction is used in which the interferometer is built between the jaws of an ordinary small micrometer, the faces of the jaws acting as two parallel mirrors, a strip plate between them being mounted on the yoke. The system is rugged.

Ein Interferenzkomparator zur Bestimmung der Differenz von Endmasslaengen (An Interference Comparator for Evaluating the Difference Between End-Standards), M. DUEHMKE. Zeit Instrumkde v65 n1 Jan 1957 p 15–7. By employing a difference method against a standard, lengths of slip-gages (up to 100 mm) can be evaluated to within 0.01μ. The method described enhances the Fizeau-fringe sharpness by multiple reflection. Interferometer described has been constructed for comparison of test sample with one that is standard, but can also be used for absolute interferometric measurement.

Achromatic Interferometer for Gage Block Comparison, T. R. YOUNG. NBS Cir 581 Apr 1 1957 p 43–50 2 figs; NBS Tech News Bul v40 n12 Dec 1956 p 176–7. Has many advantages that make it unique as an interference comparator. It is possible to measure absolute lengths with this interferometer by replacing the white-light source with a monochromatic source.

High-Precision Interferometer for Gauge Block Comparison. Engr v203 n5287 May 24 1957 p 814–5. Interfero-

metric comparator developed by NBS, Washington, D.C., allowing routine comparisons of length to be made to nearest ten-millionth of inch.

Design of a Compact Wide Aperture Fizeau Interferometer. P. R. YODER, JR., W. W. HOLLIS. J Opt Soc Am v47 n9 Sept 1957 p 858–61. A theoretical investigation of the performance of the Fizeau type interferometer as a function of the collimating lens spherical aberration and the thickness of the air space between the interferometer plates is presented. The theory developed is applied to the determination of the maximum relative aperture permissible in a simple collimating lens system for use in an interferometer of specified plate separation. It is found that an f/3 lens system consisting of two plano-convex lenses can be used in an interferometer of 10 in. aperture with the plates separated as much as 0.050 in. In such a system, the instrumental error introduced into the fringe pattern is no greater than λ/100 for mercury green light.

Some Possible Applications of the Interferometer Using Correlated Rays. R. ULLRICH, W. LOCHTE-HOLT-GREVEN. Optik v14 n11 Nov 1957 p 481–9 in German. A discussion of two-beam interferometer systems in which two beams cover a given cycle in opposite directions and then recombine. A difference in space coverage is indicated according to whether an odd or even number of reflections is involved. Systems are described for use as (a) a refractometer, (b) an interferometric system in which fringes and object are superposed, and (c) an interference length comparator.

Checking Master Gage Blocks with Interferometer. Tool Engr v40 n1 Jan 1958 p 115–6. Interferometric comparator developed by National Bureau of Standards, which makes routine comparisons of length to nearest 10 millionth of in.; this instrument will be used to check lengths of master gage blocks that control accuracy of guided missile, jet aircraft, machine tool and similar high precision parts; design and operation of instrument.

Comparator with Photoelectric Detection for Setting on Broad Interference Fringes with Precision, J. M. BENNETT, W. F. KOEHLER. J Opt Soc Am v49 n5 May 1959 p 466–7. A comparator with photoelectric detection system is described. Experimental data are reported to demonstrate that the same setting precision of ±0.2 micron is associated with the measured position of a normally exposed two-beam interference fringe, an overexposed two-beam interference fringe, a multiple-beam interference fringe, and a spectral line. The corresponding setting precisions obtained by the usual visual techniques are +6.2±3.0, ±1.1, and ±0.6 microns, respectively.

Application of Interferometry to the Routine Measurement of Block Gauges, S. P. POOLE, J. H. DOWELL, NPL. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 405–19 8 figs 2 refs. An interferometer designed at NPL in 1937 deals with twenty gages in one operation. Methods employed are given with a brief survey of sources of error. Interferometer is illustrated with details of improvements.

A New Method of Measuring Gage Blocks, J. B. SAUNDERS. J Res NBS v64C n3 July–Sept 1960 p 173. The parallel testing interferometer is quite applicable, without modifications, to the comparison of lengths of gage blocks. This note described the testing of gage blocks of all lengths, up to several metres, without having to contact them to optical flats.

The Double-Passed Fizeau Interferometer, P. HARIHARAN, D. SEN. J Opt Soc Am v50 n10 Oct 1960 p 999–1001. When the transmitted beams from a Fizeau interferometer are reflected back through the instrument, a new system of fringes is observed in which the intensity distribution undergoes a periodic modulation as the separation of the plates is changed. Accurate measurements

are possible with the help of these fringes, using a photometric setting criterion. The mode of formation of these fringes, as well as the theoretical intensity distribution in them under various conditions, are discussed.

Study on the Interference Comparator, Y. TOMONAGA. Report of the Central Inspection Institute of Weights and Measures, Japan, v10 n2 report 26 1961 in Japanese. In this paper the author describes the design of a new interference comparator (IC) to be used as precision workshop comparator. Its principle is based on that of Michelson's interferometer for white light. The experiment on this comparator shows that no change of interference colour of white light is observed unless the thickness difference between a glass plate and its compensator is over 3.4μ. Basing upon these data the beamsplitter and the double wedge glass plate are designed. The main body and the column of IC are designed so as to be more rigid than those of Mikrokator (MK), Ultraoptimeter (UM) and Projection Optimeter (PM). The measuring spindle is suspended by a pair of parallel sheet springs made of phosphor bronze, and the force necessary to displace the spindle axially by 1 mm is 28.5 gw. The maximum displacement of measuring anvil due to clamping is only 0.2μ. For IC the relation between the change of temperature Δt (deg) and that of indication $\delta_2(\mu)$ is shown to be given experimentally by the following expression: $\delta_2=0.16\Delta t$. In an ordinary conditioned room in which the temperature varies with an amplitude of about ±0.5 deg and with a period of about 30 min. the measuring spindle is to change its length about 0.5μ for one period. As the column is heated by the lamp of light source, the indication of IC changes about 0.02μ in the measurement of 100 mm gauge. But the above mentioned changes of indications do not practically affect the measuring accuracy, so far as IC is used as a comparator, because they give only shift of zero reading. The dispersion of measured values of IC ranges over only 0.01μ and is proved to be very small.

A Contact Interferometer with an Extended Measuring Range, V. P. KORONKEVICH, V. V. SKIDAN, V. A. AFANAS'EVA. Meas Techns 1960 n5 Jan 1961 p 373–6 5 figs 8 refs. Translated from Izmer Tekh n5 p 2–5 May 1960. The experimental work carried out makes it possible to conclude that the extended range interferometer can be widely used for accurate measurements of small lengths. The interferometer can be easily adapted for checking microcators, opticators, ultraoptimeters, strain-gauge calibrators, optical micrometer screws, angles of small wedges, for measuring magnetostriction, determining the linear temperature expansion coefficients, and other purposes.

Double-Passed Fizeau Interferometer. II. Fringe Systems Formed by the Reflected Beams, P. HARIHARAN, D. SEN. J Opt Soc Am v51 n4 Apr 1961 p 400–4. The theoretical intensity distribution in the fringes formed when the beams from a Fizeau interferometer are reflected back through the instrument is obtained. It is shown that, under certain conditions, the intensity distribution in these fringes exhibits a periodic modulation as the separation of the plates is changed, so that they can also be used for very accurate measurements.

Messen eines Keilförmigen Endmasses (Measurement of a Wedge-Shaped End-Measure), P. LEINWEBER. Feinwerktechnik v67 n12 1963 p 469–72 4 figs 5 refs. Describes the application of an interference comparator developed by the author in the measurement of the thicknesses at a series of points of a gage block having a small wedge angle. The process and results are discussed.

Interferometer IZK–57 for Measuring the Diameter of Balls, YU. V. KOLOMIITSOV, A. S. EGUDKIN. Meas Techns 1962 n10 June 1963 p 815–8 3 figs 3 refs. Translated from Izmer Tekh n10 p 8–11 Oct 1962. Describes an experimental model of interferometer IZK–57 for precision relative contactless measurements of ball diameters

from 1 to 10 mm by comparing them with a reference ball diameter or a block gage.

2.4.5. Measurement of Long Lengths

Méthodes Intérferentielles pour la Mesure des Grandes Épaisseurs et la Comparaison des Longueurs d'Onde (Interferential Methods of Measuring Great Thicknesses and the Comparison of Wave-Lengths), A. PEROT, C. FABRY. Ann Chim Phys v16 1899 p 289–338 7 figs. More complete and general than previous papers by authors. Useful in that cross references are given to papers by other workers.

Die Anwendung der Lichtinterferenz zu Längenmessungen auf grosseren Distanzen. (Application of Light Interference Methods to Large Distances), Y. VAISALA. Helsinki, 1923. See VÄISALA ref under 2.4.1/1927.

Standardization of a 25m Jaderin Wire in Terms of the Wave-Length of the Cadmium Red Line, N. WATANABE, M. IMAIZUMI. Imperial Acad Tokyo Proc 5 June 1929 p 273–6. The authors developed a method of Fabry and Perot to measure the length of a long standard using Brewster's white fringe and removing extraneous rays. Standardization was made first for a 6.25 cm. standard and then extended to 1, 5 and 25 m. standards and to the Jaderin wire. It is concluded that the method may be extended without much difficulty to a length of a few hundred metres. Any small variation in length can be traced from time to time by observing the positions of the white fringe in a compensator. The method may find an application in tracing the deformation of the earth's crust and in problems of a similar nature.

Application of the Interference of Light in Base Measurements, Y. VÄISÄLÄ. Translated by M. Wurzinger. Publications of the Finnish Geodetic Institute n14 1930. The method consists in a multiplication based on the application of the interference of white light. The interval between two parallel mirrors can be copied or multiplied even at great distances, the movement of the air permitting.

Die gegenwärtige Stand der Meter-Definition, des Meteranschlusses und seine internationale Bedeutung für Wissenschaft und Technik (The Present State of the Meter Definition, of the Meter Determination and Their International Significance for Science and Technology), W. KÖSTERS. Werkstattstechnik und Werksleiter v23 Dec 1938 p 527–33. Describes new Kösters interferometer for long lengths. English translation available.

Measuring a Large Displacement by Interferometry, H. BARRELL, M. J. PUTTOCK. Brit J App Phys v1 Apr 1950 p 87–91. A modified form of Michelson interferometer is used to calibrate the mechanical displacement system of an adjustable cavity resonator used to measure the velocity of propagation of electromagnetic waves. For the calibration a linear displacement of 12.7 cm was determined in standard Kr wavelengths to an accuracy of one part in a million, utilizing techniques of fringe observation and calculation which do not involve counting a progression of fringes. Displacements>30 cm can be similarly measured if suitable sources of monochromatic radiations are employed.

Two Interferometric Techniques, C. VOLET, N. CABRERA. Rev Opt (Theor Instrum) v30 Apr 1951 p 169–73 in French. A multiplication process (× 20) is described whereby a 20 cm Fabry-Perot etalon is multiplied to measure a 4-metre distance between two mirrors. The radiation required is that of a single isotope like Hg^{198} to measure the etalon, and white light superposition fringes are used in the multiplication. The effect of the dispersion of the phase change on metallic reflection is investigated.

This leads to fringe asymmetry. With the method a geodetic standard can be measured to some parts in ten million. The measurement of the metre in terms of light waves is discussed.

Some Problems Arising From the Use of Interference for the Precise Measurement of Plane-Ended Gauge Blocks. The Study of Fringes From an Air Wedge, J. TERRIEN. J Phys Radium v15 Apr 1954 p 6S–8S in French. The length of steel gage blocks can be found by comparison of the two fringe systems formed by interference between beams reflected from a reference glass surface, the upper gage block surface and the surface plate on which the block is resting. For large gage blocks, an error arises from the different character of the two sets of fringes, that form the upper surface arising from multiple reflections. The error is calculated and a method of measuring it is suggested.

Optical Interference with a Metre Path Difference, J. TERRIEN, J. HAMON. CR Acad Sci (Paris) v239 n8 Aug 23 1954 p 586 in French. Success has been achieved in obtaining interference over a path difference of 100 cm using a Michelson interferometer; the source with which this was achieved consists of isolated Kr^{86}, operating in the triple point of nitrogen (63 °K). The interference over this long path difference could only be secured in the infrared using the 9856 Å. It was not possible to secure fringes over a metre with the shorter wave 8777 and 9752 Å. It is now possible to compare in one single operation the length of one metre line standard in terms of light waves.

An Interferometric Method of Distance Measurement: Frequency Modulation Radar, G. BROUSSAUD. Rev Opt v35 n11 Nov 1956 p 593–603 in French. The equations governing the measurement of distance by optical interference methods are developed to include distance measurement by f.m. radar. This latter method differs from optical techniques not only in the wavelength employed but in the kind of problem which it solves.

A Kösters-Type Interferometer, C. F. BRUCE. J Sci Instrum v33 n12 Dec 1956 p 478–82. The design and performance are described of a Kösters-type interferometer which measures lengths of up to 500 mm directly by interferometry. Isotopic light sources are necessary for the measurement of the longer lengths, and sources containing Hg^{198} and Kr^{86}, as well as natural krypton and cadmium, have been used with this interferometer. Results of some length and relative wavelength measurements are given, to illustrate the performance of the interferometer operating in air and in vacuo.

Das genaueste Längenmessgerät der Deutschen Demokratischen Republik (The Most Accurate Length-Measuring Apparatus in the German Democratic Republic), F. SCHILLING. Techn Gemeinschaft n3 1957 p 110–2.

Interferentielle Vergleichssmethoden für Endmasse bis 1000 mm (Interferometric comparison methods for end standards to 1000 mm), M. DÜHMKE. Phys Verh Mosbach v8 n5 1957 p 134. A Kösters double prism was used in the interferential comparison of length and parallelism of 1000 mm bars mounted horizontally. The measurement uncertainty was estimated as a few hundredths of a micron.

Interferenzordnungen für die Messung langer Parallelendmasse (Interference Methods for Measuring End Standards of Great Length), C. HOFFROGGE, PTB. Zeit Instrumkde v65 n7 July 1957 p 123–5 4 figs 7 refs. The methods are for end standards which are too long to measure directly by optical interference. The overall length is therefore virtually subdivided by the images of reference mirrors, interference fringes being obtained between these mirrors and the ends of the standard. The

fractional part of the order of interference of the overall length is equal to the sum of the fractional parts of the orders of the subdivisions. Kösters double prisms are used as beam dividers.

New Gauge Interferometer, P. HARIHARAN, D. SEN. J Opt Soc Am v49 n3 Mar 1959 p 232–4. Development of interferometer for absolute measurement of length of end standards which utilizes optical arrangement in which path difference introduced between interfering beams is only half length of gage; theoretical principles; experimental measurements; advantages include simplicity of operation, compact layout and suitability for measurements on comparatively long gages.

Interferometrische Kalibrierung von Endmasstäben aus Quarz (Interferometric Calibration of End Standards of Quartz), E. ENGELHARD. Zeit Instrumkde v67 n3 Mar 1959 p 59–65 in German. A review is given of the interference methods in use in different countries for the testing and preparation of end standards. The definition of the official meter is discussed. It is considered that the uncertainty in the best cases approximates to 0.1μ. It is estimated that a five times smaller uncertainty could be attained by using the red cadmium wavelength as the standard instead of the standard meter. A ten times smaller uncertainty is attainable using Kr 86.

Instruments and Methods for Interference length Measurement Developed in the Mendeleev Metrological Institute, A. I. KARTASHEV. NPL Symposium n11, 1959, Interferometry. H.M. Stationery Office, London 1960 (Paper 2–5) p 109–24 6 figs 3 refs. Describes results of research on the design of interferometers for measuring end standards and geodetic bars of fuzed quartz from 100 to 1200 mm in length. Two types were built, one for absolute and the other for comparative measurements. Describes optical scheme and states advantages of the interferometer.

Application of Multiple Beam Interference to the Measurement of Long End Standards, J. B. SAUNDERS. J Opt Soc Am v50 n2 Feb 1960 p 183–4. A technique is described in which white light fringes of superposition are secured by combining a Fabry-Perot etalon with a Michelson interferometer. Fringes are obtainable for values of the Michelson path which are integral multiples of the Fabry-Perot path. The system can be adapted to the measurement of long end-standards.

Interference Fringes with Mercury-198 and a Path Difference of 2000 mm, I. C. GARDNER, K. F. NEFFLEN. J Opt Soc Am v50 n2 Feb 1960 p 184. A Connes type Fabry-Perot interferometer with spherical mirrors separated by 100 mm was constructed and was used as a monochromator for the Hg green line. It should have given a line width of 0.003 cm⁻¹, with which fringes should have been found over a path difference of 3 meters; in fact fringes were easily visible at 2 meters path difference, the longest obtainable on the available Michelson interferometer.

Interferometric Length Measurements on Long Parallel End Standards, M. DÜHMKE, K. KANTOR, F. HOCK. Optik (Germany) v18 n10–11 1961 p 561–6 in German. A description is given of an interferometer system, essentially a combined Fizeau and Michelson system, whereby it is possible to secure interference for end standards exceeding 100 mm in length, up to 1 metre in length. A combined Fabry-Perot and Michelson arrangement is also reviewed. Comment by K. Kantor: It is claimed that by the aid of a sevenfold multiplication of path between semi-transparent mirrors 10 cm apart, linked to a Michelson interferometer, path-lengths up to 2.8 metres still give good fringes. Comment by F. Hock: A Michelson interferometer system is described in which a polarization beam splitter is in one arm following the normal beam splitter. Thus the two polarization vibrations can be

made to traverse different path-lengths. It is shown that this enables paths double the coherence length to be measured.

1-m-Interferenzkomparator, M. DUEHMKE. Zeit Instrumkde v69 n10 Oct 1961 p 267–70. 1 m gage interferometer; description and operation of instrument for 100–1000 mm slip gages for comparative measurements; it can be connected with Fizeau or Michelson interferometers.

Wavelength Standard Comparator. Engineer v212 n5519 Nov 3 1961 p 759–60. In accordance with decision of 11th General Conference on Weights and Measures, meter is now defined in terms of wavelength of krypton 86; interferometer with photoelectric comparator now being set up at Int Bur of Standards at Sevres will enable meter standards to be compared within one part in 10^8 or better.

Metre Interference Comparator. Engr v212 n5527 Dec 29 1961 p 1100–1. Design of instrument invented by Koesters of Physikalisch-Technische Reichsanstalt (PTR) and now commercially produced by Carl Zeiss; prototype, completed in 1927, has since been redesigned by Engelhard; krypton lamp is hot cathode discharge tube surrounded by Dewar flask; sharpness of krypton lines is such that light scales of 800 mm length can be realized, having over 2,000,000 division lines with uncertainty of no more than plus or minus 0.01μ on any point; diagram.

Ein Meter-Komparator für interferometrische Längenbestimmungen in Vakuum-Wellenlängen (A meter comparator for interferometric length determinations of vacuum wavelengths), W. KINDER. Zeiss-Werkzeitschrift n43 1962 18 figs 10 refs. Describes an interferometer developed by the firm of Carl Zeiss with which gage blocks from 4 to 40 in. in length can be measured in vacuum wavelengths of the standard Kr line. This instrument represents an advanced development of the meter comparator described by Kösters in 1938.

Radiointerferometer for Measuring Long Lengths, G. S. SIMKIN, I. V. LUKIN, L. I. BIRYUKOV. Meas Techns 1961 n10 Mar 1962 p 780–3 1 fig 7 refs. Translated from Izmer Tekh n10 p 8–10 Oct 1961. Describes a double-beam radio interferometer which operates in the centimeter waveband and is intended for measuring lengths up to tens of meters in testing end gages and line measures.

Long-Path Interferometry Through an Uncontrolled Atmosphere, K. E. ERICKSON. J Opt Soc Am v52 n7 July 1962 p 781–7. An investigation was made of the degree to which the invariance of the relative dispersion of the atmosphere will permit an interferometric separation between geomagnetic path differences and path differences due to atmospheric inhomogeneities. Humidity variations are the most serious. A difference in average humidity of 1% of saturation at 15 °C would affect the comparison of two paths by approximately 2 parts in 10^8. The feasibility of photographing interference for long paths through an uncontrolled atmosphere was investigated. Photographs of channel spectrum interference were readily obtained for path lengths of 115 m near ground level.

A Method for Obtaining Interference With a Great Path Difference, N. R. BATARUCHKOVA, A. I. KARTASHEV, A. P. KIRICHENKO. Optika i Spektrosk (USSR) v14 n2 Feb 1963 p 304–5, in Russian. English translation in: Optics and Spectrosc. (USA) v14 n2 Feb 1963 p 159. Details are given of a spherical Fabry-Perot system for use with an interference monochromator. Interference patterns were easily photographed with path differences of over 2 meters.

Measurement of Large Path Differences by Means of an Interference Monochromator, A. I. KARTASHEV, A. P. KIRICHENKO. Meas Techns 1962 n8 Feb 1963 p 630–3 5 figs 2 refs. Translated from Izmer Tekh n8 p 9–11 Aug 1962. Method described which makes it possible to meas-

ure large distances without the use of intermediate steps or "multiplier" of the path difference.

Interference Monochromator with a Spherical Fabry-Perot Standard, N. A. BATARCHUKOVA, A. P. KIRICHENKO. Meas Techns 1962 n8 Feb 1963 p 633–6 5 figs 2 refs. Translated from Izmer Tekh n8 p 11–3 Aug 1962. Describes method of narrowing a spectral line and thereby increasing coherence length consisting of optical filtering by means of a Fabry-Perot standard with a preset path difference.

Comparator Measures up to 40″ with Accuracy of 0.4 Microinch, W. KINDER. Instrum & Control Systems v36 n4 Apr 1963 p 123–6. Interferometer type of meter comparator is described, developed by Carl Zeiss of West Germany in collaboration with Physikalisch-Technische Bundesanstalt, Braunschweig; interference problems; path of rays in meter comparator.

Tilted-Plate Interferometry with Large Plate Separations, H. W. MOOS, G. F. IMBUSCH, L. F. MOLLENAUER, A. L. SCHAWLOW. Appl Optics (USA) v2 n8 Aug 1963 p 817–22. With very highly collimated monochromatic light sources, such as optical masers, multiple-beam interference fringes between nearly parallel surfaces are obtained at large separations. Sharp fringes displaying the surface contours have been observed with separations as large as 20 cm. The requirements and limitations of the device are described, as well as some possible applications.

Design of Fabry-Perot Standards with Spherical Mirrors, A. P. KIRICHENKO. Meas Techns 1963 n1 Aug 1963 p 25–8 3 figs 10 refs. Translated from Izmer Tekh n1 p 18–20 Jan 1963. Deals with the design and manufacture of a Fabry-Perot standard with spherical mirrors used for filtering out spectral lines of single-isotope sources of light. It was possible to observe interference with path differences exceeding 1 m and to measure by the absolute interference method gage blocks up to 1 m long.

Interferometric Measurement of End Standards up to 1 m, Y. SAKURAI, H. YAMAMOTO. Bul Japan Soc Prec Eng v1 n1 Oct 1963 p 17–20 3 figs 3 refs. Contents: Measuring apparatus; factors that affect the accuracy of measurement; results of experiments; discussions and conclusions.

Measuring Distance with the Mekometer, R. H. BRADSELL, NPL. New Scientists v15 p 206–7 1 fig. Instrument measures distances of the order of 50 m using a centimeter wavelength pattern imposed on a light beam.

Long Distance Interferometry with He-Ne Laser, F. T. ARECCHI, A. SONA, Nuovo Cimento v32 n4 May 16 1964 p 117–21. Interference fringes have been observed up to optical path difference of 120 m (mirror separation 60 m) without substantial loss of visibility; He-Ne laser operating at 6328 A has been used.

Laser Feedback Interferometer, D. M. CLUNIE, N. H. ROCK. J Sci Instruments v41 n8 Aug 1964 p 489–92. Interferometer consists of He-Ne laser, mirror providing optical feedback, and photodetector; principle enables interferometry to be performed over path lengths of up to 50 m at either 0.6328 μm or 3.39 μm; alignment of instrument and detection of fringes is performed at 0.6328 μm; interferometer may be used to measure length, and also velocities up to at least 80 cm sec^{-1}, and produces fringes when only 1% of output is fed back; applications include machine tool control and measurement of optical path length.

Laser Calibrator for Shop. Steel v155 n13 Sept 28 1964 p 97. Lengths up to 100 in. are defined to accuracy of one part in one million by instrument called absolute interferometric laser calibrator, supplied by Airborne Instruments Laboratory Div, New York; construction of calibrator which has sensor, light reflector and electronic cabinet; aligning interferometric axis with motion axis of machine and other problems that had to be solved to develop accuracy needed.

2.4.6. Measurement of Line Standards

See also Section 4

Ruling Line Standards, H. B. LEWIS, C. G. PETERS. Mech Eng v46 mid-Nov issue 1924 p 796–8 7 figs; Am Mach v61 Dec 11 1924 p 925–8. Method of producing line standards free from measurable error by application of light interference, and end measuring machine upon which they are used.

Die Eichung der Drähte: C. Interferenzmessungen (The Calibration of Wires: C. Interference Measurements), E. GIGAS. Handbuch für die Verwendung von Invardrähten bei Grundlinien messungen; herausgegben von der Trigonmetrischen Abteilung des Reichsamts für Landes aufnahme, Berlin, 1934 33 figs. Calibration of land surveying wires by applying the Finnish geodetic method of Väisälä.

Method for Comparing a Line Standard and a Wavelength of Light, J. TERRIEN. CR Acad Sci (Paris) v238 Mar 1 1954 p 1001–3 in French. A discussion is given of a method of using glass plates with a Michelson interferometer so adapted that a line-standard can be converted optically into an end-standard. The method involves the introduction of silvered plates into the path, the plates having lines scratched into the silver and by an interchanging method the line-standard is converted to an optical end-standard.

Ein Interferenzkomparatur für Strichmasse (An Interference Comparator for Line Standards), C. HOFFROGGE, PTB. Microtechnic n6 1956 p 244–8 5 figs 10 refs. Has capacity of 1 m.

Accurate Linear Scales Ruled on Grating Engine, D. RICHARDSON, R. M. STARK. J Opt Soc Am v47 n1 Jan 1957 p 1–5. Absolute spacing ruled by grating engine is determined by ruling linear scale and using it as diffraction grating; angles of incidence and diffraction are measured with spectrometer; after wavelengths are adjusted to experimental conditions, average spacing of scale is calculated from grating equation; wavelength standards are thus used directly for determining line standards of length.

On an Instrument for Calibrating Graduated Scales up to 1 m in Terms of Wavelength of Light, Y. SAKURAI. Report of the Central Inspection Institute of Weights and Measures, Japan, v8 n4 report 20 1960 in Japanese. A brief description is given of an interferometric instrument which is designed and constructed in order to evaluate directly graduated scales up to 1 meter in terms of wavelength of light. The graduated scale to be measured is set on the base of the instrument which has the optical parts of the corner-cube interferometer. The lines of the scale are viewed by a photo-electric microscope through an optical system on a carriage which is movable along its way by means of a screw and nut. The carriage also holds the moving reflector of the interferometer at its lower surface, and the position of the reflector is made to be related with that of lines of graduated scale by applying the Eppenstein's principle. The evaluation of relative mechanical displacement of the reflector to the reference corner cube, which is on the same base, are carried out by counting the number of interference fringes which have passed through the field of the interferometer during the transference of the moving reflector. To distinguish the direction in which fringes move, two photo-tubes are arranged to view two different parts of a fringe pattern respectively where the variations of the light intensity

resulting from movement of fringes are different in phase by approximately 90°. The outputs of the photocubes are transmitted to a reversible electronic and mechanical counter and a fraction indicator. As the reference corner-cube itself is to displace in the direction of the incident beam, the interferometric instrument is also usable for scales longer than the coherent length of light source. With a view to ensure constancy of temperature, the instrument is set in an aluminum case with double wall and sandwiched sheets of Molto-pren. The accuracy of this instrument is found to be $\pm0.05\mu$ at its maximum measurable length of 1 meter, and yet a larger part of measuring error, to be caused by the deformation of the body of the instrument due to the transference of the movable carriage.

Unmittelbarer Anschuss von Strichmassen an Lichtwellenlängen, C. HOFFROGGE. Amtsblatt der PTB 1961 n2 p 192–5; Microtecnic v14 n2 p 51. An instrument for direct comparison of line standards with wavelengths of light is described. The two principal components are a photoelectric microscope and a modified Michelson interferometer. Computation of lengths by the method of coincidences of excess fractions is used.

An Automatic Fringe Counting Interferometer for use in the Calibration of Line Scales, H. D. COOK, L. A. MARZETTA. J Res NBS (Eng & Instr) v65C n2 Apr–June 1961 p 129–40 7 figs 10 refs. Interferometer is described in which mechanical, optical, and electronic adjustments are maintained stable by servo-mechanism control or by balancing. A rate of more than 1,200 fringes per second has been achieved over a range of 14 cm. An electronic interpolator permits recording the count in digital form to 0.01 fringe without ambiguity.

On an Instrument for Calibrating Graduated Scales up to 1 Meter in Terms of Wavelength of Light, Y. SAKURAI. Global Technol Apr 1961 (Digest of original Japanese article). Description of an interferometric line standard comparator. The principal components are a photoelectric miscroscope and an interferometer employing a Köster's double prism and corner-cube reflectors. A reversible fringe counter and interpolator is used to determine the order of interference.

Interference Comparator for the Calibration of Line Standards Directly in Terms of Standard Wavelengths, K. M. BAIRD. Rev Sci Instrum (USA) v32 n5 May 1961 p 549–54. An interference comparator was built for the routine calibration of line standards or scales by direct reference to the vacuum wavelength of the 0.606μ line of Kr^{86} which recently became the international standard of length. The principles of construction and the performance of the comparator are given; it is shown to yield an accuracy of calibration which is mostly limited by the nature of present-day line standards or scales, viz, a few hundredths of a micron in lengths up to one meter.

High Speed Interference Calibrator of Standard Scales—1, Y. DOI, K. SHIMIZU, T. TSUBOI, T. KONO. J Mech Lab Japan v14 n3 May 1962 p 121–38. Method for calibrating standard scale with resolution of 0.1μ; it requires no longer than 40 min to obtain calibration data for graduated lines ruled at interval of 1 mm for length of 1 m; photoelectric microscopes are fixed to bed and electric pulses generated at passage of lines across microscope axis; table motion is measured by interferometer; pulses

from microscopes and interferometer are sent to logical apparatus made of 600 parametrons and calibration data are printed out automatically. In Japanese with English abstract.

A Method for Obtaining Interference with a Great Path Difference, N. R. BATARUCHKOVA, A. I. KARTASHEV, and A. P. KIRICHENKO. Optika i Spektrosk (USSR) v14 n2 Feb 1963 p 304–5 in Russian. English translation in : Optics and Spectrosc (USA) v14 n2 p 159 Feb 1963. Details are given of spherical Fabry-Perot system for use with an interference monochromator. Interference patterns were easily photographed with path differences of over 2 meters.

Comparator Measures up to 40″ with Accuracy of 0.4 Microinch, W. KINDER. Instrum & Control Systems v36 n4 Apr 1963 p 123–6. Interferometer type of meter comparator is described, developed by Carl Zeiss of West Germany in collaboration with Physikalisch-Technische Bundesanstalt, Brunschweig; Interference problems ; path of rays in nmeter comparator.

Interference Comparators for Line Standards, K. M. BAIRD. App Optics (USA) v2 n5 May 1963 p 471–80. Reviews progress in the techniques of calibration of scales and line standards by interferometry, techniques that have been under very active development since the redefinition of the metre in terms of an optical wavelength. After a study of some general consideration, specific examples of interference comparators are described, and, finally, the effect of the development of these techniques on the usefulness of scales as secondary standards is discussed.

Interference Measurements of Graduated Standards of Length, M. L. BRZHEZINSKII. Meas Techns 1963 n2 Aug 1963 p 111–3 2 figs 3 refs. Translated from Izmer Tekh n2 p 16–8 Feb 1963. Provides some results obtained from studying the interference comparator and using it for measuring graduated standards of length. Also examines the theoretical peculiarities of its optico-mechanical system and additional improvements, as a result of which the precision and objectivity in evaluating graduated linear measures has been substantially raised.

Line Standard Interferometry, K. H. HART. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 619–24. Published by ASME. Fundamental aspects of interferometer design are presented which are required to achieve accuracy of 0.1μ in meter; problems of convection and refractive index of air are discussed; results of measurements made with interferometer developed at Nat Research Council in Canada are presented; instrument, which is equipped with photoelectric microscopes, is capable of measuring scales up to 1 m in length, to accuracy approaching hundredth of micron.

Automatic Calibrating Apparatus for Standard Scales by Counting Interference Fringes, Y. DOI, K. SHIMIZU, T. TSUBOI, T. KOUNO. App Optics v3 n7 July 1964 p 817–23. New device is described with which calibration of standard scale up to 1000 mm long can be made in terms of interference fringes in 1 hr run with accuracy of plus or minus 0.1μ; position of uniformly moving scale is continuously measured by fixed photoelectric interferometer, while instant of transit of every graduation over definite point is detected by array of photoelectric microscopes; data are processed in data-handling circuit.

2.5. Metrological Gratings

Interference Phenomena, C. BARUS. Sci v12 1900 p 617–27. Considers interferences observed on viewing one coarse grating through another, and on the projection of one piece of wire gauze by a parallel piece.

Moiré Micrometer, F. BURMISTROW. Techn Phys USSR v2 n6 1936 p 640–56 in German. A description of

an instrument using diffraction phenomena for the measurement of (a) thickness, and (b) structure of woven textiles. The idea is not new, such an instrument having appeared some years ago in Czecho-Slovakia. The present paper employs a photographic reproduction of an engine-ruled plate with a varying number of lines per in. from one end to the other. Such a plate is superposed on the

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silk stocking or other article to be tested and the shift and configuration of the interference lines is used for determinations of structure and thickness. The apparatus is described and its theory discussed.

An Apparatus for the Measurement of Small Differential Expansions and Its Use for the Study of Fused Silica, R. W. DOUGLAS, J. O. ISARD. J Sci Instrum v29 Jan 1952 p 13–15. The differential expansion is magnified by an optical lever, the sensitivity of which is increased by an arrangement of two graticules, the image of one acting as a vernier to the other. Changes of length of 10^{-5} cm can be determined. The apparatus has been used to measure differences in the thermal expansion of samples of fused silica which had been given different heat-treatments.

Interferometer Action of Parallel Pair of Wire Gratings, J. P. CASEY, JR., E. A. LEWIS. J Opt Soc Am v42 n12 Dec 1952 p 971–7. Transmission of electromagnetic waves by pair of wire gratings is treated as boundary value problem, including oblique incidence, arbitrary separation between gratings, and ohmic losses; relative merits of gratings and conducting films in interferometers; in numerical example peak transmission of grating is shown to be about 8000 times larger.

Measure Motion to 0.0001 Inch Without Friction or Wear, J. H. BROWN. Control Eng v2 n4 Apr 1955 p 50–2. Describes automatic measurement of lineal motion using optical gratings.

The Interference Systems of Crossed Diffraction Gratings. Theory of Moiré Fringes, J. GUILD, NPL. Oxford Univ Press 1956 152 p. Contents: General background; fundamental considerations; two gratings in series; characteristics of the fringe system; metrological characteristics; influence of grating defects on Moiré fringes.

Mechanical Interference in Measurement of Strain, J. R. LINGE. Aircraft Eng v29 n337 Mar 1957 p 70–4. Details of simple extensometer with gage length of 0.50 in. which uses mechanical interference of two sets of parallel straight lines to measure displacement and hence strain; interference effect exhibited by two pieces of Dufaycolor reseau placed in surface contact is employed for development purposes.

An Elementary Introduction to the Use of the Grating Interferometer, V. RONCHI. Atti Fonderie Ronchi v13 n5 Sept–Oct 1958 p 368–403. The elementary theory of the grating interferometer is presented for the benefit of those who want to apply the Ronchi test in practice, without being concerned with the intricacies of the exact theory.

A Review of the Application of Gratings to the Study of Optical Aberrations, C. MORAIS. Atti Fonderie Ronchi v13 n6 Nov–Dec 1958 p 546–602 in Italian. A review of the theory of the Ronchi fringes and their use in measuring aberrations. The work of previous authors is unified into a complete account of the effects of the Seidel aberrations. The evaluation of the Seidel sums from the fringe patterns is demonstrated and sample photographs illustrate the principal results.

Long Path Interferences (Moiré Patterns) of Electron Waves as Abbé "Objects," O. RANG, H. POPPA. Zeit Phys v153 n5 1959 p 643–52 in German. Bragg reflection of electrons by overlapping crystal lattices can give rise to a moiré pattern in the electron microscope, and additional spots in the diffraction pattern. These may be thought of as primary and secondary interference images in the Abbe sense. This is demonstrated by bright and dark field patterns of gold crystals.

The Moiré Fringe System as a Versatile Test-Object: Photoelectric Measurement of Aberrations, A. LOHMANN.

Optica Acta v6 n1 Jan 1959 p 37–41 in German. Proposal for a device in which two gratings in relative rotation provide a moiré pattern of variable spacing which is imaged by the lens under test on to a slit backed by a photomultiplier. At the same time the gratings produce a diffraction pattern, consisting mainly of three coherent maxima, which scans across the lens aperture as the gratings rotate. An a.c. signal is obtained in which the amplitude is related to the Twyman-Green pattern of the lens. Other applications of the device as an analogue Fourier transformer, for thin film measurements and for spectro-photometry are suggested.

A Simple Method of Calculating Moiré Patterns, G. L. ROGERS. Proc Phys Soc v73 pt 1 Jan 1959 p 142–4. The calculation is done by means of simple relations between the reciprocal-space transform of the moiré pattern and the transforms of the two grating patterns.

Method of Measuring Displacement Using Optical Gratings, D. L. A. BARBER, M. P. ATKINSON. J Sci Instrum v36 n12 Dec 1959 p 501–4. A method using three diffraction or shadow gratings for accurate linear measurement. Comparison between the gratings produces two alternating signals, and the change of phase difference between the signals is proportional to the distance measured.

New Measuring System. Machy (London) v96 n2461 Jan 13 1960 p 103–6. New system of measurement which can be employed either for linear or angular displacements has been developed by Paton Hawksley Electronics, Rockhill Laboratories, Bristol, largely as result of work involved in producing divided circles and diffraction and metrological gratings; system has family resemblance to well known arrangement of fixed and moving diffraction grating which is employed to produce moiré fringe effect; how microscope in which system has been incorporated is employed for measuring spacing of transverse holes in spool.

Diffraction Gratings as Measuring Scales, J. GUILD, NPL. Oxford Univ Press May 1960 208 p. An exposition of detailed information on practical moiré fringe equipment that can be adapted in the course of design. Contents: General information, linear measurement, fringe counting, fractional interpolation, gratings, and application to angular measurements.

Moiré Fringe Reading Head for Use With a Fine Grating, D. A. PALMER. J Sci Instrum v37 n8 Aug 1960 p 261–2. In the usual moiré fringe measuring system, practical difficulties arise in the use of very fine gratings. An optical system is described in which the use of a separate index grating is avoided, the moiré fringes being formed between the scale grating and the image formed by its reflection in a concave mirror. This arrangement has the particular advantage that the sensitivity is doubled. A working model has been constructed to demonstrate the principle.

Production and Performance of Metrological Diffraction Gratings, V. W. STANLEY, R. G. N. HALL. Prod Eng v40 n1 Jan 1961 p 38–44. Technique for producing diffraction gratings for use as scales for measurement, particularly for machine tool control; superposition of two gratings to produce moiré fringes; lathe performance and control for generation of fine helices; preparation of gratings by plastic replica and photographic processes; grating errors.

Precision Diffraction Gratings for Metrologic Purposes, G. N. RASSUDOVA, F. M. GERASIMOV. Optics & Spectroscopy (English translation of Optika i Spektroskopiya) v11 n2 Aug 1961 p 136–7. Method for preparing transmission diffraction gratings by etching reflection gratings ruled on layers of aluminum by ruling engine; gratings could be used for very accurate measurement of linear displacement by means of moiré bands.

Concerning an Error in the Method Using Moiré Fringes, A. PONCE. Bol Fac Ingen Montevideo (Uruguay) v7 n16 Dec 1961 p 553–66 in Spanish. Moiré fringes have been used to determine distortions of a plane surface, for example in elasticity experiments. There are two possible sources of error inherent in the simple theory, the larger due to the slope of the distorted surface, the smaller due to lateral displacements. These errors are calculated and illustrated in a typical case.

Extension de la Méthode du Moiré à des Problèmes Thermiques—Études des Déformations Rémanentes d'un Métal au Voisinage d'un Cordon de Soudure, P. DANTU. Rev Francaise de Mecanique n2–3 1962 p 117–18. Extension of fringe (moiré) method to thermal problems; study of residual deformations in weld seam zone; raster design of 400 points/sq mm was engraved on plates to be welded; after completion of welding, photograph of deformed raster was superimposed with photograph of reference raster; fringe pattern formed permitted measurement of deformations with accuracy reaching 5×10^{-5}. Before Second International Conference on Stress Analysis, Paris 1962. In French.

Multi-Sectional Gratings for Linear Measurement, G. D. DEW, NPL. J Sci Instrum v39 Apr 1962 p 141–4 6 figs 2 refs. Describes recent improvements in the techniques of preparing multi-sectional gratings for moiré-fringe measuring applications. The system enables adjacent sections to be phased with accuracy of 5–10 μin. and is applicable to gratings of the finest pitch employed in this work. A method of evaluating the phasing errors at the junctions is also described.

Moiré Fringes—Powerful Measuring Device, P. S. THEOCARIS. App Mechanics Rev v15 n5 May 1962 p 333–9. In recent years moiré fringes have found increasing application as measuring device; their applications may be classified either for measurement, as such, or for automatic tool control or monitoring; information obtainable from moiré fringes; application to metrology; measurement of topographic irregularities. 85 refs.

Widening Applications of Diffraction Gratings for Measurement and Control, W. H. P. LESLIE. Int J Mach Tool Design & Res v2 n4 Oct–Dec 1962 p 393–411. Construction of radial gratings having between 90 and 32,400 lines photographed on to plate glass disks of 12 in. diam or less are described; errors less than plus or minus 3 sec of arc are obtained; applications of radial and linear gratings to various machine tools are described; in gear hobbing machine errors were reduced to $\frac{1}{20}$ for worm/table rotation and to $\frac{1}{4}$ in actual cut gears of 20 in. diam; circuits for phasemeters for servo and for measuring purposes are contrasted, and new techniques for using batching counters with gratings described; typical applications to gear measurement and gearboxless lathe are mentioned.

Numerical Control of Machine Tools, H. OGDEN. Indus Electronics v1 n2 Nov 1962 p 59–64. Ferranti moiré fringe measuring system (Brit Patent Nos 760,321 and 810,478) comprising two optical diffraction gratings superimposed at slight relative angle, producing moving light (moiré) patterns during relative grating motion, and photoelectrically converted into digital length indications of high accuracy for direct display or print-out; applications of Ferranti coordinate positioning system to inspection and control.

Metrological Applications of Diffraction Gratings, J. M. BURCH. Progress in Optics v2, North-Holland Publishing Co, Amsterdam, 1963 p 73–108 54 refs. Theory of formation of moiré fringe signals by means of diffraction gratings; description of moiré system metrological equipment comprising photographically replicated gratings, visual and photoelectric reading heads, and electronic devices for handling moiré fringe information; advantages offered by fringe method measurements over other methods of machine tool control are discussed.

Angular Measurements by Means of a Ronchi Ruling, J. R. MEYER-ARENDT, E. D. MINER, App Optics (USA) v2 n1 Jan 1963 p 77–8. It is shown that a simple optical lever gives an angular accuracy of 2 sec of arc if it is combined with a Ronchi ruling. The system described is simpler than the two-grid method utilized by Jones. Light is sent through a grid onto the goniometer and returns back through the grid, to be viewed by a telescope. The advantages are reviewed. A grid of 133 lines per inch is best. Angular range is about 3°.

Recent Developments in Moiré Fringe Measuring Systems for Machine Tool Control, A. T. SHEPHERD. Int J Mach Tool Design & Res v3 n1 Jan–Mar 1963 p 47–59. Basic principles of measuring system; operating conditions discussed including optical arrangements, factors affecting fringe contrast, working gaps and prismatic grating optics; gratings; fringe subdivision; circuit checking facilities.

Measuring Displacement with Diffraction Gratings, S. HANDEL. Meas & Control v2 n2 Feb 1963 p 51–6. Principle of moiré fringe method of measuring relative displacement of rapidly moving parts; application of displacement detectors based on this technique to various types of machine tools where positioning can be carried out with accuracy of 1 part in 10,000.

Use of Reflecting Diffraction Gratings in Interference Systems for Measuring Linear Shifts, I, G. N. RASSUDOVA, F. M. GERASIMOV. Optika i Spektrosk (USSR) v14 n3 Mar 1963 p 406–13 in Russian. English translation in: Optics and Spectrosc (USA) v14 n3 Mar 1963 p 215–19. Reflecting and transparent diffraction gratings are combined and used to obtain interference moiré bands, reacting to the shift of one of the gratings in its plane. General properties of such a system are examined. It is shown that in systems with reflecting gratings, unlike in those of similar purpose but with two transparent gratings, the fringe contrast for certain conditions appears to be independent of the distance between the gratings, angular dimensions of the source and the wavelength interval used.

Use of Reflection Diffraction Gratings in Interference Systems for Measuring Linear Shifts, II, G. N. RASSUDOVA, F. M. GERASIMOV. Optika i Spektrosk (USSR) v14 n4 Apr 1963 p 559–63 in Russian. English translation in: Optics and Spectrosc (USA) v14 n4 Apr 1963 p 295–7. The results of experimental investigations of three variations of an interference system consisting of a reflection grating and a transparent grating are given. Systems are also examined in which one reflection grating is used and a semitransparent plate or Wollaston prism is employed as a beam splitter. The properties of different systems are compared.

Moiré Patterns, G. OSTER, Y. NISHIJIMA. Sci Am v208 n5 May 1963 p 54–63. A study of the basic properties of the Moiré patterns produced when figures with periodic rulings are made to overlap.

Long Range Measurements, R. KIMBLE. ASME Paper n63–PROD–18 May 7 1963 7 p 8 figs. Discusses particularly a system incorporating optical/electronics utilizing transmission or reflective gratings.

Optical Gratings in Measurement and Control, S. HANDEL. Meas & Control v2 n6 June 1963 p 242–6. It is shown how use of moiré fringes for machine tool position control, originally developed for continuous path, has been extended to coordinate positioning of machine tool tables; system is employed in Ferranti coordinate inspection machine, specially developed to facilitate rapid inspection of machined parts.

Photoelectric Analogue-Digical Converters for Length and Angle Measurements. Firm of Dr. Johannes Heidenhain,

Traunreut. July 1963 23 p 15 figs. Presents data regarding the operating characteristics of both incremental photoelectric encoders and coded encoders. These are mechanical to electrical converters and thus permit the use of mainly digital electronic means of measurement.

Moiré Patterns Formed with X-Rays. NBS Tech News Bul v47 n9 Sept 1963 p 160–1. During an NBS survey of techniques for studying microstructure, it was found that Moiré patterns formed in an X-ray microscope by structures which act as crossed diffraction gratings may reveal detail below the projection imaging power of the instrument.

Digital Measuring Systems, A. H. McILRAITH. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 585–91. Published by ASME. Critical survey is made of digital transducers most commonly used in machine tool control and in metrology; properties of crossed diffraction gratings are discussed and means whereby greatest accuracy is obtained from them.

Observation en Incidence Oblique des Phénomènes de Moiré par Réflexion sur une Plaque Gauchie (Observation in oblique incidence of moiré fringes obtained by reflection on deflected plate), J. EBBENI. Acad Roy de Belgique— Bul de la Classe des Sciences v50 n2 1964 p 114–24, 2 plates. Moiré fringes are obtained by super-imposing reference grating on identical deformed grating; this allows measurement of deformations; observation of fringes in oblique incidence permits determination of deflection at every point of tested plate.

Moiré Fringe Interpolator of High Resolution, A. H. McILRAITH. J Sci Instruments v41 n1 Jan 1964 p 34-7. Interpolator capable of dividing one fringe into thousand equal parts is described; 2 photoelectric signals in phase quadrature are derived from grating system and applied to sine-cosine potentiometer; grating displacement is determined from setting of potentiometer at which its output vanishes.

Theoretical Interpretation of Moiré Patterns, G. OSTER, M. WASSERMAN, C. ZWERLING.—Opt Soc Am v54 n2 Feb 1964 p 169–75. General mathematical method for solution of moiré patterns produced by overlapping of two figures; application to combinations of figures involving parallel lines, radial lines and concentric circles; theory of measurement of refractive index gradients by moiré method; analysis showing how moiré patterns are analogs of problems in physical optics, hydrodynamics and electrostatics. 16 refs.

Interpolation Arrangement to Improve Sensitivity of Diffraction-Grating Measuring System, G. S. K. WONG. Int J Machine Tool Design & Res v3 n4 Apr 1964 p 211–7. Description of diffraction-grating electronic interpolation arrangement, supported by short mathematical treatment of its logic; some possible errors are considered and their maximum possible magnitudes are expressed in terms of equivalent displacement of measuring system; arrange-

ment described was developed for particular diffraction-grating measuring system (Ferranti 4-fold counting system), but with some modifications it may be applied to other systems of similar nature.

Moiré Phenomenon, M. STECHER. Am J Phys v32 n4 Apr 1964 p 247–57. Simple mathematical analysis using shadow method predicts shape, disposition and spacing of moiré fringes produced by 2 parallel line grids; method is extended to grids of regularly spaced closed-nested-plane figures and to repeated cell structures; for any species of grid "moiré magnification" results; moiré fringes are sensitive tool for positioning or for measuring very small displacements and rotations; moiré patterns are visual aid for engineering and teaching of physics.

Moiré Fringes as Visual Position Indicators, L. O. VARGADY. App Optics v3 n5 May 1964 p 631–6. Summary of main known forms of moiré fringes for visual metrological applications is given; to observe and track displacements of moving fringe in conventional moiré system presents certain difficulties, as individual fringes have distinctive character; new types of moiré fringes were found and are discussed, where recognizable unique fringe indicates also unique position of grating displaced relative to its stationary counterpart.

Quality Digital Readout Measuring, O. MOLSTEAD. Tooling and Prod June 1964 7 p 10 figs. Describes machine for X–Y coordinate measurements using Moiré fringe system. The grating system and other units are described in detail.

An Optical Micrometer Suitable for Use at High Speed, M. C. CAREY and M. R. PIGGOTT. J Sci Instrum (GB) v42 n1 Jan. 1965 p 43–4. If a transmission grating is moved across a narrow beam of light the number of oscillations of intensity of the transmitted light measures the distance moved. A micrometer based on this principle can measure movements with a sensitivity to about 10^{-4} in. at speeds of up to 10 ft sec^{-1}, while being sufficiently robust to withstand shock loading. It can also be used at very low speeds.

Moiré-Schattenverfahren zur quantitativen Untersuchung schnell verlaufender Oberflächendeformationen von Festkörpern (Moiré Shadow Procedures for the Quantitative Investigation of Rapidly Changing Surface Deformation of Solid Bodies). E. HÄUSELER and J. POLLOK. Optik (Germany) v22 n1 1965 p 12–23 9 figs 10 refs in German. The four possible moiré procedures are investigated from the point of view of their suitability for the measurement of rapidly changing surface deformations. It is shown that only one procedure is practicable for materials with a high E-modulus. The resulting moiré lines correspond in this case to the differential of the deformation profile. A function generator is used to convert these curves into analogue electrical voltages and to perform the integrations. The procedure is illustrated by the case of the dynamic voltage field of a perspex disk which results when a duralumin bullet is fired into it.

Addendum to Section 2.

2.2.2. Method of Coincidences

Application des Phénomènes d'Interférence à des Déterminations Metrologiques (Application of Interference Phenomena to Metrological Determinations), R. BENOIT. J Phys ser 3 v7 1898 p57–68 2 figs. Describes measurement of length using four Cd lines and the method of coincidences.

2.3.1. Wavelength Standards and Light Sources,—General

Note on the Effect of Pressure upon the Series in the Spectrum of an Element, J. S. AMES, W. J. HUMPHREYS. Phil Mag ser5 v44 n166 July 1897 p 119–21.

Discusses shifts in wavelengths of spectrum lines when the pressure on the arc varied. See also other articles by HUMPHREYS, MOHLER, and HUFF: Astro-Phys J v3 1896 p 114–37, v4 1896 p 175–81 and 249–52, v6 1897 p 169–232, v14 1901 p 41–8.

Über die Interferenz des Lichtes bei mehr als 2 Millionen Wellenlängen Gangunterschied (Regarding the Interference of Light with more than Two Million Wavelengths Path Difference) O. LUMMER, E. GEHRKE. Verh Deutschen Phys Gesellschaft v4 n14 Oct 17 1902 p 337–46 5 figs 7 refs. Describes a method, based on multiple re-

Section 3. Length and Diameter Measurements by Mechancial Methods

3.1. Contact Length Standards

Standards of Length and Their Subdivision, G. M. BOND. J Franklin Inst 3d ser v117 April, May 1884 p 281–95 357–67. Early history of length standards in England and America. Development of metric standards. Molecular dimension. Methods of comparing standards. Length comparators. The Rogers-Bond Comparator.

Standards of Length as Applied to Gage Dimensions, G. M. BOND. J Franklin Inst 3d ser v117 May 1884 p 368–86. Illustrates end standard, Whitworth measuring machine, bench micrometer, plug and ring gage, and snap gage. Discussion of accuracy, tolerances, etc.

Standards of Length and Their Practical Applications. Pratt and Whitney Co., 1886 180 p. A resume covering the methods employed for the production of standard gages to insure uniformity and interchangeability in every department of manufacture including the reports of Prof. W. A. ROGERS; the Committee on Standards and Gages, A.S.M.E.; the Committee of the Master Car Builders Assn.; and including also the report of the special committee appointed by the Franklin Institute April 1964. Edited by G. M. BOND.

Comparaisons des Règles dans le Comparateur Brunner (Comparison of Standards in the Brunner Comparator), O. J. BROCH. Trav et Mem du BIPM v7 1890 p B3–B146. Contents: The comparator; bending of the standard placed on two supports; causes of errors in the comparison of standards; comparison of measuring etalons belonging to the Bureau; tables; observations.

Measurements of End-Standards of Length, P. E. SHAW. Roy Soc Proc Ser A v84 Feb 15 1911 p 589–95. Deals with bar gages having flat ends, particularly to recently made superior Johansson gages. Curves are plotted showing the variations in the readings for different points distributed regularly over the faces. Some improvements of the measuring machine are described.

A Silica Standard of Length, G. W. C. KAYE. Roy Soc Proc Ser A v85 Aug 15 1911 p 430–47. A criticism of materials used in making primary standards of length reveals objection to (1) copper alloys, (2) platinum, (3) iridioplatinum, (4) nickel, (5) invar. Fused silica, however, has a remarkable combination of good qualities (a)

very small thermal expansion, (b) very small thermal hysteresis, (c) cheapness, (d) comparative low elasticity, and (e) slight solubility in water can be treated as negligible when, as in the case of the primary standard, only skilled operators handle it. The present meter standard, the first of its kind, consists of a tube of silica with horizontal slabs of the same material fused into its end.

Adherence of Flat Surfaces, H. M. BUDGETT. Roy Soc Proc Ser A v86 Dec 22 1911 p 25–35. Experiments on specially made steel blocks showed (1) that at least 75% of the adhesions is caused by the presence of a liquid film; (2) that not more than 25% is due to atmospheric pressure; (3) that adhesion practically vanishes when no film is present. Breakage occurs in liquid itself and not between liquid and steel, only 4% of force required to rupture film is due to surface tension. Tensile strength of water may amount to 60 atmos. Adhesion is 300 to 900 lbs. per sq. in.

Large Comparator, W. KÖSTERS. Kaiserl. Normal-Eichungs Kommission. Wiss Abh n8 1912 p 87–109. Describes at length, with numerous illustrations, the construction and use of the large comparator used by the above commission.

Mesures des étalons Johansson par une Méthode Optique (The Measurement of Johansson Gages), A. PERARD, L. MAUDET. CR Acad Sci v154 June 10 1912 p 1586–8. Johansson gages of length varying from 100 mm to 1 mm were measured by being inserted between the faces of other Johansson gages and were thus measured in the usual way by the method of differences. The gages were in no case wrong by more than 0.2 micron. Further tests of planeness and parallelism resulted in showing the excellence of the gages in shape.

Einfacher Komparator zum Prüfen von Endmassen bis zu 5 m Länge (Simple End Comparator for Checking End Standards up to 5 m Length), W. BREITHAUPT. Zeit InstrumKde v33 n7 July 1913 p 226–7 2 figs.

Les Determinations des Étalons à Bouts (Determination of End Standards of Length), C. E. GUILLAUME. Rev Gen d'Elec v4 Aug 10 1918 p 171–8. A historic account,

brought up to date, of methods of comparing end standards and line standards. The old practice was to observe by microscope the point of contact of a point and its image reflected in the polished square end of the end standard. Later Benoit and Guillaume improved this method by having a fine thread stretched horizontally on the squared faces of the ends. Still later, about 1900, a method was used at Sévres in which specially prepared sphere-ended agate contacts were brought by known constant pressure against the ends of the standards. Discrepancy of 4μ between contact and optical methods was discovered. Cause found to be lens aberration, and optical method was henceforth discredited. Two modern methods are described. Advantages of sphere-ended and plane-ended standards are considered.

Les Calibres Industriels de Longueur (Industrial Length Standards), C.-E. GUILLAUME. Bul Soc Francaise des Electriciens v8 Dec 1918 p 383–400 5 figs. Development of present principles of gaging; comparisons of various standards; gaging machines of the Société Genevoise. Writer believes advisability of ascertaining from manufacturers their experience with the various metals used in manufacture of gages and deciding from study of reports on a standard which will satisfy all requirements.

Types of End Standards, R. L. RANKIN. Iron Age v104 Dec 25 1919 p 1331–2 5 figs. Relative value of flat, cylindrical, spherical and other end standards.

Comparator, Millionth. The National Physical Laboratory—Slip Gauge Comparator. Eng v110 July 2 1920 p 19–20. Detailed description. See also Dictionary of Applied Physics, R. GLAZEBROOK, p 385–6.

Precision Measuring and Inspection Devices, R. J. WHIBLEY. Machy (N.Y.) v27 Oct 1920 p 135–9 10 figs; Nov 1920 p. 242–5 6 figs. Minimeter and gage comparator used by National Physical Lab., England, for inspecting precision gage-blocks. Devices permit readings to accuracy of one millionth of an inch.

Genauigkeiten der Messzeuge (The Accuracy of Measuring Instruments), R. P. SCHRÖDER. Betrieb v4 Feb 11 1922 p 269–74. Notes on gage blocks, initial comparative, trial and working gages. Measurement of work-pieces.

Comparator for Checking Precision Gage-Blocks, F. D. JONES. Machy (N.Y.) v28 May 1922 p 689–93 6 figs. Extremely sensitive mechanical apparatus, which has proved very effective at plant of Pratt & Whitney Co. for testing accuracy of precision gage blocks, shown in Figs. 3, 4, 5, and 6.

End Measuring—Bars and Slip Gauges, A. J. C. BROOKES. Machy (London) v25 Nov 20 1924 p 244–9 3 figs. How to check them; recommendations.

Études sur les Étalons a Bouts. Deuxième Mémoire: Étalons a Bouts, Plans (Study of End Standards. Second Report: Flat End Standards), A. PÉRARD, L. MAUDET. Trav et Mém du BIPM v17 1927 95 p 34 figs 2 appendixes. Description of Johansson gage blocks and their metrological properties; comparison with line standards using ruled auxiliary blocks; interferometric method; study of one block; measurement of block combinations; mechanical and optical contact; phase dispersion; experimental verification of Hertz formulas for deformation.

Contact of Flat Surfaces, F. H. ROLT, H. BARRELL. Roy Soc Proc v116 Oct 1 1927 p 401–25. Lubricants, such as vaseline oil and ordinary lubricating oil, form wringing films between polished surfaces of steel and glass of thicknesses of 0.007μ and 0.008μ respectively, when artificial means of spreading them between the surfaces is applied. The contact between flat surfaces which are wrung together can be repeated with an accuracy of about

0.01 to 0.02μ. This does not represent the thickness of the part of the film separating the planes containing the high regions on the surfaces. Lapped surfaces of gages show evidence of wear during repeated wringings.

Beitrag zur Entwicklung von Dehnungsmessern kleiner Messlänge (Contribution to the Development of Extension Instruments for Measuring Short Lengths), K. BOTT-CHER. Zeit Instrumkde v48 Mar Apr May June 1928 p 116–25, 178–87, 234–47, 285–92 21 figs. After a brief survey of known instruments for measuring short lengths, the author discusses a series of requirements which such instruments should possess. A modification of the double lever indicator is found to be more accurate than the Okhuizen apparatus, the average error being about 25×10^{-6} mm. Experiments are described whereby the efficiency of the new instrument is calibrated.

Millimicro Comparator and Gage Blocks. Am Mach v73 Dec 4 1930 p 901–2. A precision measuring instrument claimed to be accurate within half a millionth of an inch has been announced. This device is mechanical and positive in its measurements and may be readily used by an inexperienced operator. The instrument employs an adjustable, corrugated anvil to support the work. A vertical plunger carrying an extremely hard contact point is raised and lowered by a slight pressure on the operating lever. Motion of this point is transmitted to a pointer viewed through a microscope. This comparator is claimed to be suited to checking the size and parallelism of flat surfaces such as those of shop gage blocks.

Apparatus for Comparison of Length of Gages, C. MOON. J Res NBS v10 n2 Feb 1933 p 249–55 1 supp sheet. Design and operating principles of apparatus for comparing spherical-ended gages of quartz having very small thermal expansion with standard flat-ended gages of steel which have relatively large coefficient of expansion; sensitivity permits repetition to within 0.1 micron or 1 part in 1,000,000 on gages 10 cm long.

A Study of Glass Surfaces in Optical Contact. LORD RAYLEIGH. Roy Soc Proc v156A Aug 17 1936 p 326–49. The method of getting glass and silica plates into optical contact and the behaviour of scratches in hindering contact are discussed. Scratches made with a cutting diamond or steel wheel cutter raise a ridge on the glass while those made with a writing diamond (splinter) do not. A method to determine the mechanical work done in separating two contacted glasses is given, and of the value found, 70 ergs/cm². half can be recovered on recontacting. Very variable results are found for the pull required to separate two contacted glasses, the maximum being 4.5×10^7 dynes/cm². Reflection from the interface between two contacted wedges of glass or silica is slight but measurable and varies from one specimen to another. The reflecting power is not affected by pressure, but the cause of variation is not known. Reflection between silica glass and a liquid of equal index depends on the method of preparation of the surface and is being investigated.

End-Gauge Comparator of High Sensitivity, A. TURNER, F. H. ROLT. Eng v146 n2787 Aug 12 1938 p 183–5. Illustrated description of comparator designed at National Physical Laboratory, principal aim being to produce instrument with magnification factor at least equal to that of larger of two existing millionth comparators (30,000 to 1), and of such form that several block gages up to 5 in. in length could, in turn, be readily stood or slid into position under measuring head.

Measuring Millionths of Inch in Gage Room, M. C. COFFMAN, C. H. BORNEMAN. Gen Elec Rev v41 n11 Nov 1938 p 502–3. Higher standards of precision in length measurements are now possible through recent application of new General Electric electric gage head to tailstock of Pratt and Whitney measuring machine in Schenectady Works Tool and Gage Department; machine originally

built to measure mechanically to 0.00001 in. lengths of gage standards up to 80 in.

Care of Gage Blocks, K. F. KIRCHHOFER. Tool & Die J v7 n11 Feb 1942 p 27–9 and 34. Suggestions concerning correct procedure in handling gage blocks; correct method of wringing blocks; testing and checking micrometer with help of blocks.

Care and Use of Slip Gauges, N. A. ESSERMAN, E. E. ADDERLEY. Austral Council Sci & Indus Res J v16 n2 May 1943 p 57–68. Slip gages known as block gages in America; deals with corrosion, burrs, accessories and wringing.

Master Disks. NBS Commercial Stand (CS(E) 124–45 1945 8 p. Standard covers major essential requirements for master disks (American Gage Design) from above 0.105 in. to and including 8.010 in.

"Microptic" Vertical Measuring Machine. Eng v159 n4133 Mar 30 1945 p 246–8; Indus Power & Prod v21 n235 May 1945 n 229, 231, 234. Illustrated description of instrument which embodies new principle in precision measurement of gage blocks, small parts, etc.; there are no multiplying devices whatever, actual movement of measuring contact being read directly by means of microscope; it is manufactured by E. R. Watts and Son; accuracy of instrument may be relied upon under any conditions to within 0.0001 in.

Measurement of Long End-Gauges by Comparison with Precision Line Standards. C. E. ARREGGER. Can J Res F v23 p 185–91 May 1945. The comparison of end-gauges is made by "wringing" short blocks to each end, with lines to convert them to line-gauges. 20-in. and 10-in. end-gauges were compared in turn with a meter standard, using a microscope line comparator as a transfer. Precautions to ensure max. accuracy are detailed. The greatest deviation from the mean measurement was less than 2μ. Comparisons between the rules agreed to within 10^{-5} in.

Das Messen mit Endmassen und Messcheiben, W. GROTH. Werkstatt und Betrieb v81 n12 Dec 1948 p 353–8. Precision measurement of distance between two points, parallel axis or product plane surfaces by parallel limit gages, cylindrical rods and wheels; angle measuring by limit gage, sinus and tangent rulers; conic surface measurement by rulers and Johansson and Fritz Werner clamps; drawings.

Comparison Measurement of Slip Gauges, A. W. MUSK. Machy (London) v75 n1940 Dec 29 1949 p 919–24. Anvil of transparent material developed by Taylor, Taylor & Hobson, Ltd. Leicester used for checking comparative dimensions of slip gages against reference gages; it makes it possible to check almost simultaneously comparative size and degree of flatness; calibration procedure described.

Importance of Surface Finish as Applied to Gage Blocks. H. J. CHAMBERLAND. Western Machy & Steel Wld v41 n12 Dec 1950 p 64–6. General discussion of finish standards and practices; new technique removing all amorphous metal or wire edge on gage blocks protects their surface finish through introduction of second parabolic curve blending original radius with finished surface of gage.

A New Method of Measuring the Depth of Haemacytometer Counting Chamber Cells, L. O. C. JOHNSON. J Sci Instrum v29 Apr 1952 p 130. The depth of a haemacytometer counting chamber is measured by means of a rocker, supported by the base of the chamber, with two arms which may be rested in turn on the flanking surfaces to the left and right of the chamber. The angular displacement of the rocker between these two positions of

rest is measured by an autocollimator. The accuracy of measurement is about $\pm0.2\mu$.

Adhesion and Contact Error in Length Metrology, C. F. BRUCE, B. S. THORNTON. J. App Phys v27 n8 Aug 1956 p 853–9. Studies of nature of strong adhesive contact between finely finished steel and glass surfaces when trace of liquid exists between them; these surfaces are of kind that are of practical use in length metrology where such adhesive action or "wringing" is of considerable importance, for example, in use of slip gages; how presence of liquid introduces dimensional contact error.

Pneumatic Slip Gauge Comparator, P. J. SIM. Machy (London) v94 n2425 May 6 1959 p 1009–15. Reference made to direct jet type of pneumatic comparator developed by National Standards Laboratory, C.S.I.R.O., Chippendale, Australia, in which there is no gaging contact to cause wear or damage; after period of satisfactory operation of instrument in calibrating slip gages, design has been prepared for improved version which is to be built as single unit; construction and use of prototype described.

On the Use of Slip Gages (Gage Blocks), P. V. DENISOV, Meas Techns 1958 n2 Aug 1959 p 127–31 3 figs 6 refs. Translated from Izmer Tekhn n2 Mar–Apr 1958 p 7. The physico-chemical processes taking place on the working surface of slip gages which substantially affect the wringing are completely ignored. The underestimation of the role played by the physico-chemical processes causes sticking and results in premature wear of the gages. Article describes investigation of adhesive and frictional forces and develops six rules for the use of gage blocks.

Gage Blocks of Superior Stability: Initial Developments in Materials and Measurement, M. R. MEYERSON, T. R. YOUNG, W. R. NEY. J Res NBS Eng & Instrum v64C n3 July–Sept 1960 p 175–207; see also similar unsigned article in Iron Age v185 n20 May 19 1960 p 152–3; Machy (London) v97 n2503 Nov 2 1960 p 1025–8. Processes, technical aspects and techniques involved in development of three sets of gage blocks are explained, and future research indicated; blocks are made from treated 410 and 52100 stainless steel, and have shown dimensional stability of 1×10^{-7} in./in./yr over one year period. 20 refs.

Stability of Block Gauges, A. Z. POLKOVA. Meas Techns 1959 n12 Sept 1960 p 932–3 2 refs. Translated .from Izmera Tekhn n12 Dec 1959 p 8. Discusses methods of measuring instability and tolerances on stability.

Development of More Stable Gage Blocks, M. R. MEYERSON, T. R. YOUNG, W. R. NEY. Matls Res & Stand v1 n5 May 1961 p 368–74; see also abstract in Metal Treatment & Drop Forging v28 n193 Oct 1961 p 407–9, 418. Long range research program aimed at accuracy of one part in 10 million in gage block length calibrations is underway at US Bur of Standards, to meet need for greater precision in production for atomic and space age; development of steel gage blocks with maximum dimensional change of 0.2μ in./in./yr is described; observations for one yr on 2 steels (410 stainless and 52100) given total of 14 treatments are reported.

Investigation of the Wring Capacity of Block Gauges, L. CH'AO-TSENG, A. S. AKMATOV. Meas Techns 1960 n10 July 1961 p 839–43 8 figs 6 refs. Translated from Izmer Tekhn n10 p 19–22 Oct 1960. The authors aimed at investigating: (1) the effect of the microgeometrical profile, the metal structure and its defects, hardness, the physical nature of the metal (the grade of steel), mechanical properties, and the physico-chemical purity of the surface; . (2) the volumetric physicochemical properties of the lubricant, the physical properties of its molecules, their atomic structure, isomerism, intramolecular mobility, polarizability, polarity, and chemical activity; (3) the method of obtaining an intermediate lubrication layer, its

"training," "thickness," physical condition, structure, mechanical properties, and the nature of intermolecular interactions.

Search for Ideal Gage Block Material, R. A. GIERLICH. ISA Proc Preprint 2.3.62 for meeting)ct 15–8 1962 5p. Developments of recent years are discussed from standpoint of gage block makers who must somehow reconcile his methods with findings of US Bur Standards and requirements of his customers, if ultimate gage block is to become working tool in laboratories of industry.

The Parallelism of a Length Bar with an End Load, D. C. WILLIAMS, NPL. J Sci Instrum v39 Dec 1962 p 608–10 2 figs 3 refs. The flexure of an engineer's length bar supported horizontally at two positions with a flat wrung to one end is analyzed. Formulas are given for support positions which do not introduce errors in parallelism at the ends. The effect of the flexure on the length of the bar is shown to be negligible.

Checked Your Gage Blocks Lately?, H. EASTMAN. Am Mach/Metalworking Mfg v107 n5 Mar 4 1963 p 56–8. Recommendations on how to conform with government contracts which require adequate gage surveillance programs, with special emphasis on "pedigree" of measurement standards; calibration laboratories; importance of measuring technique and what should be done to minimize uncertainties; preparing blocks; checking flatness; temperature stabilization; light contact pressure of comparator recommended; blocks of different materials; equipment maintenance.

The Effect of Micro- and Macro-Configurations of Block-Gauge Measuring Surfaces on Their Wringing Capacity, Z. I. KREMEN'. Meas Techns 1963 n2 Aug 1963 p 114–7 4 figs 3 refs. Translated from Izmer Tekhn n2 p 19–21 Feb 1963. Among factors affecting the wringing capacity an important part is played by the quality of the measuring surfaces (height, shape and position of microirregularities) and by their geometrical precision (their flatness in the lapped and free condition). This article deals with investigations into the effect of the above factors on the wringing capacity.

Variation in Contact Error Between Repeatedly Wrung Surfaces, E. G. THWAITE, R. T. LESLIE. Brit J App

Phys v14 n10 Oct 1963 p 711–3. A controlled experiment is described for determining the variability of contact error between highly flat steel surfaces when repeatedly "wrung" together; this led to an estimated standard deviation of 0.292×10^{-6} in. for the distribution of the contact error and an "on the average" tolerance limit about the mean at the 90% level of $\pm 0.52 \times 10^{-6}$ in. A linear increase of length with serial order of wringing of approximately 0.08×10^{-6} in. per wringing was observed and has been attributed to a progressive formation of asperities on the surface.

Gage Block of Superior Stability—2. Fully Hardened Steels, M. R. MEYERSON, W. A. PENNINGTON. ASM—Trans v57 n1 Mar 1964 p 3–25. Possibility of obtaining temporal dimensional stability of 1 to 2×10^{-7} in./in./yr in through-hardened steels with high hardness levels was studied; effects of various fabricating techniques and stress-relieving temperatures on the surface residual stresses were established and results correlated with observed trends in stability patterns; presence of surface compressive residual stresses was effective in reducing rate of contraction in 52100 steel on submicroinch level; quantitative relationship between dislocation content and length changes was established and tentative finding of instability of carbides noted; it was found that hardened structure of 52100, or similar conventionally hardened steels without secondary hardening peaks, cannot be fully stabilized at hardness level of RC 65 even with extended tempering.

Gage Blocks of Superior Stability—3. Attainment of Ultrastability, M. R. MEYERSON, M. C. SOLA. ASM—Trans v57 n1 Mar 1964 p 164–85. Materials and techniques required to produce degree of temporal dimensional stability of 0.1 to 0.2 μin./in./yr (ultrastability) and surface hardness of R_c 65 minimum are described; 3 categories of materials and processes included in study are steels with annealed cores and hardened surfaces, steels with partially hardened cores and hardened surfaces, and cermets and ceramics; 9 of 11 types had surface hardness of R_c 65 or greater; at or above these hardness levels, dimensional stability obtained with best surface hardened steels exceeded that of through-hardened steels; 2 titanium carbide types were ultrastable.

3.2. End Measuring Rods and Measurement of Long Lengths

Rotary Comparator, J. PERNET. Archives Néerlandaises v5 1900 p 395–406. The form of transverse comparator which is least subject to errors produced by bending is that of Wild, in which the rods to be compared are mounted in a frame in a vertical plane and are lifted vertically into sight. This form of comparator fails when the rods are to be immersed in liquids. The author constructs a rotary comparator which admits of exchange with extreme smoothness and simplicity. A stout cylinder rotates about its own axis which is placed vertically. The cylinder carries a table in the form of a leminscate, on each of the leaves of which one of the rods is mounted, and supported at ½ and ¾ of its length. Full details are given.

Mètres a Bouts (Meter End Standards), J. R. BENOIT, C. E. GUILLAUME. Trav et Mém du BIPM v12 1902 123 p 13 figs. Describes the comparisons of Tresca section end standards and a vertical comparator of special design. Two methods of measurement were applied, one optical and the other mechanical.

Some Gaging and Measuring Methods at the Works of the Westinghouse Machine Co. Am Mach v27 Aug 4 1904 p 1013–5. Illustrates instruments and describes methods

of using them. Large inside and outside micrometers, and large calipers.

An Analysis of General Flexure in a Straight Bar of Uniform Cross-Section, L. J. JOHNSON. Trans Am Soc Civ Engrs v56 Feb 1906 p 169–96. States the problem and gives the solution.

Some Gaging and Measuring Methods in American and British Shops. Am Mach v30 p 328 1907. Methods of using exceptionally large micrometer calipers.

Premières Déterminations des étalons a Bouts; Exécutées au Bureau International (First Determinations of End Standards), C. E. GUILLAUME. Trav et Mem du BIPM v15 1913 31 p 3 figs. Method; measuring instruments; expansion of steel standards; correction of the elastic deformations including bending and compression; principal measurements of 100, 200, 400, and 1000 mm.

Études sur les Étalons a Bouts. Premier Mémoire Broches et Calibres, (Study of End Standards. First Report of Calibration of End Standards), A. PÉRARD. Trav et Mém du BIPM v15 1913 170 p 54 figs. Various forms of end standards; measurement of absolute value;

instruments; measurement by longitudinal displacement; measurement by transverse displacement. The Hartmann comparator, its functions, study of the comparator, principal measurements, carried out with the comparator. Recent determinations of decimeter standards. Conclusions relative to the constancy of standards.

Comparator for a Base Unit at Potsdam, F. KUHNEN. Zeit InstrumKde v33 Jan 1913 p 1–9. An elaborate comparator of the usual type for comparison of 4 meter and 5 meter standard bars with 1 meter standards. Drawings and photographs. Few details. No results to indicate accuracy are given.

Large Measuring Machines Constructed by Société Genevoise. Eng v98 Sept 11 1914 p 323–6. One of these is adapted to measure a gage of even 3 m long. One new feature in the machine is a rolling foot, allowing that change in temperature shall produce no strain along the length of the bed. The most accurate of the machines described measures to 1 micron. The reference scale, instead of being fixed, is placed at the horizontal level of the micrometer screw and moves with it. The advantage here is that a cosine error, instead of as usual a sine error, is introduced.

Comparators for the Indian Government. Eng v100 Aug 20–27 and Sept 3 1915 p 179–82, 208–11, 232–5. A comparator of 24 m. divided into six sections, and a separate 4 m. comparator; latter used for comparison of length and determination of coefficient of expansion.

Measuring in Millionths of an Inch. Practical Engr v68 Nov 16 1923 p 273–4 2 figs; Engineer v 136 Oct 5 1923 p 363. Describes generator comparator used by makers, Pitter Gage & Precision Tool Co., Ltd., Eng., in process of manufacturing end gage bars; readily adapted to do all measurements which can be performed in ordinary anvil type of horizontal measuring machines.

Application of Micrometers in Railway Shops, M. H. WILLIAMS. Ry Mech Engr v98 1924 p 481 553.

Über die genaue Messung grosser Durchmesser (Regarding the Accurate Measurement of Large Diameters). H. SCHMIDT. Maschinenbau v7 1928 p 720. (English translation is available.) Sets forth the conditions necessary for accurate measurement of large diameters, particularly when micrometers are used. both by direct measurement and by indirect measurement wherein the height of arc corresponding to a certain length of chord is measured.

Messung an sperrigen Werkstuecken, P. KUEHNE. Maschinenbau v16 n7/8 Apr 1937 p 207–11. Measurements of unwieldy parts of locomotives, railroad cars, and airplanes; measurements during manufacture, after completion and in operation; illustrations of equipment measured and equipment used.

Accuracy in Large Roller Bearings, E. T. COBB. Steel v102 n14 Apr 4 1938 p 44–7 and 78. Accuracy of large measurements maintained by Bantam Bearings Corp., South Bend, Ind., based upon measuring machine which measures directly up to 80 in. in increments of 0.00001 in. and is periodically checked against Johansson blocks and special long gage pins; factors entering into accuracy of bearings, from raw material to finished product, discussed.

Einteilung der Endmasse (Division of End Gages), R. P. SCHRÖDER. Werkstattstechnik und Werksleiter 1939 n6 p 173.

Beitrag zur Aufstellung und Herstellung langer Massstäbe (Support and manufacture of long measuring rods), A. JOTZOFF. Zeit Instrumkde v60 Apr 1940 p 112–6. After description of the measurement technique and difficulties of fabrication of long measuring rods a proposal is discussed which yields simultaneously a higher measuring accuracy and reduced manufacturing cost.

Das Vermessen von Lokomotivrahmen (Measurement of Locomotive Frames), K. HUPE, Tech Mitteilungen Krupp-Tech Ber v9 1941 p 33.

Messgeräte für grosse Längen (Measuring Devices for Large Lengths), H. SCHMIDT. Werkstattstechnik und Werksleiter v36 1942 p 278. Various items of gaging and measuring equipment are described, including a measuring machine for measuring lengths to 7 m (23 ft.) with usual parallel-end standards and longer lengths with special end standards.

Messen grosser Werkstücke; Messgeräte; Passungssystem über 500 mm (Measurement of large workpieces; measuring equipment; systems of fits over 500 mm), N. N. SAWIN. Skoda-Mitteilungen v6 1944. English translation is available as paper No. 31 of the Symposium on Engineering Dimensional Metrology, NPL, October 1953. An interpretation (in German) of the standards proposal, by Dr. Ing. Leinweber, is available.

Stick Micrometer. Engr v178 n4619 July 21 1944 p 52–3; J Sci Instrum v21 n9 Sept 1944 p 163–4; Eng v158 n4109 Oct 13 1944 p 286. Brief illustrated description of instrument made by Pitter Gauge and Precision Tool Co. consists of micrometer head reading in increments of one onethousandth of an inch, 1-in. spherical end piece, and 1, 2, 3, 5, 12, and as many 24-in. pieces to make up any length required.

Measurement of Long End Gauges by Comparison With Precision Line Standards, C. E. ARREGGER. Can J. Res v23 sec F n3 May 1945 p 185–91. Operation of comparing end standard of length with reference line standard is carried out by method which is simple in principle, but which demands careful experimental technique; in operation described two Johansson type gages of 20 in and 10 in. length, were compared with line standards which themselves had been compared directly with legal Canadian standard metre. Bibliography.

Constant-Length Bar for Outdoor Use, H. I. ANDREWS. Eng v163 n4226 Jan 10 1947 p 25–6. Bar used as standard of length in measuring small changes in length (few thousandths of inch) in railroad ties; design chosen consists of steel tube; below one end of bar is attached small cylindrical reservoir heated internally by means of insulated electric heating element. In a research in the U.K. on concrete and other forms of railway ties it was necessary to measure small changes in length, of a few thousandths inch in ties approximately 8 ft. long, in very exposed positions under all weather conditions and temperatures varying from 20 to 90 °F. The standard bar of constant length, 9 ft. 3 in. long, consisted of a closed steel tube 2 in. in diameter. Below one end was attached a small cylindrical reservoir which communicated with the interior of the tube. The system was evacuated, sealed, and charged with 2 pounds of liquid sulfur dioxide. When in use the reservoir was heated internally by an insulated electrical heating element. A bimetallic thermostat was provided. As the SO_2 began to boil the vapor pressure increased, and the vapor condensed on the inner walls of the tube, flowing back to the reservoir. Continuous circulation thus established maintained a constant temperature of 94 ± 0.1 °F at which the thermostat was set. Considering all sources of error, the maximum error in any gage length was never likely to exceed 0.00015 in. By using an invar instead of a steel tube this could be reduced to 0.000013 in.

Measuring Large Precision Parts, N. N. SAWIN. Machy (London) v71 n1829 Nov 13 1947 p 541–4. Tests to establish system of tolerances for measuring large pieces over

500 mm during and after machining processes; factors involved in production of large components within prescribed tolerances; departures from geometrical form, elastic deformation during machining, effects of temperature, inaccuracies of measuring tools, and errors in measuring; measurements and calculation for ring and wheel assembly given.

The Coordinate Setting Machine, as Sponsored by the U.S. Air Force, published by Fairchild Aircraft Division, Hagerstown, Md., Apr 1952. Contents: Introduction; its background; establishing the collimation line; setting the machine to dimensions; setting a typical fitting; the universal positioner; optical rectangle; conclusion; specifications.

The Precise Establishment of Long Coordinates in Factories, O. S. READING, U.S. Coast and Geodetic Survey. Paper No. 30, Symposium on Engineering Dimensional Metrology, NPL, Oct 1953 p 485–93, H.M. Stationery Office, London.

Report of an Investigation for the British Standards Institution into the Accuracy with Which the Industry Measures Large Dimensions, P. W. HARRISON. Paper No. 32, Symposium on Engineering Dimensional Metrology, NPL, Oct 1953 p 527–36, H.M. Stationery Office, London. A progress report covering the investigation conducted in U.K. Up to that time the workpieces had been measured by thirteen firms and organizations and repeat checks had been made by NPL.

Instrumentation and Measuring System Employed to Position Some Features of the Harwell B.E.P.O. Pile Over Distances up to 80 Ft., V. B. HESSEN. Paper No. 34, Symposium on Engineering Dimensional Metrology, NPL, Oct 1953 p 563–76, H.M. Stationery Office, London. Includes establishing on the floor of the pile a normal plane from which all vertical dimensions could be taken; positioning of the tubes; description and principle of application of a tape gage for measurements up to 20 ft.

Investigation into Accuracy of Industrial Measurements of Sizes up to 80 Inches, P. W. HARRISON. Instn Mech Engrs Proc v169 n47 1955 p 977–85 (discussion) 985–92. Need to formulate proposals for extension of Int Standards Assn system of Limits and Fits above 500 mm has required improved knowledge of accuracy of industrial measurement of such sizes; in investigation by National Physical Laboratory this information was obtained for diameters up to 2000 mm; it was found that industrial measurements tend to be too small, especially at larger diameter.

Combination Length Bar Standards, L. W. NICKOLS. Machy (London) v89 n2284 Aug 24 1956 p 473–9; (Mach Shop May–Sept 1956). Influence of screwed joints upon overall length; determination of torque used when screwing length bars together by hand; measurement of changes in overall length caused by screwing together length bars made in accordance with British Standard 1790: 1952; development of new type of screwed connection where change in length per connection is negligibly small and is independent of assembly torque.

Messdraht-Längenmesser, eim neues Geräte zum messen grosser Abmessungen im Maschinenbau (Wire Length Measurement. A New Apparatus for Measurement of Large Dimensions in Machine Construction), M. BOGUS-LAWSKI, L. K. KAYAK (Moscow). Feingerätetechnik v5 n10 p 431 Oct 1956. Designs for both external and internal measurements are described. Errors are from 10 to 2×10^{-7} parts.

How to Measure Large Dimensions, H. W. SCHMIDT. Am Mach v100 n26 Dec 3 1956 p 145–7. Large bores, long dimensions, and other large work can now be accurately measured without special single purpose gages; long gage

blocks, or gage bars are combined up to 50-ft. length; any wanted dimension split into 0.0001 in. can be built up by normal and long gage blocks, cutting gage costs.

Eine Laengenmessmaschine fuer Messlaengen bis 6000 mm, G. DIETTRICH, K. KAATZ. Werkstattstechnik und Maschinenbau v48 n5 May 1958 p 276–81. Machine for measuring lengths to 6000 mm; construction and operation of optical machine to measure length of large interchangeable dynamo parts at Siemens-Schuckert works, Berlin; critique of accuracy.

Die Genauigkeit der Messung grosser Laengen in der Werkstatt, H. SCHMIDT. Werkstattstechnik und Maschinenbau v48 n6 June 1958 p 309–15. Accuracy in measuring great lengths (500–10,000 mm) in workshop; results of measurements made in England, Italy, and Germany at request of subcommittee ISO/TC3/SC1; discussion of methods and instruments.

Report on Accuracy of Measurement of Large Dimensions. Report read by I. H. FULLMER at meeting of Standards and Metrology Division, AOA, Jan 14 1959 11 p 9 figs 10 refs. Gives results and analysis of measurements of 30, 50, and 80 in. castings. Contents: Review of past practice, similar investigations abroad, measurement program, sources of data, results of measurement, analysis of results.

How to Measure Long Pin Gages, F. H. ROLT, G. GOD-FREY, S. C. BOTTOMLEY. Am Mach v103 n18 Sept 7 1959 p 126–7. Machines developed by Hilger & Watts, London that are capable of measuring gages up to 30 ft. long; design and operation of two machine types; readings can be obtained to 0.00005 or 0.0001 in.

Measurement of Large Dimensions, F. P. VOLOSEVICH, Meas Techns 1958 n4 Dec 1959 p 396–9 10 figs. Translated from Izmer Tekhn n4 July–Aug 1958 p 12. Article describes equipment developed for measuring dimensions, including: lightweight external dial micrometers with widened anvils; minimeter with an extended column; gage block with foot; horizontal optical comparator for 3.5 m range; device for measuring by means of gage blocks; internal micrometer; scribing slide gage.

Specification for Length Bars and Their Accessories. Brit Stand Instn—BS 1790 1961 33 p. Standard relates to length bars of cylindrical type, in inch sizes up to 48 in. and metric sizes up to 1200 mm, having parallel end faces finished by lapping, while longer bars are to conform to certain clauses; provision is made for 2 designs, one with complete plane faces and other with annular faces surrounding internally threaded hole at one end or both ends of bar; 4 grades of bar accuracy are reference, calibration, inspection, and workshop.

Universal Measuring Comparator Type IKU–2, N. F. DELYUNOV, E. I. ROZENBERG, E. P. SMIRNOVA. Meas Techns 1961 n8 Feb 1962 p 601–4 2 figs 2 refs. Translated from Izmer Tekhn n8 p 1–3 Aug 1961. A comparator having a mm scale with range up to 500 mm. The instrument is intended for direct and differential measurements of internal and external linear dimensions of various articles. The differential dimensions are measured by comparing the measured article with block gauges, templates or reference details.

Utilization of Wood for Making Large-Size Measuring Devices. I. P. VAGANOV. Meas Techns 1961 n8 Feb 1962 p 607–10 1 fig 6 refs. Translated from Izmer Tekhn n8 p 7–9 Aug 1961. Wood diameter-measuring caliper gauges are convenient to use, provide more efficient and accurate measurements as compared with the best metal gauges and micrometers, and the ambient air temperature virtually has no effect on measurement results. Wooden measuring equipment has a number of advantages as com-

pared with metal equipment, providing the peculiarities of wood are taken into account.

Parallelism of Length Bar with End Load, D. C. WILLIAMS. J Sci Instrum v39 n12 Dec 1962 p 608–10. Flexure analysis of engineer's length bar standard supported horizontally at 2 positions with flat wrung to one end; formulas for support positions which do not introduce errors in parallelism of ends; effect of flexure on length of bar is shown to be negligible.

Vertical Type Comparator for Measurement of End Standards, P. HOLMES, E. R. HARRISSON. Microtecnic v17 n1 Feb 1963 p 8–14. Illustrated description of instrument constructed at Defense Standards Laboratories, Australia, for measurement of end standards up to 40 in. long; measuring head employs electromagnetic pickup which is rigidly connected to datum platen; special attention was given to reduction of heating effects due to

presence of observer; discrimination of instrument is 0.1μ in.; method used to calibrate instrument is described.

Long Range Measurements, R. KIMBLE. ASME—Paper 63—Prod-18 for meeting May 7–9 1963 7 p. Problems of greater flexibility and range of measurement in gage manufacture to cope with environmental problems of chips, coolant, and space limitations; concepts of tolerances and repeatability, readability and response in measurement techniques are reviewed; use of system incorporating optical/electronics is reported to offer potential in long-range measurement field.

Gauge Blocks for Large Sizes, I. P. VAGANOV, N. M. SHCHIPACHEVA. Meas Techns 1963 n8 Feb 1964 p 649–50. Translated from Izmer Tekhn n8 p 15–6 Aug 1963. Gives results of various experiments to evaluate several parameters.

3.3. External Diameters

See also Subsection 3.5

New Measuring Machine, F. GÖPEL. Zeit InstrumKde v34 June 1914 p 180–3. Communicated from the Phys Techn. Reichsanstalt. This is to measure the diameter of a cylinder carrying a coil of wire. The measuring parts are light and, being provided with slide movements, can be easily moved to various parts of the cylinder. The latter is so mounted that it can be rotated on its axis when between the contacts of the measuring machine. Microscopes are used to measure the position of the contact rods, which have pointed ends.

Mesure Mécanique d'une Aire Sphérique. Les Sphérimètres (Mechanical Measure of a Spherical Surface; Spherometers), P. VANET. Genie Civ v74 Feb 1919 p 96 6 figs. Principle of planimeter applied to measurement of area of closed figure drawn on a spherical surface.

Zwei Schnellvergleicher für zylindrische und plattenformige End-masse (Two Rapid Comparators for Cylindrical and Flat Gage Blocks), F. GÖPEL. Werkstatts-technik v14 Dec 15 1920 p 625–9 10 figs. Describes comparator designed by author for rapid and very accurate relative measurements of cylindrical gage blocks, and one based on same principle for measurement of flat gage blocks up to 100 mm.

Pratt and Whitney "Super-Micrometer." Machy (N.Y.) v29 Sept 1922 p 68–9. Also Am Mach v57 Aug 31, 1922 p 355. Has a capacity up to 8 in. diam. and settings are made by use of standard inch blocks. Head is graduated to 0.0001 in., and is driven by a belt connected to a knurled handwheel, slippage of which indicates proper contact pressure. Work supports of various forms are provided.

Federal Dial Comparator. Am Mach v58 May 24 1923 p 782. Dial indicator mounted on an arm extending over a base. Supplied with a fixture for holding round work.

Société Genevoise Bench Micrometer. Am Mach v59 Nov 29 1923 p 823–4. Equipped with test comparator tube which serves as pressure indicator. Can be read to 0.00005 inch.

Carl Zeiss Optimeter. Am Mach v61 Oct 2 1924 p 560. Incorporates optical method of measurement that eliminates all moving parts except a small mirror. Optical system is housed in a right-angle tube, adjustably mounted in an arm on a sturdy column. Vertical optimeter is shown in fig. 1 and optimeter with horizontal measuring attachment is shown in fig. 2.

The Measurement of Fine Wires, G. A. TOMLINSON. J Sci Instrum v4 Dec 1926 p 74–5. A mechanical method

of measuring fine wires is described. The measurement is made at a point and with a very light pressure so that no deformation occurs. The accuracy of the measurement is 0.00001 in.

Measurement of Very Fine Quartz Suspension Fibers, G. A. TOMLINSON, H. BARRELL. J Sci Instrum v4 Oct 1927 p 410–3. The paper describes two indirect methods of measurement. One is purely mechanical and involves a measurement of the elastic strain under a known tension, from which the mean cross-section can be found. The other method depends on the observation of certain diffraction phenomena produced in white light. In a set of fibers measured, the diameter varied from 3.3 to 0.6μ. The optical method is found to become unreliable when the diameter falls below about three wavelengths.

Mikrotast-Feindrahtmesser (Microtast Fine Wire Measurer), M. BARTHOLDY. Zeit für Feinmech und Prazision v35 Oct 12 1927 p 250–1. Microtast mounted on column for measuring diameters of small wires.

New Zeiss Projection Optimeter. Instrum v1 May 1928 p 257–8 4 figs; Am Mach v68 1928 p 123. Outstanding feature is visible reading of scale by both eyes instead of by microscope; more valuable in mass inspection; table has serrated surface; range of scale to plus and minus 0.005 in.; scale gradationed 0.00005 in.

Über die genaue Messung grosser Durchmesser (Accurate Measurement of Large Diameters), H. SCHMIDT. Maschinenbau v7 n15 Aug 2 1928 2 figs. Comparison between direct measurement with a micrometer and indirect measurement (height of arc). Demonstration of large errors of the indirect method. English translation available.

Ein optisches Mikrometer (Optical Micrometer for Measuring Fine Threads), I. RUNGE. Zeit für Techn Phys v9 n12 Sept 28 1928 p 484–6 8 figs. Describes an optical system in which the distance between diffraction bands produced by the thread, related to the dimensions of the apparatus, gives the diameter of the thread with an accuracy of above 0.25% when the diameter is of the order of 10 to 80 microns.

Inspection of Micrometer Spindles at the Zeiss Works, H. SIMON. Am Mach v70 n4 Jan 24 1929 p 175–6 3 figs. Testing head of Zeiss micrometer spindle thread to 0.00005 in. by combined linear and angular measurements is described; Zeiss micrometers are guaranteed not to vary more than 0.000125 in. in 1-in. length; details of Zeiss lead-testing machine.

New Amplifying Comparator. Instrum v2 n8 Aug 1929 p 281–2 1 fig; Am Mach v69 Nov 29 1928 p 866. Ames amplifying comparator described eliminates horizontal stresses and strains and consequent differences in readings on same piece of work when shifted about under measuring point; all readings are positive and positively repeat, regardless of direction in which work is passed under point.

Elektromechanisches Messgeraet fuer Feindraehte (Electromechanical Measuring Equipment for Fine Wires), M. BARTHOLDY. Kruppsche Monatshefte v10 Nov 1929 p 184–5 1 fig. Equipment has been designed in order to overcome disadvantages of measuring with calipers by which errors result from deformation and motion of measuring spindle; wires can be measured from 0 to 0.05 mm; size is indicated electrically on scale graduated in 50 sections, each representing 0.001 mm with 0.0001 mm exactitude.

Optical Measuring Machines, Eng (London) v129 n3344 Feb 14 1930 p 236–7 11 figs. Measuring machine made by C. Zeiss, of Jena, dispenses with use of micrometer screws and gage blocks, which are subject to slow molecular changes, and of hydraulic feelers, which must exert some pressure, and is based upon comparator principle; optical system of optimeter is explained by diagram.

Bausch and Lomb Optical Comparator. Am Mach v72 Mar 20 1930 p 508. Accuracy to within 0.00005 in. is embodied in the optical comparator for comparison and measuring purposes on parts with flat surfaces, balls, or cylinders. The instrument is built into a strong steel casing. The optical comparator is supplied in two models, the first of which has an eyepiece which is inclined 60 deg. to the measuring axis, and the other with a 90-degree eyepiece. It is also possible to supply an instrument with a projection attachment. The range of the calibrated scale is plus or minus 0.004 in. Objects up to 6 in. in height can be compared.

Société Genevoise Micro-Indicator Stand. Am Mach v72 Apr 24 1930 p 706–7. A stand to make use of the micro-indicator tube is being manufactured by the Société Genevoise d'Instruments de Physique, Geneva, Switzerland. By its use the micro-indicator tube can be converted to a comparator. The base and column of the stand are of very heavy construction, the total weight being 48 lb. The table for supporting the pieces tested is 5 x 7 in., and is made flat within 0.0001 in. This table is provided with six T slots, which serve for securing two angle plates in any position or a V-block for the support of cylindrical pieces. The micro-indicator itself is supported in a heavy arm secured to the column by a strong clamp. The axis of the indicator is 3⅜ in. from the column. It is possible to measure flat pieces as large as 12 in. in width. The vertical capacity of the apparatus is 6 in. when using a spherical contact point.

Beitrag zur Methodik der Fasermessung (Fiber Measurement), B. SCHULZE. Papier-Fabrikant v29 n1 Jan 4 1931 p 4–5 1 fig. Easily constructed apparatus employed for direct determination of dimensions of fibers by measurement of projection.

Société Genevoise Model U–3 Micro-Indicator Stand. Am Mach v74 May 28 1931 p 843. This stand is designed for use with the fanshaped micro-indicator. It has an oval-shaped base 10 in. long x 7½ in. wide and rests on three rubber feet. A socket is bored to provide for the interchangeable mounting of different types of lower anvils or tables. The table is hardened and lapped optically flat. It is 1⅝ in. in diam. Arm movement is 6 in. The micro-indicator unit itself is mounted in the arm through an adjustment ring on the upper part of the supporting arm. The stand is 13¼ in. high and weighs 32 lb.

Tables for Société Genevoise Micro-Indicator Stand U–3. Am Mach v75 Sept 10 1931 p 435. A modification of micro-indicator stand U–3 comprises a V-block as the table adapting it to the support of small cylindrical pieces from ⅛ to 2 in. Pieces up to 6 in. can be checked on a large flat table of 4⅛ in. diameter. An adjustable square is also furnished for attachment to the column of the stand and serves as a stop.

Pratt & Whitney Electrolimit External Comparator. Am Mach v76 Jan 28 1932 p 151. The "Electrolimit" external comparator provides fast and accurate means for inspection of production. Maximum distance between anvil and spindle is 4 in. The anvil has a serrated surface 1½ x 3½ in. The anvil can be removed easily, and on the reverse side is a V-block. This equipment can be plugged into a 110-volt, 60-cycle line. Standard magnification of the circuit will cause the needle to travel about ⁷⁄₁₆ in. for each 0.001 in. variation in size.

Measurement of Fibre and Yarn Diameters by Diffraction Method, J. A. MATTHEW. J Textile Inst v23 n3 Mar 1932 p T55–T70 1 supp plate. Introduction and summary; theory, method, calibration and performance of diffraction method; details of other applications. Bibliography.

Standardization of Micrometers, A. KUTAY. Vestnik Standardtizatziyi n2 (50) Mar–Apr 1933 p 43–8 in Russian. Micrometer standards developed by Gage and Measuring Instrument Board of U.S.S.R.; micrometer errors; methods of determining deviations of surfaces from level and parallel; factors affecting micrometer errors, particularly scale graduation.

British Standard Specification for Micrometers (External). Brit Stand Instn—BS Specification n870 1939 18 p. Specification applies to: external micrometers having frame holding micrometer spindle and nut on one side opposite anvil on other with individual measuring ranges of 1 in. up to 11 to 12 in., and 25 mm up to 275 mm to 300 mm; setting gages for micrometers above 1 in. or 25 mm.

O.M.T. Omtimeter. Eng v150 n3909 Dec 13 1940 p 477; Mech Wld v109 n2819 Jan 10 1941 p 21–2. Illustrated description of Omtimeter, particular feature of which is projection attachment permitting instantaneous viewing at normal reading distance; range of scale of instrument is 0.005, and graduation in divisions of 0.00005; greatest height of work that can be accommodated is 7 in. and largest diameter is 6 in.

Draft Specifications for External Measuring Comparators. Eng v151 n3929 May 2 1941 p 358. Specification issued by British Standards Institution being circulated for technical comment; comparator is defined as measuring tool, consisting of measuring head on rigid stand over work table.

Engineers' Comparators for External Measurement. Brit Stand Instn—BS n1054—1942 9 p. General construction; work table; adjustments for size of work and for zero setting; measuring contact; operating pressure; stops to mechanisms; pointer; scale; accuracy of performance; protection during transport; marking.

Optical Comparators. J Sci Instrum v19 p 141–2 Sept 1942. Two models of the "optiage" are described. Both are for direct visual comparison of work with a standard, employing mech. and optical magnification. In one model the magnification is ×1,000, with a range of 0.001 in.; estimations to within 0.00002 in. are claimed. The second model has a magnification of ×100, with a scale of ±0.01 in., allowing estimations to 0.0001 in. A pivoted lever engages a fixed prism, rotation of which is shown optically. Drawings and details are given.

Accessories for Mechanical Comparator. Eng v156 n4044 July 16 1943 p 47–8; Engr v176 n4565 July 9 1943 p 37–8. Illustrated description of some new attachments for use with "Sigma" vertical comparator; first type is adjustable locating stop designed to facilitate placing of cylindrical work with its diameter exactly in line with plunger; second attachment is designed to facilitate checking of diameters of internal bores.

Mechanical Comparator. Eng v161 n4190 May 3 1946 p 414. Illustrated description of comparator manufactured by Sigma Manufacturing Co., intended for finer measurement; it has reading range of 0.002 in., or 0.001 in. on each side of zero line.

Large Cylinder and Taper Comparator for Gauge Measurement, R. H. FIELD. Can J Res v25 n3 (sec F) May 1947 p 238–41, 3 supp plates. Illustrated description of comparator for accommodating cylinders or cones with maximum diameters of 12 in. and lengths up to 48 in. designed and constructed during war at National Research Laboratories, Ottawa.

Le Comparateur, son Emploi son Fonctionnement, B. HUMBERT. Microtecnic v1 n5, 6, Oct 1947 p 241–4, Dec p 290–9. Comparator, its use and operation; illustrated description of various types, including some recent instruments manufactured in Switzerland. (In French and English.)

Measuring Diameter of Fine Wire, R. W. CARSON. Wire & Wire Prod v22 n12 Dec 1947 p 967–71, 995 (discussion) v23 n1 Jan 1948 p 63. Discussion of advantages and limitations of various types of diameter measuring instruments; analysis of effect of anvil pressure on accuracy of measurement; electronic micrometer is illustrated and described. Before Wire Assn.

Electronic Inspection. Aircraft Prod v10 n112 Feb 1948 p 52–4. Principles and applications of Cornelius comparator.

Tool for Measuring Large Diameters, C. BARNES. Eng Inspection v14 n1 Spring 1950 p 36–9. Difficulty of measuring diameters of large gear blanks during process of turning with giant calipers or large vernier gages; principles of instrument devised to simplify such measurements, which comprises, essentially, accurately constructed welded frame mounting dial gage and contact blocks; maintenance and use of gage. Reprinted from Machine Shop Magazine.

Dimensional Control on Automatics, Machy (London) v76 n1966 June 29 1950 p 925–6. Method developed by Sigma Instrument Co. Ltd., Letchworth, employing one vertical comparator in conjunction with range of suitable fixtures of simple design and so constructed that all dimensions on component can be measured, as distinct from being gaged, without resetting comparator; instrument and inspection sequence are described and illustrated.

The Diffraction of Electromagnetic Wave on a Dielectric Cylinder as a Method of Thickness Measurement for Quartz Threads, E. EBERHARDT. Zeit Angew Phys v3 n7 1951 p 242–6 in German. Theory is developed and experimental apparatus described for a comparative method of measurement of quartz threads. An experimentally obtained group of curves gives the relation between diffraction phenomenon and thread diameter. The accuracy and usefulness of the method is verified by data obtained with an electron microscope. The measuring accuracy of 7% is claimed for threads in the range $10–0.5\mu$.

A Simple Method for the Measurement of the Thickness of Very Thin Fibres and Threads, W. VOIGT. Optik v11

n11 p 509–10 1954 in German. A microscope attachment is described which allows the diameter of a fibre to be calculated. The fibre is in contact with another fibre or foil, whose movement is determined as the test piece is rotated. Examples of the method are given.

How Optics Replace Costly, Time-Consuming Inspection, J. P. WRIGHT. Am Mach v98 n8 Apr 12 1954 p 168–9. Application at Brown & Sharpe Mfg. Co. of optical method of measuring alignment errors in micrometers; interpretation of spindle relationship to anvil by relative position and motion, of their images on collimator reticle; operation with angle comparator can be carried out by unskilled inspectors more accurately in less than 2 min; micrometers can be manufactured more accurately than before.

Precise Measurement of Diameter of Fine Wires, I. G. MORGAN. Engr v200 n5206 Nov 4 1955 p 646–7; Eng v180 n4686 Nov 18 1955 p 703; Machy (London) v87 n2242 Nov 4 1955 p 1097–9. Apparatus for measuring diameters of wires to within 0.00001 in.; angle of tilt is measured by mirror and autocollimator and diameter of wire may thus be determined; apparatus developed in Metrology Division of National Physical Laboratory.

Comparator for Measuring Average Diameter of Work Which Has Nominally Circular and Uniform Cross-Section, L. W. NICKOLS. Machy (London) v88 n2251 Jan 6 1956 p 43–5; Engineer v200 n5214 Dec 30 1955 p 933–4. Comparator enables rapid measurements to be made and is particularly suitable for work in which departures from circular cross section may be appreciable, provided that these departures do not include any reentrant curves; construction of comparator; its setting and operation; range of measurement is from 1 to 2 in. diam; under favorable conditions error may be about plus or minus 0.001 in. Communication from NPL.

Measurement of Diameter of Opaque Cylinders by Scanning Microscopy, J. A. DOBROWOLSKI, W. GODFREY, P. N. SLATER, W. WEINSTEIN. J Opt Soc Am v47 n2 Feb 1957 p 186–90. Experiments show that for cylinders of diameter near optical resolution limit, scanning microscope gives too large size estimate; variation of error with aberrations and numerical aperture of scanning objective, and with wavelength and state of polarization of light were determined.

Precision Comparator for Small Cylindrical Work, J. C. EVANS, W. F. ATKINS. Engr v203 n5285 May 10 1957 p 716–7; Machy (London) v90 n2321 May 10 1957 p 1074–6; Eng v184 n4770 Aug 9 1957 p 182–3. Simple comparator designed at National Physical Laboratory, to enable diameters of small cylinders to be measured by simple technique to accuracy with plus or minus 0.00001 in.; by use of wedge, effect of errors of micrometer screw are reduced tenfold.

New Instrument for Precise Measurement of Fine Wire Diameters, L. WALTER. Wire & Wire Prod v33 n5 May 1958 p 543, 583–5. Equipment developed in National Physical Laboratory in Great Britain provides means of measuring wire up to about 0.01 in. diam to accuracy of 0.00001 in. or better; principal design feature is use of very light contact load at measuring anvils, thereby reducing to minimum errors of measurement due to compression of wire.

Messunsicherheit beim Messen von Durchmessern über 500 mm (Measurement Uncertainty in the Measurement of Diameters over 500 mm), L. WIZENEZ. Werkstattstechnik v49 n6 1959.

Measurement of Fibre Diameter Variation by Optical Diffraction, W. J. ONIONS, B. ELLINGHAM. Brit J App Phys v10 n7 July 1959 p 328–32. A theory is developed relating the intensity of light refracted at any given angle by a parallel array of opaque fibres of unequal diameters with the mean diameter and the coefficient of variation of fibre diameter. The ratio of the intensities of the first minimum and the first maximum is shown to depend upon the coefficient of variation of fibre diameter. This affords an opportunity of measuring fibre diameter variation. The possibilities and limitations of the method in practice are explored.

Berührungloses Messen grosserer Aussen und Innendurchmesser (Contactless Measurements of Large External and Internal Diameters), K. RÄNTSCH, E. LEPPER. 4 FOKOMA Munich Oct 6–7 1959 p 1959–10. Contactless measurement is an acute problem of the progressive finishing technique to the metrologist. This problem is solved electrically, pneumatically, and optically. The explanations of this paper are concerned only with optical contactless measurements, especially for external and internal diameters. Next the demands placed on new equipment are set forth for large measurements. An especially remarkable such measuring equipment is the flawless, contactless indication response of the cylinder surface. For this the field of surface indication is especially treated. Optical indicators of known and of newer kinds are systematically arranged and closely elucidated. Two principal groups of indication responses are thus developed. These chief groups are further classified. Thereby the application possibilities of the single indicators may be recognized. From this knowledge conclusions are derived for practical application in metrology. The already obtained experimental information presents a prospect of future flawless measuring methods.

An Image-Splitting Microscope for Accurate Measurement, J. DYSON. Nature (London) v184 Nov 14 1959 p 1561. Describes how, by fitting in the eyepiece a suitable image splitting device, the two images may be sheared across each other until edge-to-edge contact is obtained. By reversing the shear until edge-to-edge contact is again obtained, the diameter of the object may be measured. The technique is illustrated by application to blood corpuscles.

Systematik und Kennwerte von Laengenmessgeraeten fuer Bohrungen und Wellen mit Durchmessern ueber 500 mm (Systematic and Characteristic Values of Length Measuring Equipment for Holes and Shafts with Diameters over 500 mm), L. WIZENEZ. Werkstattstechnik v50 n8 Aug 1960 p 424–30. Design equipment, construction and materials employed for principal components of length measuring instruments for bores and shafts with diameters of over 500 mm; physical and technological characteristics; it is proposed that system of classification of instruments according to their measuring accuracy be established.

Tentative Methods for Measuring Diameter or Thickness of Wire and Ribbon for Electronic Devices and Lamps. American Society for Testing and Materials, ASTM Stand Part 2 F16–61T p 1495–501 5 figs. Describes procedures for measuring the diameter or thickness of round and flat wire (ribbon) 0.060 in. (1.524 mm) maximum, used in electronic devices and lamps. Mechanical measuring methods are based on the use of a sensitive measuring head with calibrated force settings, shaped measuring anvils to reduce errors caused by material curvature or waviness, and a method for presetting the anvil spacing by means of gage blocks or cylindrical master standards.

Fehlermöglichkeiten beim Messen Zylindrischer Teile mit Kugeligen Messflächen (Possibility of Errors in the Measurement of Cylindrical Parts with Spherical Measuring Surfaces), O. NIEBERDING, S. TROST. Zeit für Practische Metallbearbeitung v55 p 163 1961.

Optische Praezisionsgeraete fuer die Drahtmessung (Optical precision instruments for measurements on wire), A. METZ. Draht v12 n4 Apr 1961 p 153–4. Description of following Leitz instruments and their use : "Tolerator" for checking thickness tolerances within 1μ; two types of "Ultra-Projectometer" for checking tolerances with 1μ and 0.1μ, respectively ; measuring microscope, for instance, for determination of wall thickness of insulation of cable.

A Machine for the Precise Measurement of External Diameter, I. G. MORGAN, F. R. TOLMON, NPL. Machine Shop Mag v23 p 463 Aug 1962; Machy (London) v101 n2595 Aug 8 1962 p 295–301. Machine constructed at NPL has capacity from 0.2 in. to 3 in. and employs pneumatic measuring system ; design requirements ; principle of operation ; mechanical details and pneumatic system described ; method of use ; performance results ; new machine is capable of reproducing comparison between cylinder and slip gage to accuracy of about plus or minus 2μ in.

New Method of Measuring Diameters of Balls to High Precision, S. P. POOLE, NPL. Machy (London) v101 n2605 Oct 17 1962 p 904–7 ; Am Mach/Metalworking Mfg v107 n12 June 10 1963 p 159–61 ; Machine Shop Mag v23 n11 Nov 1962 p 618–21 3 figs 2 refs. Equipment described was designed to improve accuracy of measurement for balls of sizes below 0.2 in. in diam. by eliminating errors introduced through imperfect measuring faces ; measurements are made under very small measuring loads and true sizes of balls, i.e., diameters in uncompressed state, can therefore be accurately derived ; equipment, method of measurement and measuring force described. It is used in conjunction with the NPL-type slip gage interferometer and embodies a 5 mm parallel faced quartz block as the standard of reference. The sizes of balls below 0.2 in. diameter are measured by reference to the quartz block standard in terms of wavelengths of monochromatic light.

A Machine for the Precise Measurement of External Diameter, I. G. MORGAN, F. R. TOLMON, NPL. Quality Engr v26 n4 1963 8 p 6 figs 1 ref. The machine is designed for the measurement of diameter of standard cylinders from 0.2 to 3 in. to an accuracy of $\pm5\mu$ in. The cylinder is compared with gage blocks by means of a caliper having spherical steel anvils whose displacements are detected by a pneumatic measuring system. The anvils exert contact forces of only 3 g so that elastic deformation is negligible. The cylinder and gage blocks rest in close proximity and are not handled during measurement.

Compensated Electrical Instrument for Remote Measurements of Displacements, M. I. BELYI. Meas Techns 1962 n8 Feb 1963 p 641–2 1 fig 2 refs. Translated from Izmer Tekh n8 Aug 1962 p 17–9. Instrument uses a method of compensating two eunfs for direct measurement of linear displacements over large distances with an error not exceeding 10μ.

Instrument for Automation of Large Diameter Testing, V. A. TRUTEN'. Meas Techns 1963 n6 Nov 1963 p 465–70 2 figs 7 refs. Translated from Izmer Tekh n6 p 9–13 June 1963. From examination of existing methods it was found that instruments based on the decimal system and the rolling principle meet the requirements for precise and objective measurements, high efficiency, easy handling, and mechanical strength.

3.4. Internal Diameters

The Measurement of Large Internal Diameters, G. W. BURLEY. Prac Engr Jan 30 1913. Describes the rod gage and its use.

Length Gage, D. R. GALLAGHER. Machy (N.Y.) v26 Sept 1919 p 74; also May 1920 p 849. Describes a pin gage comprising a wooden handle and two wood screws. Gages of this type have been used successfully on work up to 60 inches in diameter.

Tapered Ring Gages, V. E. AYRE. Machy (N.Y.) v26 June 1920 p 971. Gives formulas for measuring tapered ring gages by means of balls.

New Light on Internal Measurements, J. BATH. Am Mach v54 June 30 1921 p 1110–4 4 figs. Forms of contacts for measuring cylindrical surfaces. Results induced by presence of oil on surfaces in contact. Holes measured by line contact. Measuring surfaces cleaned with soap and water. The holding film as a detector of irregularities. Interference bands in a ring produced by oil film.

Neue Optische Messverfahren für den Werkzeug und Maschinenbau (Zeiss Internal Measuring Machines), A. STEINLE. Maschinenbau v3 Jan 24 1923 p 244–9 15 figs. Description of Zeiss measuring machines and applications.

Measuring the Internal Diameter of Transparent Tubes, J. S. ANDERSON, G. BARR. J Sci Instrum v1 Oct 1923 p 9–15. Two methods: (1) Immersing the tube in a suitable liquid and varying the wavelength of the illuminating beam until equality of refractive index is attained so that, the system now being homogeneous, the diameter can be measured directly; (2) taking an X-ray shadow photograph of the tube and measuring the image found. Between the two methods accurate measurements can be effected no matter what the outside shape of the tube may be.

"Zeiss" Inside Measuring Attachment for Horizontal Optimeter. Am Mach v65 Aug 5 1926 p 264. To facilitate the work of measuring bores, both absolute and relative. Accuracy of 0.00004 in. claimed.

Société Genevoise Comparator for Small Internal Diameters. Am Mach v66 Mar 3 1927 p 389–90 1 fig. Made by Société Genevoise d'Instruments de Physique of Geneva, Switzerland, for use in measuring internal diameters of small size. Range 0.16 to 0.24 in. Comprises a rectangular table and a comparator tube.

"Standard" External and Internal Comparators. Am Mach v74 June 11 1931 p 925. The external gage is available with a dial indicator or a fan-shaped scale. The dial-scale is graduated to 0.0001 in. in widely spaced divisions, whereas the fan-shaped scale is graduated to 0.00005 in., and may be fitted with tolerance markers. Optically flat 4-in. tables with serrated surfaces are furnished with the external gages. Pieces up to 6 in. in height can be accommodated under the direct-acting dial plunger. The internal gage is for exploring holes for bell mouth, taper, and out-of-roundness. Ball racings and bushings can be quickly checked for the above conditions. The dial is graduated to 0.0001 in. The work is slipped over two arms projecting from the body. Comparators for bores from ½ to 3 in. and up to 3 in. in length are available.

Internal Attachment for Zeiss Vertical Optimeter, G. SCHERR CO. Am Mach v76 Aug 31 1932 p 983. Measurement of bores from ¼ to 4 in. to within 0.00005 in. accuracy can be done with an adjustable internal attachment, which is now available for the Zeiss vertical optimeter, an optical precision amplifying gage. Means

are also provided for determining taper and for finding both minimum and maximum diameter of the bore. The attachment slips over the vertical post of the optimeter.

Optische Pruefung von Hohlraeumen und langen Bohrungen (Optical Testing of Hollow Spaces and Long Bores), G. ZIEHER. Maschinenbau v16 n13/14 July 1937 p 347–50. In order to obtain required exactness of modern production methods special measuring tools have to be designed; equipment for measuring bores, wall thickness, tapering, parallel alignments, etc., described.

Electric Indicator Gauge. Machy (London) v54 n1397 July 20 1939 p 504–6 and v55 n1416 and 1417 Nov 30 1939 p 213–7 and Dec 7 p 241–3. Illustrated description of gage or comparator developed by AEG, Berlin in cooperation with Bauer & Schaurte, which can be used for both external and internal measurements; gage comprised mechanical and electric units, together with indicating equipment.

Rachenlehrenpruefung mit Innenmessgeraeten, H. SCHORSCH. Werkstattstechnik und Werksleiter v34 n2 Jan 15 1940 p 21–5. Testing of jaw type gages by aid of internal measuring disk according to DIN and ISA specifications, described.

Internal Micrometers. Brit Stand Instn—BS n959—1941 15 p. Specification applies to internal micrometers comprising measuring head, extension rods with or without spacing collars, and in smaller sizes, handle; provision made for three sizes of measuring heads in both inch and metric units.

"Three-point method" of Measuring Bores, C. C. STREET. Instrum v14 pt1 n1 Jan 1941 p 6–7. Principle of method is that of determining change in altitude of isosceles triangle that can be contained in bore under inspection; mathematical discussion shows manner in which such gage can give true difference in diameter between master setting ring and bore under inspection.

Bohrungsmessung mit Zwei- und Dreipunkt-Geraeten, G. BERNDT. Zeit Instrumkde v 61 n3 Mar 1941 p 69–82. Second part of discussion on principles, methods, and advantages of "two-point" and "three-point" instruments for measuring bores; formulas for evaluating required dimensions from measured values for point, ball and rounded gages.

Method for Measuring the Internal Area of Section of a Glass Tube, D. J. BEHRENS. Phil Mag v31 Mar 1941 p 199–203. The external and apparent internal radii at the section are determined from 3 microscope readings and the determination repeated at intervals at 30° around the section. The author gives the theory, which is applicable whether the internal or external sections are concentric or not, so long as the external section is circular and the internal section is everywhere concave.

Electrical Tube Gauge, E. FAWSSETT. Eng v156 n4057 Oct 15 1943 p 301–2. Illustrated description of electro-mechanical instrument for measuring internal diameter of long tubes, which is capable of being used by semi-skilled labor, particularly women, in quickly checking internal diameter of air heater tubes in position.

Electric Gaging to High Accuracy, W. F. ALLER. Elec Mfg Feb 1944. Describes Sheffield internal-external measuring instrument.

Electrolimit Internal Comparator. Western Machy & Steel Wld v35 n3 Mar 1944 p 108–9. Some applications of Pratt & Whitney Electrolimit internal comparator are presented; series of photos and brief description given.

Size Control. Automobile Engr v34 n454 Oct 1944 p 397–400. Reasons for use of end standards are discussed, with special reference to end standards produced by Pitter Gauge and Precision Tool Co.; description also given of two devices developed by this Company, stick micrometer for internal measurements and Universal Measuring Block.

Bore Inspection, A. E. THOMAS, T. E. JONES. Aircraft Prod v10 n116 June 1948 p 187–8. Fine measurement of interrupted and soft surfaced bores; new method evolved at AID Test House, Harefield; application to measurement of rotor subassembly for high pressure fuel pump; method gives accuracy to within 0.00002 in. and with appropriate modification of anvils and stylii, it might satisfactorily be applied to other problems of internal measurement.

Comparator Gauge for Internal Measurements, L. SANTER. Commonwealth Engr v35 n11 June 1 1948 p 435–6. Principles of dial instrument developed during investigations on creep in timber at split ring and shear plate connector joints; based on Scott-Russell straight line motion, gage eliminates personal error in setting, allows much greater number of readings to be recorded in limited time, is much easier to read and requires less skilled operators.

Rings and Plugs Checked to Hundredth of a Thou, M. J. PUTTOCK, NPL. Mach Oct 16 1948. Describes method of using an electric gage for the precision measurement of circularity, concentricity, and straightness of plain and tapered rings and plugs.

Comparator for Measuring Diameters of Small Holes, E. R. DYMOTT, W. O. JENNINGS. Machy (London) v73 n1878 Oct 21 1948 p 590–1. Experimental apparatus assembled for measuring diameters of ring gages and holes from 0.5 in. (13 mm) down to 0.1 in. (2.5 mm) by comparison with slip gages; comparator gives results accurate to plus or minus 0.00003 in (0.0008 mm).

Bore-Measuring Micrometer. Eng v167 n4339 Mar 25 1949 p 272; Engr v187 n4860 Mar 18 1949 p 312. Matrix Micro-Maag internal micrometer introduced by Coventry Gauge and Tool Company is suitable for measuring bores between 1 and 2 in. diam and up to 15 in. deep, to within 0.0001 in.; photographs, drawings.

Odd-Sized Holes to Millionths, E. J. TANGERMAN. Am Mach v93 n24 Dec 1 1949 p 77–80. Steps taken at Bryant Chucking Grinder Co., Springfield, Vermont, toward achieving superprecision finishing of odd sized holes by grinding; special electronic gage produced by company; correct assembly of gage blocks, and new developed heavy duty clamp considered as most important factors in attaining standard within ±0.000002 and in transferring dimension to hole within 0.000008.

Measurement of the Internal Diameters of Metallic Capillary Tubes, C. T. COLLETT, J. C. HUGHES, F. C. MOREY. J. Res. NBS v45 p 283–8 Oct 1950. The uniformity of the internal diameters of some metallic capillary tubes was studied by means of a small thread of mercury, using X-ray technique, following the method of Fisher. Eight tubes out of a group of twelve were selected as suitable for use in an absolute viscosimeter, and flow constants were computed. The tubes studied were about 15 ft long, with an internal diameter of about 0.015 in. Maximum deviation from the average diameter in most cases was about 1.5% or less.

Matrix Micro-Maag as Internal Gauging Standard, M. MAAG. Microtecnic v6 n1 1952 p 26–9. Set of gages comprising internal micrometers, and assortments of reference rings, measuring needles and various adjuncts; internal micrometer is three-point contact instrument with accuracy of 1 micron permitting detection of out of

roundness; particulars of various types of Micro-Maag sets for use as workshop reference standards.

New Precision Internal Measuring Machine, C. O. TAYLERSON, A. TURNER, NPL. Symposium on Engineering Dimensional Metrology Proc. 1953 p 73. Measures ring gages from 0.1 to 1.5 in. to ±0.0001 in. by comparison with gage block combinations.

Diffraction Patterns in Circular Aperture Less Than One Wavelength in Diameter, S. L. ROBINSON. J App Phys v24 n1 Jan 1953 p 35–8. Measurements of diffraction patterns from 0.2 to 1.0 wavelength in diameter with plane polarized electromagnetic wave incident normally; microradiation relative to that of unperturbed beam determined at points along electric and magnetic diameters of apertures; data disagree with calculations from Young's circuited form.

Shardlow Imicro Internal Micrometer. Machy (London) v82 n2112 May 8 1953 p 879–80. Micrometers introduced by Tesa, S. A. Renens-Lausanne, Switzerland, are produced in many ranges by British company; construction of micrometer and method of operating anvils described.

Pneumatic Gaging Applied to the Measurement of the Bore of Tube, R. CHITTLEBURGH, E. F. POWELL, G. F. MORTON. J Sci Instrum v31 p 20–2 Jan 1954. A method is described which enables the bore of a tube to be measured accurately at all positions along the length of the tube. The method is particularly suited to the measurement of the bore of tube manufactured to close tolerances. With a method of amplification incorporated into the system, it is possible to determine whether the bore of tube having large tolerances, e.g., ½ in. bore with a tolerance of +¹⁄₃₂ in., lies within those tolerances. A steel ball is placed within the tube and held in position by an electromagnet. The ball serves as the second constriction in a pneumatic system, air at constant pressure being supplied to one end of the tube through a first constriction of fixed size. The pressure developed between the two constrictions is a measure of the gap between the steel ball and the inner wall of the tube.

Measurement of Small Holes, I. A. GRIGOR'EV. Dept of Sci and Indust Res. Her Majesty's Stationery Office, London 1956 137 p. Discusses contact devices and methods as well as contactless methods.

Measurement of Small Holes, L. A. GRIGOR'EV. GB Dept Sci & Indus Res 1956 137 p. Study of possibility of applying limit plug gages in sizes below 1 mm; series of tolerances for holes between 0.1 and 18 mm diam; contact devices and contactless methods; application of internal gages with taper pin, spring type internal gage, and other mechanical means of measuring small holes. Translated from Russian.

Internal Measuring Machine. Engr v203 n5274 Feb 22 1957 p 304. Machine made by Coventry Gauge and Tool Company stated to be capable of measuring diameters of finely ground or lapped bores to accuracy of plus or minus 0.00001 in. or less; it is basically comparator using high precision slip gages as reference standards.

Prototype Instrument for Measuring Diameters of Very Small Bores, P. W. HARRISON, G. M. SEVERN. Machy (London) v94 n2428 May 27 1959 p 1210–3. Instrument developed at National Physical Laboratory is capable of measuring bores down to 0.03 in. diam, with lengths up to 1½ in. to accuracy of about 0.00002 in.; principle of operation; contact sensing device; measuring stylus; apparatus described; observational procedure.

Machine for Precise Measurement of Internal Diameter, I. G. MORGAN, F. R. TOLMON. Machy (London) v95 n2451 Nov 4 1959 p 941–6. Prototype machine built by National Physical Laboratory; existing equipment, primarily Zeiss universal measuring machine, was used to

save initial expense, and measuring range is therefore limited to diameters between 1.5 in. and 3.5 in.; diameter of ring to be measured is established by comparison with known size of reference standard of box form built up from slip gages and lapped steel endplates; measuring equipment and procedure; performance tests.

Machine for Precise Measurement of Internal Diameter, I. G. MORGAN, F. R. TOLMON. Microtecnic v14 n1 Feb 1960 p 14–20. Prototype machine for precise measurement of internal diameter; machine was developed for confirming performance of existing machines for diameters up to 6 in. (150 mm) and investigating possibility of improving upon accuracy of measurement at present obtained; comparative tests show agreement between machines and that accuracy of plus or minus 5μ in. (plus or minus 0.125μ) can be obtained.

Minutes of Meeting No. 3 on Internal Diameter Calibrations and Measurements of the Measurements Research Conference. NBS June 15 1960. Contains schematic drawings of various commercial measuring devices.

Verfahren zum Erfassen der Umkehrpunkte Beim Messen grosser Bohrungen und Wellen, L. WIZENEZ. Werkstattstechnik v50 n7 July 1960 p 363–70. Methods for determining "reversal points" in measuring large bores and shafts; errors occurring in sensing of cylindrical bodies; three different sensing methods, their advantages and disadvantages described.

Measurement of Dimensions in Inaccessible Places, I. A. KUPTSOV. Meas Techns 1959 n12 Sept 1960 p 939 1 fig. Translated from Izmer Tekh n12 Dec 1959 p 13. The universal lever instrument with dial gage is being widely used in measuring the deviation of holes from a common axis, the thickness of walls at a considerable depth in small holes, the direction of teeth and internal grooves of small diameters, and other similar dimensions.

Instrument for Measuring Very Small Bores, P. W. HARRISON, G. M. SEVERN. Engr v210 n5460 Sept 16 1960 p 467–9. Modifications and additions made to prototype at National Physical Laboratory; electric motor now drives worm shaft and relay halts stylus; smaller stylus, 0.014 in. ball on tungsten stem, extends range down to bores of 0.02 in. diam; holes down to 0.0008 in. diam have been made.

Further Development of NPL Prototype Instrument for Measuring Very Small Bores, P. W. HARRISON, G. M. SEVERN. Machy (London) v97 n2497 Sept 21 1960 p 699–700; Quality Engr v24 n6 Nov–Dec 1960 p 181. Reference made to instrument previously described by authors (see Engineering Index 1959 p 665); circuit for instrument modified; construction of even smaller stylus comprising ball of 0.014 in. diam mounted on tungsten stem.

A Method of Measuring Internal Diameters of Pipes by Means of an Electrical Hole Gauge, D. E. ROKHMAN, V. R. TYR. Meas Techns 1960 n2 Nov 1960 p 94–5 1 fig. Translated from Izmer Tekh n2 Feb 1960 p 6. The instrument here described is intended for measuring pipe diameters over their entire length for research purposes; yet, a further improvement of its design and, in particular, its equipment with a centering device, will convert this instrument into an engineering tool for checking the internal diameter of pipes. If required, the variations of the internal diameter values can be recorded on an oscilloscope film.

End-Pieces for Internal Measurement Devices, I. S. VASILENKO. Meas Techns 1960 n2 Nov 1960 p 95 2 figs. Translated from Izmer Tekh n2 Feb 1960 p 7. In the case of internal grooves or stepped diameters it is often difficult to measure dimensions accurately. For such measurements attachment IZO–1 to micrometer UIM–21, with an end-piece which has a large diameter sphere, can be used.

Measurement of the Internal Cell Length of Glass Measuring Cells, H. MORET. Rev Sci Instrum (USA) v33 n2 p 241–3 Feb 1962. The paper describes a novel method, which would appear to be of general application. An accuracy of a few microns is claimed. A brief description indicates how the method can be extended to determine the cell length over the whole cell window area.

Measuring Small Internal Dimensions on an Optimeter, P. U. MARKOV. Meas Techns 1961 n10 Mar 1962 p 790–1 5 figs. Translated from Izmer Tekh n10 p 16–7 Oct 1961. A measuring method was developed based on the utilization of a horizontal optimeter and brackets redesigned for the purpose of measuring small holes.

Eine neue Messmaschine fuer Innendurchmesser, W. KIRCHNER, G. BRAUNE. Werkstattstechnik v52 n6 June 1962 p 291–4. New measuring machine for inside diameters; design and construction of machine used in particular for bores of ring gages; it operates according to principle by Abbe and has range from 3 to 120 mm; measuring inaccuracy is only plus or minus 0.1μ in.

Some Inside Facts on Inside Measurement, L. O. HEINOLD, JR., ISA Proc Preprint 2.4.62 for meeting Oct 15–8 1962 6 p. New standards for equipment performance, ring geometry and laboratory reporting are suggested which must be acted upon before state of art can move forward.

Measurement of Small Holes by Means of the "Magic Eye," B. Ya. VERKHOTUROV. Meas Techns 1962 n9 Apr 1963 p 726–8 4 figs 1 ref. Translated from Izmer Tekh n9 p 12–4 Sept 1962. "Magic eye" is a tube 6E5 attachment to a universal microscope. When the probe touches the measured hole the shadow in the tube spreads, thus indicating a contact. The component with the hole under test is placed on the microscope stage. The probe is inserted to a certain depth into the hole, the position of the diameter plane is found and the diameter of the hole $d = L + d_p$ is determined, where L is the difference in the readings of the microscope scale, d_p is the diameter of the probe.

Een nieuwe meetmachine voor het Meten van Inwendige Diameters. (New machine for measuring internal diameters), J. M. MULLER. Polytechnische Tijdschrift v19 n11 May 27 1964 p 464–7. Design and operation of machine developed by Kugelfischer Georg Schaefer & Co, Schweinfurt, West Germany; special design features which were made necessary by high requirements to be met by measuring machine; illustrated description of some components which are particularly important for accuracy of machine.

3.5. Measuring Machines and Bench Micrometers

The Whitworth Measuring Machine. Proc Inst Mech Engrs 1856; Am Mach v47 1918 p 189.

Measuring Machines, Cornell. Am Artisan November 1874; Am Mach v29 May 17 1906 p 655–6.

The Whitworth (Millionth) Measuring Machine, T. M. GOODEVE, C. P. B. SHELLEY, 1877.

Standards of Length as Applied to Gage Dimensions, G. M. BOND. J Franklin Inst 3d ser v117 p 318–86 May 1884. Illustrates end standard, Whitworth measuring machine, bench micrometer, etc. Discusses accuracy, tolerances, etc.

Standard Measurements in Machine Construction, F. J. MILLER. Am Mach v15 9 Jan 7, 21 1892 14 figs. Prof. Sweet's bench micrometer is shown in Fig. 5.

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The Army Gun Factory Comparator, J. E. HOWARD. Notes on the Construction of Ordnance n63, Ordnance Office, Washington Oct 13 1893 10 p 10 figs. Describes a transfer comparator, designed for laying off the distances defined on a line standard bar, and establishing definite distances between or over the ends of contact points for the adjustment of end measures, either for interior gage rods and measures or for exterior diameter calipers. Its capacity is from 0 to 70 in. for gage rods and from 5 to 75 in. for exterior calipers.

Automatic Recording Instrument for End Measurements, L. HARTMANN. CR Acad Sci v120 1895 p 1024–9. Briefly describes (without illustrations) an instrument which measures to 0.001 mm. lengths by comparison with end standards. Instrument records measurements. Can be used for measuring diameters of cylinders, etc.

An Electric Micrometer for Laboratory Use, P. E. SHAW. Phys Rev v16 Mar 1903 p 140–57 6 figs. An instrument of considerable adaptability having delicacy of 0.0001 mm or less, accuracy, and great length of scale.

A New English Measuring Machine. Am Mach v26 July 2 1903 p 964–5 5 figs; Eng v108 p 104–5 July 25 1919. A description of the Newall Measuring Machine, having a tilting level indicator.

The Improved Electric Micrometer, P. E. SHAW. Proc Roy Soc A v76 Aug 4 1905 p 350–9. Limits to its practical sensitiveness (4×10^{-8} cm) have been reached. Paper states in detail the form, peculiarities, and limitations of the apparatus. First used for the measurement of the amplitude of a telephone diaphragm.

Recent Improvements in the Newall Measuring Machine. Am Mach v28 Nov 30 1905 p 734–5 3 figs. Illustrates and describes the new features recently introduced and the increase in size, the latest machine having a capacity of six feet. Discussion, J. E. STOREY, Am Mach v29 Feb 8 1906 p 183, Applications of the Newall correcting device to precision lathes.

Six-foot Measuring Machine. Constructed by the Newall Engineering Co. Ltd. Eng v81 Jan 19 1906 p 78–9 6 figs; Am Mach v29 Apr 12 1906 p 488–9. Designed for use with contact or line standards. Has spirit-level indicator.

The English Precision Lathe and the Newall Measuring Machine, J. E. SWEET. Am Mach v29 Feb 8 1906 p 172–3 5 figs and discussion, J. E. STOREY, April 12 p 488–9, and J. E. SWEET, May 17 p 655–6. Design of screws and nuts for precision work. Includes description and illustration of the Cornell measuring machine with references.

An Electrical Measuring-Machine for Engineering Gages and Other Bodies, P. E. SHAW. Eng v81 June 29 1906 p 865–8 13 figs. Abstracted from the Proc. Roy. Soc. A v77 Dec 1 1905 p 340–64 10 figs. Describes a method having the advantage of being more sensitive than the old method, and giving an illustrated description of the machine. See also Sci. Am. Supplement Apr 7 1906.

Transverse Comparator, W. KÖSTERS. Wissenschaftliche Abh der Kaiserlichen Normal-Eichungs Commission, v8. Julius Springer, Berlin, 1908.

A Measuring Machine of Simple Construction, O. E. PERRIGO. Am Mach v31 Aug 20 1908 p 271–2 6 figs. A work gaging machine with sliding contact plunger and multiplying levers for moving the indicator pointer over a graduated arc.

The Picard and Colomb micrometer, Am Mach v32-2 Oct 7 1909 p 620–1 2 figs. Report of the Committee of Economic Arts of the French Society of Encouragement for National Industry on micrometer measuring machine, for measurement of objects with parallel sides or the diameters of cylinders. Has hydraulic indicator.

An Electro Micrometer, G. J. MURDOCK. Am Mach v32 Dec 16 1909 p 1025–7. Illustrated description of a tool for accurate measurements, general testing, and comparison. Especially adapted for obtaining accurate measurements of the inside diameter of bushings and other work when held in a chuck, where the hole is so small that the common inside micrometer cannot be used.

Messmaschine von H. Hommel, D. GÖPEL. Mech Ztg 1910 p 1–5.

Automatic Micrometer Calipers. Mech Engr (GB) v26 Aug 26 1910 p 248–51 17 figs. Illustrated description of a series of automatic calipers made in England. Fig. 1, auto calipers, 1 inch between jaws, divided in .01 in. and $\frac{1}{16}$ in. to $\frac{1}{128}$ in. Fig. 2, do. Fig. 3, large auto calipers with from 6 to 38 in. reach. Fig. 4, large auto calipers, with base to screw to bench, for measuring leather or large metal, etc., sheets. Figs. 5, 6, 7, types of graduated dials. Fig. 8, autocalipers, divided to 0.001 inch. Fig. 9, Imperial auto wire gage, to give direct readings in W.G. Nos. 1 to 30. Fig. 10, Vulcan patent plate gage. Fig. 11, auto sliding calipers, to measure up to 6 in., dial marked every 1 mm. Fig. 12, Auto sliding calipers with one dial in mm and 1 in inches. Fig. 13, large auto micrometer with 5 in. dial to measure $\frac{1}{8}$ in., marked in 0.0005 in. Fig. 14, large auto micrometer with handle. Fig. 15, large auto micrometer. Fig. 16, large auto micrometer with 7 in. dial for quickly measuring large quantities of samples. Fig. 17, auto micrometer with large reach of frame for measuring thickness of sheets of felt or similar materials.

A Standard Measuring Machine, P. E. SHAW. Roy Soc Proc Ser A v87 Oct 31 1912 p 385–90. Gives an outline of the scope of an improved type of machine constructed by the author on the principle of electric touch (Science Abstract No. 1116, 1906) and now installed at the NPL. Details and results to be given later.

The Reinecker Measuring Machine, A LEMAN. Zeit Instrumkde Beib4 Feb 15 p 33–9 and Mar 1 1913 p 45–8; D Mech Ztg (Berlin) 1913 p 33 and 45. Communication from the Phys-Techn Reicchanstalt. The peculiarity of this machine as compared with the usual mechanical touch machine invented by Whitworth, is the indication of contact shown by the rise of a dilute solution of alcohol in a capillary glass tube. Sectional drawings are given and some methods of adjustment are indicated.

Electrical Measuring Machine, P. E. SHAW. Inst Mech Eng Proc v2 Mar–Apr 1913 p 579–629; Elect Rev v73 July 25 1913 p 127; Electrician v72 Oct 10 1913 p 9–11. A new measuring machine is described founded on the principle of electric touch (See Sci. Abs. 1116–1906 and 718–1911). Applicable to measurement of cylindrical, spherical, or parallel-faced bodies. The present machine embodies improvements. Unit of measurement is 0.0001 mm.

Large Measuring Machines Constructed by Société Genevoise. Eng v98 Sept 11 1914 p 323–6. One of these is adapted to measure a gage of even 3 m long. One new feature in the machine is a rolling foot, allowing that change in temperature shall produce no strain along the length of the bed. The most accurate of the machines described measures to 1 micron. The reference scale, instead of being fixed, is placed at the horizontal level of the micrometer screw and moves with it. The advantage here is that a cosine error, instead of as usual a sine error, is introduced.

Slocomb Bench Micrometer. Machy (N.Y.) v21 Mar 1915 p 591. Range 0 to 6 in. Graduated to 0.0001 inch.

Methods of Measurement, D. T. HAMILTON. Machy (N.Y.) v22 Oct 1916 p 100–8 18 figs. A survey of measuring machines and comparators. The following types of universal measuring machines are shown : Fig. 8, Brown & Sharpe measuring machine, Figs. 12, 13, Slocomb standard measuring machine; Figs. 14, 15, Société Genevoise measuring machine ; Figs. 16, 17, 18, Newall standard type of measuring machine ; Fig. 20, Reinecker measuring machine.

A Length Comparator for Determining Linear Coefficients of Expansion, W. L. DE BAUFRE. J Am Soc Naval Engrs Nov 1916. Construction and operation with method of calculating.

Mikroskop Fühlhebel für Schrauben-Messmaschinen (Microscopic Indicator on Measuring Machines), F. GOEPEL. Zeit InstrumKde v37 July 1917 p 142–5. From the Phys Techn Reichsanstalt. The anvil end of the measuring machine is controlled as usual by a spring. On being pressed back, when a gage is being measured, the far end of the anvil bears against a sensitive lever by which any movement is multiplied 30- or 40-fold. The end of the long lever-arm carries an illuminated index mark, which is viewed by a low-power microscope. The unit is 0.0001 mm.

The Taft-Peirce Measuring Machine, E. J. BRYANT. Am Mach v47 Nov 22 1917 p 913–4 ; Inspector, v1 p 9 and 17 Aug 15 1919.

A Simple Form of Measuring Machine. Engr v125 Apr 5 1918 p 302 1 fig ; Iron and Coal Trades Rev, March 8, 1918. Measuring machine made by Armstrong, Whitworth and Company, Ltd., is adaptable to a variety of gage measurements. Cylindrical feeler is used. Specially shaped anvils are provided for various classes of work. Major, pitch, and minor diameters of screw thread gages can be measured.

Coats Precision Fluid Gage. Am Mach v49 Sept 5 1918 p 451. Describes Prestwich amplifying comparator having a diaphragm which actuates fluid in a capillary tube.

A Universal Measuring Machine. Am Mach v53 July 8 1920 p 49–53 14 figs. Engr v129 May 7 1920 p 472–3 and p 476 9 figs partly on 2 supp plates. Construction and method of operation of universal measuring machine made by Société Genevoise and designed for accurate measurement of pieces of all shapes. Machine is intended as primary standard of measurement for use chiefly for measuring gages or parts of all descriptions, for measuring screw threads and as a rapid comparator. All measurements are made with reference to a standard scale mounted in a case, shown at the left side on top of the bed, it being read by means of a microscope, never coming in contact with the object being measured. The axes of the scale and of the work being measured are directly in line, thus reducing the chance of error. The headstock at the right contains an indicator to enable the obtaining of the same pressure for each measurement. The fixture in the center is for use when measuring screw threads.

Precision Measuring and Inspection Devices, R. J. WHIBLEY. Machy (N.Y.) v27 Oct 1920 p 135–9 10 figs. Optical methods developed at British National Physical Laboratory, for facilitating inspection.

Leonard Optical Comparator, 12 in. Am Mach v53 Oct 1920 p 88. The machine is intended to register accurately length measurements up to 12 in. within a limit of 0.0005 in. It has a heavy-section box bed, on the machined top surface of which are mounted two headstocks, one fixed and one adjustable. Each headstock carries an anvil, the measurement being made between the anvils.

The fixed headstock carries a light box and the optical element, also the amplifying mechanism. The amplifying mechanism is so designed that any slight movement of the main body adjusts the ratio between the two sides of the first lever, maintaining the ratio of 7 to 1. The smallest lever is the most important feature of the whole unit, as any slight error on this causes considerable alteration to the scale. A total magnification of 1,000 can be obtained.

Neure Feinmessgeräte für die technische Längenbestimmung (Modern Measuring Instruments for the Technical Determination of Lengths), G. BERNDT. Zeit VDI v65 June 18 1921 p 639–43 19 figs. Discusses improvements in comparative measurements with gage blocks and measuring machines. Almost the same accuracy can be obtained with mechanical and optical lever gages, such as minimeters, optimeters, microscopic lever gages, etc., which are described. Details of Göpel and Kösters interference comparators, used for finer measurements. Summary of all measuring machines in which the order of fineness has been changed from 0.00001 to 0.000001 inch. Describes the following briefly and critically : 1 Pratt and Whitney, 2 the German form which employs a liquid indicator, 3 Geneva Society with microscope and later for use with indicator, 4 machines with indicators by Eden and Sears, 5 machines using indicators by Göpel, 6 Zeiss optimeter, 7 Shaw's electric micrometer, 8 the interference comparator of the Reichsanstalt, 9 other less well known forms.

An Extensometer Calibrating Device, R. L. TEMPLIN. Chem and Met Eng v25 Aug 10 1921 p 248–51 5 figs. Describes various instruments and methods of operation.

Accurate End Measurement on Measuring Machines Using a Screw, H. BAKER. Engr v134 July 28 1922 p 81–3 6 figs. Experiments relating to attempts to measure correctly to one ten-thousandth of a millimeter. Description of machine used and methods. Using a machine of the Société Genevoise make, with the endeavor to attain consistent work to .1 micron the author finds many precautions necessary, which are enumerated. Experiments with oil film in micrometer screw, with dry screw, high tension, etc.

The Pratt and Whitney Supermicrometer. Am Mach v57 Aug 31 1922 p 355 ; Machy (N.Y.) v29 Sept 1922 p 68 ; Am Mach v66 Mar 31 1927 p 552 ; Eng v124 Dec 9 1927 p 747. Instrument which occupies position intermediate between ordinary micrometer calipers and an elaborate measuring machine, is intended for general use by tool makers, inspectors and mechanics, in shops where measurements of 0.0001 in. are required. Has a capacity of 8 in. and settings are made by use of gage blocks. Has controlled measuring force and work support of various forms.

Messmaschinen und ihre Bedeuting für den modernen Betrieb, H. SCHULTZ. Präzision v2 May 1923 p 104.

Transversal und Longitudinal—Komparatoren für Längenmasse (Transverse and Longitudinal Comparators for Length Measurements), W. KÖSTERS. Präzision v2 1923 p 168.

The Wickman Gauge Measuring Machine. Engr v135 Mar 9 1923 p 266–8 8 figs. Machine for verification of workshop gages, to be carried out quickly and accurately.

Measurement of Thin Elastic Plates, C. CHENEVEAU, J. CALLAME. CR Acad Sci v177 Nov 5 1923 p 872–4. Describes a form of apparatus devised to measure accurately the thickness of a thin plate of elastic material. A vertical rod, bearing a fiducial mark, rests on the plate so that the pressure is constant and as small as possible. The height of the mark is measured by means of a microscope. The pressure may be altered, if desired, by placing weights on a pan carried at the top of the rod.

Bethel-Player Measuring Machine and Comparator, Am Mach v61 n13 Sept 25 1924 p 521 1 fig. Uses gage blocks as standards and a tilting level as an indicator.

Technische Messgeräte (Technical Measuring Instruments), W. BLOCK. Maschinenbau v3 Nov 13 1924 p 1036–8. Discusses basic difference of scientific and technical measuring, independence of foreign instruments, simplification of existing instruments, etc.

Universal Measuring Machine. Machy (N.Y.) v31 Jan 1925 p 387–8 5 figs. Improved machine known as Hanson-Whitney universal type, which is in part a comparator and in part direct measuring machine using precision screw and large graduated measuring wheel and vernier for obtaining accurate measuring. Two multiplying lever indicators are embodied in the machine.

End Measuring Machine at the National Physical Laboratory. Machy (London) v26 Apr 28 1925 p 113–4 2 figs. Special micrometer head stock and indicating tailstock form essential parts of machine. Measurement of short gages and of thermal expansion of short gages by interference methods.

High Precision Measuring Machines, T. TODD, Am Mach v63 Sept 10 1925 p 420. Discussion of article by J. K. WOOD, Am Mach v62 p 945. Deals with measuring pressures of workmen.

An Electrically-Controlled Micrometer Caliper, C. MOON. J Opt Soc Am and Rev Sci Instrum v11 Oct 1925 p 453–8. A description of a special micrometer caliper fitted with electrical control for remote operation. The headstock and tailstock are supported by a heavy ring frame. The headstock screw is driven by a very small electric motor, and in the tailstock there is a mechanism which automatically stops the motor by opening a set of electric contacts when the critical measuring pressure is reached. The caliper was designed for measuring the diameter of a precision single-layer inductance coil while both coil and caliper were in a constant temperature enclosure.

Thickness Measurements of Compressible Materials, R. W. BROWN. India Rubber Wld v76 July 1 1927 p 197–8 5 figs. It is believed that appreciable increase in accuracy of measuring compressible materials will be realized with more general recognition of effect on such measurements of linear accuracy, foot size, foot pressure, and parallelism of feet; standardization of these factors would eliminate confusion existing at present.

The Hilger "Tenthou" Comparator, C. F. SMITH. Machy (London) v31 Dec 1 1927 p 263 2 figs. Brief account of optical gage or comparator which measures differences to accuracy of 0.0001 in. (0.00254 mm); designed to measure depressions in rubber; projects bright line on white scale 10 in. length, divisions of which measure to 0.05 in.; total difference of 0.02 in. measured directly to 0.0001 in., and by estimation to 0.00005 in.; small constant pressure applied to object by contact point; only one moving part.

Motor Micrometer of Glasgow Transit-Circle, L. BECKER. Monthly notices Roy Astron Soc v88 May 1928 p 604–6. An electrically driven micrometer, running 280 rev. per sec. without appreciable variation by means of which greater accuracy could be obtained than by another mode of observation.

The Calibration of Extensometers, R. K. TEMPLIN. ASTM Preprint v96 for mtg June 25 1928 8 p 3 figs. Details of new design of calibration device suitable for calibrating extensometers arranged for measuring deformations on gage lengths varying from $\frac{1}{2}$ to 10 in., inclusive; device indicates total deformations to nearest 0.000002 in.; errors due to temperatures, design, workmanship, and manipulation are discussed; calibration data pertaining to micrometer screw are included together with results

obtained on few different types of commercial extensometers.

Carl Zeiss Precision Measuring Machine, G. SCHERR. Instrum v1 Nov 1928 p 483–4 2 figs; Am Mach v69 Oct 4 1928 p 561–2; Machy (London) v27 Mar 18 1926 p 815–6 5 figs; Western Mach Wld v20 329–30 Sept 1929 4 figs. Construction is based on entirely new optical principle, whereby micrometer screws as well as devices for controlling their rather excessive measuring pressure have been eliminated entirely; in their stead only glass scales are being used together with optical indicator; these glass scales will not wear and therefore retain their original accuracy indefinitely. Scale is accurate to 0.00005 in.

An Instrument for the Measurement of Thickness of Compressible Solids, M. C. MARSH. J Sci Instrum v6 Dec 1929 p 382–5 4 figs. Instrument combines sensitivity and robustness, for measurement of thickness of compressible fabrics over very wide range of pressures.

Ames Dial Gage for Thin Materials. Am Mach v73 Aug 7 1930 p 266. Rapid and accurate measurement of thin materials can be effected by the dial gage illustrated. The dial reads to 0.000025 in. Any size of contact points can be furnished. The gage is finished in black crystalline lacquer.

Grid-Glow Micrometer, R. W. CARSON. Electronics v4 June 1932 p 191 and 204. Hand micrometer with electrical means of indicating instant of contact between micrometer and center of ribbon failed; satisfactory measurements of elastic hysteresis effects were finally made by using Westinghouse DKU–612 grid-glow tube.

Microlux Optical Micrometer. Eng v134 July 15 1932 p 79. Micrometer manufactured by Fritz Werner, Berlin, for gaging finished parts within fine limits; fundamental features are that manual touch is replaced by constant mechanical pressure, reading is very greatly magnified, and it can be distinguished without aid of eyepiece.

Van Keuren Light-Wave Micrometer, VAN KEUREN CO. Am Mach v76 Aug 3 1932 p 920. An accurate bench micrometer, the instrument has a 6-in. measuring wheel graduated in 0.0001 in., permitting readings of 0.00001 in. An optical flat is held in contact with a 3-in. steel flat with spring pressure and is connected by a tension rod to the arm supporting the micrometer head. Bending of the arm is detected by movement of the light-wave interference bands.

Messmaschinen, G. BERNDT. Archiv fuer Tech Messen v2 n17 Nov 1932 p T167 (2p). Layout and operating characteristics of length and thickness measuring machines with particular regard to designs by Société Genevoise d'Instrumentes de Physique and Zeiss.

Screw Micrometer Gages for Rubber Specimens, W. L. HOLT. J Res NBS v10 RP549 May 1933 p 575–82. Screw micrometers combined with an electrical contact indicating device have been adapted to measuring the dimensions of soft rubber parts. Three types of gages have been built. Two of these are vertical gages for thickness measurements and the other is a horizontal gage for dimensions, such as the width of test specimens and the diameter of cylindrical or spherical parts. Measurements made with the micrometer gages are compared with (1) the thickness or diameter computed from the volume and (2) those made with the usual type of dial gages. The micrometer gage measurements agree very closely with the computed values due to the precision of the micrometer screw and the fact that there is little compression of the rubber at points of contact.

Extensometer Comparator, A. H. STANG, L. R. SWEETMAN. J Res NBS v15 n3 Sept 1935 (RP822) p 199–203,

1 supp plate; Mech Wld v98 n2550 Nov 15 1935 p 473–4. Comparator for calibration of extensometers, compressometers, micrometer dials, and strain gages described; comparator has given satisfactory results in calibrating length-measuring instruments used for materials testing.

Jig Borer Measuring System. Engr v164 n4255 July 30 1937 p 135. Method of measurement used for setting table of Newall jig boring machine; illustrated description of micrometer device, known as "Micro Locator," used for positioning table and trains of rollers with micrometer attachment in position for setting longitudinal slide.

Société Genevoise Measuring Machine. Machy (London) v53 n1369 Jan 5 1939 p 429–31. Universal measuring machine developed by firm in Geneva, Switzerland; arrangements permit of great diversity of operations on single unit; weight of carriage supported on ball bearings, with result that wear of guideways is eliminated; in addition to two micrometer microscopes, goniometric microscope is provided.

Neuere optische und elektrische Geraete und Verfahren zur Laengenmessung, F. MUELLER. Maschinenbau v18 n13/14 July 1939 p 339–40. Recent optical and electric equipment and methods for measurement of lengths; illustrated description of equipment.

Convenient Electrical Micrometer and Its Use in Mechanical Measurements, R. GUNN. Trans ASME (J App Mech) v7 n2 June 1940 p A–49–52. Simple micrometer of mechanical and electrical stability; electric current output from micrometer is accurately proportional to impressed mechanical displacement. Zero drift, hysteresis, temperature, and pressure variations reduced to less than 1%. Special circuits described which permit indication of sums, differences, ratios, or products of mechanical displacements.

Measuring to 0.000025 in. Without Pressure, R. W. CARSON. Elec Mfg v40 Oct 1941 p 80–4 164–70 9 figs. Describes micrometer in which contact at the micrometer produces operation of a relay which lights indicating lamps. Unit responds to changes of no more than $4\mu''$ at the contact point. Unit makes consistently repeatable measurements of soft, flexible or compressible materials as well as hard metal parts.

Calibrator for Strain Gauges and Extensometers, D. A. MORRELLI. Commonwealth Engr v29 n12 July 1 1942 p 290–1. Instrument evolved by author has proved very satisfactory in use being robust, steady and easy to use; it involves no close clearances, or exceptionally precise machine work, and will handle large or smallest extensometers with equal ease.

A Note on Electromagnetic Induction Micrometers, Including a Novel Circuit, Incorporating Metal Rectifiers, R. J. COX. J Sci Instrum v19 Aug 1942 p 117–20. Utilizes changes in inductance of iron cored coil produced by changes in lengths of air gaps in its magnetic circuit.

Verwendung ueblicher Messgeraete zu Sondermessungen (Use of Ordinary Measuring Instruments for Special Measurements), L. TSCHIRF. Werkstattstechnik und Werksleiter v36 n23/24 Dec 1942 p 491–4. Illustrated description of test apparatus for control of small calipers; measurement of surface thicknesses and symmetries; control of spaces between holes.

Proving-in Paper Micrometer, J. M. FINCH. Bell Lab Rec v21 Jan 1943 p 121–2. It has been proposed that a dial micrometer would be a satisfactory alternative instrument to pressure-adjusted machinists' micrometers and more easily manipulated; to determine the comparative merits of these devices, tests were undertaken and the results are discussed.

Precision Measurement. Automobile Engr v33 n434 Mar 1943 p 123–5. Developments exhibited by E. H. Jones (Mach Tools) Ltd; various new designs for making some form of measurement comparison; trend is towards evolution of fine precision apparatus that is not too complex or too delicate for use by comparatively unskilled operators.

Micrometer for Long End-Measurements. Eng v158 n4109 Oct 13 1944 p 286; Engr v178 n4619 July 21 1944 p 52–3; J Sci Instrum v21 n9 Sept 1944 p 163–4. Brief illustrated description of PVE stick micrometer for making measurements of this kind, manufactured by Pitter Gauge and Precision Tool Co.

"Microptic" Vertical Measuring Machine. Eng v159 Mar 30 1945 p 246–8. A new type of vertical measuring machine is described in which no multiplying devices are employed, the actual movement of the measuring contact being read directly by means of a microscope. Its normal capacity covers measurements from zero to 4 in., the reading being made directly to within 0.00005 in. and by estimation to 0.00001 in. For consistent and accurate readings, temperature control is necessary. The main scale is engraved on a block of glass and a graticule scale gives readings to 0.01 in., a micrometer scale, visible in one half of the microscope field, giving the figures in the next 3 decimal places.

Das Komparatorprinzip und sein optisches Aequivalent, K. RAENTSCH. Optik v2 n3 Aug 1947 p 235–42. Principle of comparator and its optical equivalent; Abbé's comparator principle applied to sliding gage, micrometer screw and apparatus for longitudinal measurements; description of "Zeiss" apparatus built on Eppenstein's optical principle; photographs, diagrams.

Improved Ultramicrometer According to Dowling's Method, G. GUSTAFSSON. Aeronautical Res Inst Sweden—RSAB (Roy Swedish Air Board—Translation n6) 1948 6 p. Principles of length measurement by determining variations in capacity from corresponding changes in anode current of electron tube; though requiring only one tube and very simple components this type of ultramicrometer offers comparatively high degree of sensitivity and shows good reproducibility; design details and sensitivity data. English translation from Ann Phys 1935.

Zeiss Measuring Machine. Machy (London) v75 n1908 May 19 1949 p 660–2. Standard of reference and optical compensating system employed on new 2m measuring machine. Abstract from BIOS Report No. 1809.

Der Perflectokomparator (The Perflectocomparator), R. SCHULZE. VDI Zeit v93 n2 p 41–4 Jan 11 1951. Very accurate measuring instrument for calibration of gages and workpieces. Very wear resistant; photographs, diagrams.

Micro-Inch Micrometer of One-Tenth Inch Range, E. B. BAKER. Rev Sci Instrum v22 n6 June 1951 p 373–5. It is pointed out that many instruments exist which will magnify small displacements to almost any degree desired but always at expense of range; while micrometer screw is notable exception, it does not give electrical output; construction details of device which combines lever, micrometer screw, sensing element, and servomotor to achieve desired purpose.

Machine for Testing Dial Gauges, D. C. BARNES, C. BARNETT. Engr v198 n5150 Oct 8 1954 p 496–7. Continuous machine developed at National Physical Laboratory to speed up testing of gages and to give more detailed record of their errors; if errors are present, they are shown by movements of indicating pointer, and magnitude of errors may be observed by relation to two fixed reference lines. Communication from NPL.

New Comparator for Measuring Pitch Errors of Root Serrations on Gas Turbine Blades, L. W. NICKOLS. Machy (London) v86 n2218 May 20 1955 p 1085–8; Aircraft Prod v17 n6 June 1955 p 212–4. New comparator constructed at National Physical Laboratory measures pitch of pressure flanks of serrations, and may be easily adapted to measure pitch of centers of grooves; principle of operation; workholder, turret, setting fixture and other components described; setting and operating comparator.

Gerät für die Prüfung von Zeigerlehren (Apparatus for the Testing of Dial Gages). Feingerätetechnik v5 n10 p 436–7, 471. In the National Physical Laboratory, Teddington, a continuous working apparatus was developed, which makes possible a quick calibration of dial gages.

Some Instruments Developed Recently by Carl Zeiss, Jena. Machy (London) v89 n2291 Oct 12 1956 p 851–4. Instruments described include large toolmakers' microscope, 3-meter capacity length measuring machines, Zeiss recording hob testing machine, and electrolytic polisher, which incorporates microscope whereby progress of polishing operation can be observed.

A Critical Evaluation of High-precision Electromechanical Linear Measuring Systems, F. BROWER. Elec Mfg Aug 1957 p 128–41 28 figs 8 refs. Summarizes the advantages and limitations of commercially tried approaches to closed-loop machine tool position-measuring, some conventional, some off-beat and some proprietary, with a frank discussion of the accuracy, linearity, resolution, and sources of error of each.

Untersuchungen an handelsüblichen Feinmessgeräten, D. LÖBELL. Werkstattstechnik und Maschinenbau v48 n2 Feb 1958. Gives results of experiments relative to the dependence of measuring force on measuring travel; the relationship between measuring force and scatter of micrometer instruments; also result from rambles.

Technische Feinmessgeräte, Weg und Ziel ihrer Gestaltung (Technical Fine Measuring Equipment, Manner and Aim of Their Design), H. PLESSE. Fourth Res and Construction Colloquium. Mach Tools and Factory Sci, Munich v1 p B67 Oct 6–7 1959. Electronic equipment, independent or as construction elements. The article gives a specific description of electronic fine measuring equipment with a classification according to the different methods of work, whereby single processes are accurately set forth.

Technische Feinmessgeräte, Weg und Ziel ihrer Gestaltung (Technical Fine Measurement Apparatus, Manner and Aim of Their Design), H. SCHORSCH. Fourth Res and Construction Colloquium. Mach Tools and Factory Sci, Munich v1 p B63 Oct 6–7 1959. Recently the economy of measurement has been added to the previously determined technical viewpoints as to the design of measuring apparatus. Proceeding from this the necessary measuring times and automation are simultaneously investigated as to the relative positions of absolute and comparative measuring equipment and the action of these relative changes appraised on the future relative positions of single and multiple purpose equipment.

Komparatorsystem und Werkzeug Maschine (Comparator System and Machine Tools), K. RÄNTSCH. Fourth Res and Construction Colloquium, Mach Tools and Factory Sci, Munich v1 p B55 Oct 6–7 1959. The comparator

principle in its classical form is in general not satisfactory with machine tools. A few possibilities for the lessening of measuring errors of the first order with length measuring machines are presented. Finally its translation to machine tools is discussed, and indeed takes place for machines with which the workpiece may be measurably shoved in one direction as well as for such with which the measurable displacement is in two crossed directions. The described knowledge may give stimulation for the measuring technique of practicable equipment of modern machine tools.

Length Measurement Using Dynamic Technique, R. G. N. HALL, V. W. STANLEY. Machy (London) v97 n2502 Oct 26 1960 p 959–64. Principle of linear measurements as function of time which is of particular value where dynamic calibration of scale or machine is required; description of apparatus and of technique which has many applications; its use in calibration of particular lathe which has servo-control system, using grating as reference scale.

SIP Type CLP–10 Photo-electric Longitudinal Comparator, A. W. ASTROP. Machy (London) v99 n2554 Oct 25 1961 p 944–62. Details of new length measuring and comparing equipment of outstanding accuracy and design recently developed by Société Genevoise d'Instruments de Physique, Geneva, Switzerland; theoretical metrology on which instrument is based; mechanical, electrical and optical design features; special premises which are required to house comparator and its associated equipment.

What Makes a Good Gage Block Comparator? J. H. WORTHEN. Quality Assurance v1 n1 Oct 1962 p 45–7. Discusses gage block calibration, repetitive accuracy, test technique, calibration accuracy, and other considerations.

Slow-Motion Micrometer Drive, F. R. TOLMON. Machy (London) v101 n2607 Oct 31 1962 p 1016–7. Prototype "4-in. drum" micrometer with slow motion drive developed by NPL in Great Britain; design and operation of instrument which has now been in constant use for more than year for calibrating various types of displacement sensitive devices of high magnification and short range; graph shows result of calibration of pneumatic measuring system using slow motion micrometer drive.

A Slow-Motion Micrometer Drive, F. R. TOLMON, NPL. Mach Shop Mag v24 n1 Jan 1963 p 35–7 2 figs. Designed for calibration of displacement sensitive devices.

Vertical Type Comparator for Measurement of End Standards, P. HOLMES, E. R. HARRISSON. Microtecnic v17 n1 Feb 1963 p 8–14. Illustrated description of instrument constructed at Defence Standards Laboratories, Australia, for measurement of end standards up to 40 in. long; measuring head employs electromagnetic pickup which is rigidly connected to datum platen; special attention was given to reduction of heating effects due to presence of observer; discrimination of instrument is 0.1μin.; method used to calibrate instrument is described.

A New Instrument for Measuring Radial Internal Clearance of radial ball bearings, S. AOKI, M. YOSHITSUGU. Bull Japan Soc Prec Eng v1 n1 Oct 1963 p 9–12 10 figs. Contents: causes of errors involved in conventional measuring methods and methods for minimizing such errors; GML's proposal; development of the new instrument.

3.6. Manual Measuring Tools

3.6.1. General

Small Instruments of Measurement, J. HORNER. Cassier's Mag May 1905. Illustrates and describes various small instruments of precision, giving some account of the care needed in their manufacture and their uses.

Note sur Quelques Jauges et Calibres (Notes on gages and measuring appliances), G. RICHARD. Rev Mécanique v19 n2 Aug 1906 p 124–51 65 figs. With illustrations of a variety of micrometer and vernier calipers, and a discussion of precise measurements in the shop.

Calipers and the Art of Calipering, F. A. STANLEY. Am Mach v30 Mar 7 1907 p 327–62. Contributed and editorial articles dealing with various phases of the subject.

Evolution of the Spring Caliper. Am Mach v30 Mar 7 1907 p 327–8. Some interesting particulars regarding this tool.

Aids in Setting Calipers to a Steel Scale. Am Mach v30 Mar 7 1907 p 358–9. Accurate results obtained by means of adjustable stops on steel scales for setting calipers.

The Side Play of the Calipers. Am Mach v30 Mar 7 1907 p 359–61. Making allowances when boring holes for running, shrink, and press fits.

Gages and Interchangeability in Small-Scale Manufacture, F. A. HALSEY. Am Mach v32 June 10 1909 p 960–1. Illustrates and describes applications of the indicating beam caliper, explaining its advantages.

New Machinists' Tools. Am Mach v32–1 June 3 1909 p 943–4 10 figs. Describes machinists' tools brought out recently by the Brown & Sharpe Mfg. Co., including a universal surface gage, tempered steel rules with beveled edges, tempered steel rules with figure graduations, test indicator, tubular inside micrometer gages, height gage attachment, heavy micrometer calipers, improved toolmakers' clamp, hardened square with beveled edges, and heavy automatic center punch.

Measuring Tools. Machinery's Reference Book n21 1910. History and development of standard measurements; calipers, dividers, and surface gages; micrometer measuring instruments, miscellaneous measuring tools gages.

Height Gages for Inspecting, A. C. LINDHOLM. Machy (N.Y.) v17 Sept 1910 p 51–2 2 figs. An indicating height gage having two columns is shown in Fig. 1. An instrument for measuring the height gage settings is shown in Fig. 2, which consists of a vertical series of notched size blocks and a micrometer suitably mounted on a base.

Pioneer Steps Toward the Attainment of Accuracy, L. D. BURLINGAME. Am Mach v41 Aug 6 1914 p 237–43. Work done at Brown & Sharpe plant in developing accurate machinists' tools including standard rules, wire gages, cylindrical and caliper gages, and micrometer calipers. Also machine tools and shop methods.

An Exact Method of Setting Dividers. A. L. CONATY. Machy (N.Y.) v25 May 1919 p 859. Describes vernier caliper provided with holes for setting calipers.

Shop Use of Octaval Notation in Shop Measurements, A. WATKINS. Mech Eng v41 Nov 1919 p 870–1 and 905 4 figs. Advocates adoption of octaval notation to denote British binary inch fractions in workshop and on workshop measuring instruments. Octaval rule, simple vernier calipers, double vernier calipers, single-screw micrometer, and two-screw micrometer using octaval notation are described and discussed.

Use of Precision Balls for Accurate Measurements, R. L. RANKIN. Machy (N.Y.) v26 Nov 1919 p 236–8 6 figs. Machy (London) v15 Nov 27 1919 p 273–4 7 figs. Practice of U.S. Bureau of Standards in use of precision balls as attachments for machines and for taking direct measurements in inspection of gages.

New Precision Measuring Device. Machy (N.Y.) v27 Mar 1921 p 657–8 2 figs. Device for measuring within hundred-thousandth part of an inch by use of only six precision measuring blocks, designed by B. M. W. Hanson, Hartford, Conn. Sliding parallels actuated by micrometer.

Steel Balls as an Aid in Measuring, R. H. KASPER. Am Mach v54 Apr 21 1921 p 696–7. Describes applications in finding center line of hole, locating position of hole, measuring depth of hole having rounded bottom, measuring thickness of bushing wall, measuring thickness of double concave web.

Schoop "Out Slide Mikes" for Measuring Diameters. Am Mach v58 Mar 22 1923 p 462. A tape having special graduations and vernier, which is wrapped around the object whose diameter is to be measured.

Modern Precision Measuring Instruments, W. L. WHITMARSH. Army Ordnance v4 May–June 1924 p 381–4, 400 8 figs. Describes standard types, including micrometer caliper, vernier calipers, vernier bevel protractor, fluid gage, etc., and their functioning and use.

Zeiss Fine Measuring Tools. Machy (London) v26 Apr 30 1925 p 144–8 12 figs. Describes measuring tools placed on market by Carl Zeiss, Jena, Germany, including depth gages, micrometers, dial indicator, passameter twist drill gage, geartooth caliper, and optical dividing head. See also p 334.

The Development of Automatic Measuring Devices and the Use of Optical Methods, E. BUCKINGHAM. Am Mach v69 n18 Nov 1 1928; ASME Trans v51 n4 Jan–Apr 1929 p 5–6.

Development of Measuring Devices, Primarily Manual, J. A. HALL. Machine-Shop Practice (ASME Trans) v51 n4 Jan–Apr 1929 p 13–6 and discussion 16–7. History of development of devices for making linear and angular measurements; go and not go gages; length standards; Johansson and Hoke gage blocks; use of comparators; difficulties in fine measurements; discussion by E. Oberg covered practical use of measurements. Am Mach v69 n18 Nov 1 1928.

Circumstantial Evidence from Hairs and Fibers, C. A. MITCHELL. Chem and Industry v49 May 30 1930 p 451–4. For purpose of evidence in criminal courts, it is necessary that any evidence given should be capable of verification; very useful measuring instrument is Kew micrometer; for accurate measurement of width of hairs and fibers, Zeiss standard measuring glass with glass micrometer in circular or linear measurements will be found trustworthy; identification of isolated hairs; distinctive human hairs; hairs of animals; fibers of furs; vegetable fibers.

Grundlagen, Mittel und Beispiele zweckmaessiger Werkstattmessverfahren, T. DAMM. (Berichte ueber betriebswissenschaftliche Arbeiten. bd. 6.) Berlin. VDI Verlag, 1931 31 p Illus. Principles that underlie various measuring instruments used in machine shops, accuracy of these instruments and proper methods of using them. Eng. Soc. Library, N.Y.

"Crescent" Tape-Rule. Am Mach v74 June 25 1931 p 997. This 6-ft. tape-rule has an accurate steel tape that automatically winds into a sturdy case 2 in. in diameter and yet when completely withdrawn is rigid because it is of tempered steel, stiffened by special forming. The rule is nickel-plated and has prominent dark markings in inches to 16th for the No. 696, and in 10ths and 100ths of a foot (engineers' measure) for the No. 696D. The rule blade is returned automatically by pressing the center button.

Stanley Flexible Rigid Steel Rules, Stanley Rule and Level Plant, New Britain, Conn. Am Mach v76 May 19 1932 p 656. These pull-push rules with a 6-ft. steel blade, coiled in a watch-size case, are graduated in sixteenths. The rule is a concave steel strip that may be bent as desired and yet is ordinarily rigid.

Messen von Bohrungen, G. BERNDT. Werkstattstechnik v28 n11 June 1 1934 p 217–9. Shortcomings of fixed boring calipers with respect to control of forms and their efficiency; for this reason they are supplanted by test indicators and micrometers; fundamental design principles; advantages and disadvantages.

Beitraege zur Bestimmung der Masse von Rachenlehren, G. BERNDT. Werkstattstechnik und Werksleiter v29 n18 Sept 15 1935 p 359–63. Contribution to determination of dimensions of micrometers; rules for design and shaping of micrometers and test calipers.

Improved Equipment for Toolroom, R. HARRIES. Machy (London) v64 n1647 May 4 1944 p 477–83. Illustrated description of some designs for measuring equipment and methods of construction; extending range of micrometer; built-up sine bar; radial setting arms; vernier height gages from steel rules; bench micrometers for long measurements.

Precision Instruments and Their Application, J. TITSCH. Technique v19 n6 June 1944 p 390–3. Discussion of calipers, micrometers, verniers, indicators and other common precision instruments.

Size Control. Automobile Engr v34 n454 Oct 1944 p 397–400. Reasons for use of end standards are discussed, with special reference to end standards produced by Pitter Gauge and Precision Tool Co.; description also given of two devices developed by this Company, stick micrometer for internal measurements and Universal Measuring Block.

Braille Instruments Aid Blind Inspectors. Iron Age v157 n21 May 23 1946 p 56–7. Brief description of special braille marked gaging instruments developed in Great Britain as aid to rehabilitation of war wounded; instruments now available include vernier calipers and height gages, and micrometers reading to 0.0001-in.; operating and setting procedures explained.

Pitch-Checking Instrument and Micrometer Slip Gauges. Eng v168 n4367 Oct 7 1949 p 380. Matrix screw thread pitch checking instrument and set of slip gages for checking micrometers, known as "Matrix Mikechex" introduced by Coventry Gauge & Tool Co.

Srodki Zwiekszajaco Dokladnosc Odczytan na Wzorcach Kreskowych, A. TOMASZEWSKI. Mechanik v122 n12 Dec 1949 p 461–3. Means of increasing accuracy of linear scales; diagrams.

Know Your Measuring Tools, H. E. LINSLEY. Am Mach v95 n7 Apr 2 1951 p 101–12. Common measuring tools used at bench, layout table and machine, are discussed; scales and tapes; simple and vernier calipers; micrometer calipers; squares and protractors; height and surface gages; miscellaneous gages; how to read vernier and micrometer.

Common Gage Types, R. H. WILCOX. Mill & Factory v51 n2 Aug 1952 p 97–101. Details of main gaging devices currently in industrial use; with exception of pneumatic, electronic and electrical; rules and tapes; calipers; height, depth, and surface gages; micrometers; thread gages.

Linear Measurements—Instruments & Apparatus. ASME Power Test Codes PTC 19.14 1958 Supp ASME, New York, 1958 14 p. Types of instruments and methods of linear measurement likely to be required by ASME Power Test Codes; instruments which determine their range of application.

A Set of Measures and Instruments for Mobile Automobile laboratories, B. N. VORONTSOV. Meas Techns 1959 n11 Sept 1960 p 849–51 2 figs. Translated from Izmer Tekh n11 Nov 1959 p 13. Describes a set of measuring devices conveniently portable and especially suited for mobile labora-

tories. These are designed for checking universal linear measuring instruments, instruments for measuring the hardness of metals, and for checking dial inside calipers.

Universal Measuring Block, R. D. PURVIS. Machy (Lond) v103 n2662 Nov 20 1963 p 1154–7. Equipment described, meeting requirements of accuracy and also those of full utilization of instrument, consists basically of block of close grained cast iron which has accurately machined central vees and locating pads on base, sides and ends; these pads allow block to be set in any of 5 positions while maintaining squareness, parallelism and symmetry with central vees to high degree of accuracy; applications indicated; equipment was found to be extremely useful for toolroom and experimental machine shop applications.

Classification and Comparison of Measuring Instruments, T. BUSCH. Tool & Mfg Engr v54 n1 Jan 1965 p 53–5. Tabulation of linear measuring instruments ordinarily used in manufacturing gives range, precision, sensitivity linearity and reliability for scales, vernier, micrometer, gage blocks, indicators, comparators, flat and squares.

3.6.2. Micrometers

New Brown & Sharpe Measuring Instruments. Iron Age Sept 27 1900. An illustrated description of micrometer calipers and gages.

The Use of Micrometer Calipers for Regular Machine Shop Gages, J. T. SLOCOMB. Am Mach v24 May 2 1901 p 494–5. An illustrated article explaining the uses made of the micrometer caliper in the machine shop.

New Micrometers, W. WEICHOLDT. Zeit InstrumKde v6 Mar 15 1902 p 53–5. These are made with wheel and lever motions, and the length is given by the reading of a pointer on a circular scale, the instruments reading directly to from 0.02 mm to 0.0001 mm.

Periodic Errors of Micrometer Screws, H. ROSENBERG. Zeit InstrumKde v22 Aug and Sept 1902 p 246–54 and 269–75. Mathematical treatment.

Instruments de Mesure de Haute Precision (Measuring Instruments of High Precision), A. GALASSINI. Rev Mécanique v13 July 31 1903. Especially describing the micrometers of Bariquand and Marre, as adapted for precise measurements in the workshop.

Micrometer Gages, A. L. MONRAD. Am Mach v26 Oct 29 1903 p 1524–6. Convenient tools described, including micrometer surface gage, micrometer height gage and micrometer beam caliper.

The Improved Electric Micrometer, P. E. SHAW. Proc Roy Soc A v76 Aug 4 1904 p 350–9. Limit to its practical sensitiveness (4×10^{-8} cm) has been reached. States in detail the form, peculiarities, and limitations. First used to measure the amplitude of a telephone diaphragm.

Some Micrometer Measuring Instruments, A. L. MONRAD. Machy (N.Y.) v11 Sept 1904 p 41–4. Illustrated description of the writer's own designs of micrometer surface gage, micrometer square, micrometer lathe tool, small inside micrometer, micrometer depth gage, and micrometer lathe stop.

A New Type of Micrometer, W. C. DURFEE. Harvard J Eng June 1906. Describes what is called a rolling lens micrometer and its chief merit is said to be its ease of manipulation.

Accuracy of Modern (Optical) Micrometers, M. D. EWELL. Proc Am Phil Soc v46 Jan–Mar 1907 p 187–90. Eight modern scales on glass by different makers have been compared, and two older ones (of 25 years ago). No

advance in precision is shown, the results not even equalling those of the early period. Exceptionally good results are, however, shown by a glass scale by Leitz and a photograph by Möller. On the other hand the maximum $+$ and $-$ divergence in a glass scale by Watson is 4.6μ in 0.1 mm, and in one by Bausch and Lomb 2.8μ.

Some Gaging and Measuring Methods in American and British Shops. Am Mach v30 Mar 7 1907 p 328–32. Large micrometers and other calipers ; their use by inspectors and machinists ; gaging big work.

Standard Gages and Micrometers in the Shop. Am Mach v30 Mar 7 1907 p 332–4. Micrometers of special design are illustrated. Discussion regarding fits.

Micrometers. Am Mach v30 Mar 7 1907 p 351–6 361–2. Early history of the micrometer caliper ; calibration of two Brown & Sharpe micrometer screws ; a micrometer made in a Chinese shop ; the use of micrometer calipers for regular shop gages, some modern micrometer calipers.

Radius Micrometer, W. A. FARRAR. Machy (N.Y.) v14 Sept 1907 p 56–7 5 figs. Two forms of radius micrometer for setting turning or boring tools are described. Two micrometer heads are so mounted that the ends of the spindles just coincide with the axial line joining the centers when the barrels register zero.

Micrometer Attachment for Reading Ten-thousandths, P. L. L. YORGENSEN. Machy (N.Y.) v14 Feb 1908 p 399. Disk mounted on barrel having 250 graduations.

Sensitive Indicating Micrometer. Machy (N.Y.) v15 Sept 1908 p 31. Uses a mercury column in a glass tube and supported by a diaphragm as an indicator.

An Electro Micrometer, G. J. MURDOCK. Am Mach v32 Dec 16 1909 p 1025–7. Illustrated description of a tool for accurate measurements, general testing, and comparison. Especially adapted for obtaining accurate measurements of the inside diameter of bushings and other work when held in a chuck, where the hole is so small that the common inside micrometer cannot be used.

Ball Point versus Anvil Type Thread Micrometers. Machy (N.Y.) v16 Mar 1910 p 564 3 figs. Points out that the anvil type detects drunken threads whereas the ball type does not.

Plant Inside Micrometer Caliper. Machy (N.Y.) v17 Nov 1910 p 237–8. A set of two inside micrometers for measurements from $\frac{1}{2}$ to 2 in., each of which is provided with handle perpendicular to the micrometer axis which may be rotated to lock the setting of the instrument.

Some Uses of the Micrometer, G. W. BURLEY. Mech Wld Feb 23 1912. Explains the value of this precision tool and describes uses to which it can be applied.

An Electric Micrometer, B. THIEME. Zeit InstrumKde v32 Oct 1912 p 322–5. A fine micrometer screw is mounted on a rigid frame and can be rotated by gearing. Readings of 0.1μ can be obtained. Electrical contact is employed using a galvanoscope as an indicator.

Slocomb Direct-reading Micrometer. Machy (N.Y.) v21 Dec 1914 p 326–7. Micrometer caliper for measuring the size of wire, having a deep frame provided with a disk dial at the end of the thimble on which the size of wire is given in steel wire gage, decimal equivalent of an inch, and iron wire gage.

Howe We Came to Have the Micrometer Caliper, L. D. BURLINGAME. Machy (N.Y.) v21 June 1915 p 778–88. Development of fundamental principles and improved features.

How We Came to Have the Slocomb Shop Micrometer, J. T. SLOCOMB. Machy (N.Y.) v21 Aug 1915 p 999–1000. Account of the designing of the micrometer caliper.

Common and Special Micrometer Calipers, F. SERVER. Machy (N.Y.) v21 Nov 1917 p 231–5 16 figs. Describes and illustrates tube micrometer, thread comparing micrometer (cone anvil and spindle), plate micrometer, paper micrometer, ball anvil-micrometer with relieved frame, heavy type micrometer, micrometer with interchangeable anvils for large work, beam micrometer, micrometer for measuring three-sided piece, micrometers with special points, depth micrometers, thread micrometer.

The Micrometer Head in Tool Work, H. F. PUSEP. Am Mach v48 Jan 10 1918 p 59. Cites examples of lathe work, measuring equipment for the milling machines, boring a jig leaf, etc. Ten applications are illustrated.

Ball Point Attachments for Micrometer, G. C. HANEMAN. Machy (N.Y.) v25 Mar 1919 p 645. Describes some methods of attaching balls to the contact points of micrometers.

Micrometer Height Gage, H. KIEHNE. Am Mach v51 Aug 7 1919 p 258.

The Effect of Finger-Heat upon the Micrometer Gauge, L. PYLE. Sci Am Supp v88 Sept 20 1919 p 185 3 figs. Illustrates right and wrong ways to handle a micrometer caliper and gives curve showing expansion with time as the micrometer is held in the hand.

The Davenport-Slocomb Direct Reading Micrometer. Am Mach v52 Mar 4 1920 p 528–9. Counting wheels are mounted on a sleeve that runs concentric with the spindle. Reads from 0 to 999 thousandths.

Brinnell Indentation Micrometer. Am Mach v52 Apr 29 1920. A micrometer for measuring the diameter and depth of the indentation made in applying the Brinnell test. As may be noted from the illustration the instrument will register both horizontal and vertical measurements as separate graduations are provided. The dimensions of the impression can be read to 0.01 mm and the hardness value quickly determined by reference to tabulated data.

Testing the Accuracy of Micrometers in Common Use, C. A. HUBBELL. Am Mach v53 July 29 1920 p 209–10. Summary of results of test carried out on large number of micrometers in commercial use.

Ueber die Messgenauigkeit von Schublehren und Mikrometern (The Accuracy of Sliding Gages and Micrometers), O. KIENZLE. Werkstattstechnik v14 Aug 1 and 15 1920 p 426–8 and 442–5 13 figs. Points out that faults occurring in all measuring instruments are inaccuracy of construction, wear and tear on measuring surface, faults due to different temperatures, to different pressure when measuring, and to faulty readings.

Normung der Mikrometer (The Standardization of Micrometers), R. P. SCHRÖDER. Betrieb v3 Nov 25 1920 p 97–100 4 figs. Discusses gradation of size, accuracy, and gap. Notes on limit gages.

Bath Internal Micrometer and Master Ring Gages. Am Mach v54 Mar 31 1921 p 578–9. Micrometer is provided with four jaws fitted to inclined dovetail grooves in the body, and movement of the jaws is controlled by an accurate micrometer screw.

Bath Micrometer Plug Gage. Machy (N.Y.) v27 Apr 1921 p 795–7 5 figs. The gage has four measuring jaws provided with true cylindrical contact surfaces and held in perfect alignment with the sliding member by means of closefitting dovetailed slots. The measuring jaws are

expanded or contracted when the slide is moved back and forth through the operation of a micrometer screw. It is claimed that, as the movable jaws fit tightly in the dovetailed grooves of the slide and are controlled by an accurate screw without backlash, an instrument is obtained which is as rigid as a solid plug.

Die Aufbiegung von Schraubenmikrometern (The Spreading of Micrometer Frames), G. BERNDT. Betrieb v3 June 25 1921 p 574–81 12 figs. Results of experiments with a number of screw micrometers by different firms. Formula for calculation of semi-circular frames. Tables of permissible amounts of spreading of frame and weights for rectangular cross-section frames.

Checking the Accuracy of Micrometer Measurements, E. SHELDON. Am Mach v55 Oct 6 1921 p 562–4. Notes on close measurements with micrometer; possibilities of error due to mechanical defects.

Genauigkeitsansprüche an Mikrometer und Fühlebel (Accuracy Requirements of Micrometers and Lever Gages), G. BERNDT. Betrieb v4 Feb 11 1922 p 280–4. Relation between measuring and reading accuracy of screw micrometers. Suggestions for increasing accuracy of lever gages.

Inside Micrometer and Height Gage (Comb.). Iron Age v110 July 13 1922 p 84. Tool made by Reed Small Tool Works. Combination set comprises a micrometer head, adjusting wrench, 5 rods and ½ in. spacer for capacity 2 to 7 in., 5 additional 5 in. spacers, and height-gage base attachments of two different forms.

Slocomb Inside Micrometer. Am Mach v58 Apr 5 1923 p 532b. Provided with an auxiliary cap for measuring large diameters.

Measuring Threads Accurately with Micrometers. Can Machy v31 May 1 1924 p 31–2 and 51 6 figs. Hints on accurate use of micrometers.

Proper Care Essential to Micrometer Accuracy. Can Machy v32 July 24 1924 p 25–6 6 figs. Hints on use and care of measuring instruments.

Slocomb Tube Micrometer. Am Mach v61 Sept 18 1924 p 480. Micrometer caliper of standard construction except frame is designed to support a stud extending at a right angle to the spindle and forming the anvil.

Mikrometer und Messapparate (Micrometers and Measuring Instruments), P. DUCKERT. Zeit InstrumKde v44 Oct, Nov and Dec 1924 p 443–53, 483–94, and 547–55; and v45 Apr 1925 p 176–85. A description, with numerous illustrations and diagrams, of various types of micrometers. For a comprehensive treatment of the theory of the various instruments the author refers to the treatise by E. Becker in Valentiner's Dictionary of Astronomy, 3, Sec 1.

Brown & Sharpe Direct-Reading Micrometer No. 26. Am Mach v63 Oct 1 1925 p 567; Eng v121 Jan 8 1926 p 60. Direct reading feature consists of a set of numbered dials which are actuated by the movement of the measuring screw through steel indexing gears.

Wear of Micrometer Screws. Machy (London) v27 Jan 14 1926 p 521–22 2 figs. Report of series of experiments made at Zeiss plant.

Screw Thread Micrometer Calipers, H. BENTLEY. Indus Mgmt (London) v13 June 1926 p 261–2 2 figs. Application of micrometer calipers to measuring V-type screw threads.

Brown & Sharpe No. 11 Micrometer. Am Mach v67 July 28 1927 p 173. Has enlarged opening in frame and small size of the frame at its anvil end, designed to measure odd-shaped pieces.

The Meter-Inch Micrometer. Model Engr & Light Machy Rev v57 Sept 1 1927 p 202–3 3 figs. Combination of metric and inch micrometer instrument which as a whole is considered accurate within satisfactory limits; calibration of screw for progressive error at intervals of 0.1 in. over its 1 in. of length showed it to be within 0.0001 of inch total, and within 0.003 mm by metric measure.

Brown & Sharpe Nos. 90, 91, and 92 Micrometers. Am Mach v68 Apr 26 1928 p 714. Combined range 12 to 24 in. Each tool is provided with four interchangeable anvils of different lengths.

Micrometer for Measuring Diameter of Quartz Fibers. Eng v125 June 1 1928 p 655 2 figs. Capacity .020 mm. Galvanometer serves as an indicator.

Brown & Sharpe Micrometers. Am Mach v68 June 28 1928 p 1063–4. Nos. 60 and 62 micrometer calipers, range 1 to 2, and 2 to 3 in. Inside micrometer No. 276 provided with 10 changeable anvils.

Brown & Sharpe Blade-and-Disk-Anvil Micrometers. Am Mach v69 Sept 27 1928 p 521–2. Special micrometers for measuring forming tools. Thin blades on the ends of anvil and spindle permit them to enter the narrow slots and grooves of forming tools.

Starrett No. 210 Micrometer for Comparing Screw Threads. Am Mach v69 Oct 25 1928 p 668.

Lufkin Direct-Reading Micrometer. Am Mach v73 July 24 1930 p 187. This direct reading micrometer gives the total measurement without difficult and often incorrect additions. This reading is shown at a glance by an ingenious arrangement of the figures on the sleeve. The hub markings are the same as on the regular type of micrometers. Hundredths of thousandths are indicated by a long line. The three shorter lines indicate 0.025, 0.050, and 0.075, and are arranged so that they appear as a group of three.

Mischker Square-barrel Micrometer. Am Mach v73 Nov 13 1930 p 796. Quick setting by means of a ratchet to within 0.025 in., and then final measuring by means of a graduated barrel, are features of this square-barrel micrometer. The measuring stem with its square barrel is removable and is intended for use with a set of frames of varying sizes. The stem is provided with a short thread sufficient for one complete turn or 0.025 in. movement. An inside stem is provided with the set.

Neo-Micrometer. Eng v131 n3413 June 12 1931 p 775 2 figs. Instrument is made in two forms, smaller instrument having range of from zero to 12 in. in between gage points, and corresponding range for larger instrument being from zero to 40 in.; each can be used for both internal and external measuring.

Starrett Thimble-Friction Micrometer Caliper. Am Mach v75 Dec 10 1931 p 900–1. A friction-stop mechanism eliminates the inconvenience of reaching beyond the thimble to operate the stop. Since the stop disengages at exactly the same pressure each time, the operator is assured of uniform contacts. Range of the instrument is 0 to 1 in. by thousandths or, for an extra charge, by ten-thousandths.

Starrett Micrometers with Tungsten-Carbide Tipped Anvil and Spindle. Am Mach v76 Jan 28 1932 p 150. The anvil and spindle of micrometers are now available with facings of cemented tungsten carbide to give greater wear resistance. The frame is cut away to facilitate use

in places where the ordinary micrometer cannot be inserted.

Brown & Sharpe Micrometer Calipers with T. C. Surfaces. Am Mach v76 June 23 1932 p 800. Micrometer calipers (1-in. size) in several styles have the ends of the spindle and anvil faced with tungsten carbide, useful where the micrometers are subjected to unusual wear.

Laengenmessung mit Schraublehren, G. BERNDT. Archiv fuer Technisches Messen v2 n15 Sept 1932 p T137 (2 p). Principal factors contributing to errors in length measurements with screw calipers.

Starrett #700 Inside Micrometer Caliper. Am Mach v76 Nov 23 1932 p 1175. Dimensions between 0.200 and 1 in. can be measured directly in thousandths. The micrometer combines the sliding jaws of a slide caliper and the easy reading thimble and sleeve arrangement of a micrometer caliper. One jaw is fixed and the other is attached to the sleeve.

Micrometers. Mech Wld v104 n2712 Dec 23 1938 p 611–2. Specification applying to micrometers having bow-shaped frame holding micrometer spindle and nut on one side opposite anvil on other with individual measuring ranges of 1 in. to 11 to 12 in., and 25 mm up to 275 mm to 300 mm and to setting gages for micrometers above 1 in. or 25 mm. One of series of Brit Standards Instn. Specifications in course of production for engineers' precision tools.

Take Good Care of Micrometers. Mill & Factory v32 n3 Mar 1943 p 108–20. Tool craftsmanship charts pointing out some of more common abuses to which micrometers are subjected; preventive measures.

Improved Micrometer Allowing Lateral and Rotary Adjustment. Indus Power & Prod v21 n232 Feb 1945 p 90. New micrometer head comprises easily operated means of locking thimble in new rotary and lateral positions on spindle, after insertion of shim or shims between flange on spindle and internal flange on thimble.

Micrometers and How to Use Them, G. W. DAWSON. Motor Service July 15 1946 p 124, 154, 157, 218. Micrometer measurement reading and interpretation explained, including recommendations for care and handling.

Multi-Purpose Micrometer. Engr v182 n4729 Aug 30 1946 p 196. Brief description of new form of micrometer introduced by E. H. Hones (Machine Tools), Ltd. designed for use on wide range of work not adapted to measurement by standard type of instrument; consists of standard micrometer barrel at base of sleeve on which is mounted block instead of usual frame.

How to Read Micrometers and Verniers, J. FOSTER. Power Generation v52 n3 Mar 1948 p 81–3. Instructions for use of typical micrometer as used in machine shops; principle of operation; English type micrometer; metric type micrometer; vernier micrometer; vernier caliper; universal bevel protractors.

Measurement of Close Tolerance Parts. Matls & Methods v29 n4 Apr 1949 p 79, 81. Method of correcting observed micrometer readings to obtain actual dimensions of part of standard temperature (68 °F).

External Micrometers. Brit Stand Instn—BS n870—1950 19 p. Provisions for micrometers with measuring ranges of 0 to ½ in. and from 12 to 24 in. (with their corresponding metric equivalents); requirements relating to micrometers with interchangeable anvils and various measuring ranges up to 24 in. (600 mm).

Measurement of the Thickness of Capacitor Paper, W. SOUDER, S. B. NEWMAN. NBS Cir n532 10 p 1952.

The definition of thickness must be carefully analysed before choosing an instrument for such measurements. Three methods are available: (1) by direct observation across an edge section by means of a micrometer microscope, (2) by measuring the separation of two geometric surfaces between which one or more specimens are placed. and (3) by determining the mass of a definite area of sample and computing the thickness, using the density parameter. Measurements have been made on some commercial thin capacitor papers, using the interferometer, micrometer microscope, mechanical micrometers, and the surface analyser. These data have been analysed. It has been found that the precision dial micrometer or the precision screw micrometer may be used for such measurements. The size and type of contact and the load to be applied will depend on the needs of the manufacturer and user of the paper.

Micromaster. TESA, Ltd., Switzerland, Bul 28 Nov 1952 3 p 7 figs. Micrometer giving a partial digital readout with graduations on thimble and sleeves arranged side by side. Longitudinal play is eliminated by use of differential screw threads.

Micrometer with Setting Shown Numerically. Eng v177 n4590 Jan 15 1954 p 87. "Micromaster" micrometer developed by Tesa, Ltd, Switzerland, is similar to normal micrometer, but divisions are more widely spaced and setting is indicated by numerals.

New Design of Height Gauge, H. A. CHIVERTON. Machy (London) v87 n2235 Sept 16 1955 p 695–6. Gage developed by author is based on micrometer principle instead of usual vernier scale, and affords number of advantages, including low cost of manufacture, and exceptional robustness; design details.

A Universal Test-Piece for Use with Micrometers of Throat over 100 mm, A. N. DOLGUSHEV. Meas Techns 1959 n2 Feb 1959 p 97–8 1 fig. Translated from Izmer Tekh n2 Feb 1959 p 14. A test piece having ball tips for checking parallelism of faces.

Modern Measuring Instruments—Electric and Electronic Gages, F. W. WITZKE. ASTME Tech Papers v60. book 1, paper No. 245. Electronic gage heads now provide extreme precision and accuracy for standards laboratory use. Performance specifications are listed.

A Device for Checking Micrometers for Dimensions over 100 mm, YU. F. AKSYUK, YA. P. VOLOSIN. Meas Techns 1959 n5 June 1960 p 311 1 fig. Translated from Izmer Tekh n5 May 1959 p 9. The proposed device permits the checking of micrometers with a wide measurement range (over 100 mm) by means of length standards with the maximum size of the block equal to 25 mm, thanks to the presence of an auxiliary adjustable stopper.

Evaluation of the Measuring Efforts in Micrometer Instruments, A. I. SUVOROV. Meas Techns 1962 n4 Sept 1962 p 278–9 2 figs. Translated from Izmer Tekh n4 p 8–9 Apr 1962. Relates measuring effort to stability of micrometer readings and methods of its measurement.

An Improved Precision Height Gage, L. B. VALE, Ames Research Center. NASA SP–5001 Nov 1963 12 p 3 figs 4 patent refs. For sale by Office of Tech. Services, Dept. of Commerce, Washington, D.C., 20230, price 50 cents. Describes a wedge parallel actuated by a micrometer which yields performance and accuracy superior to those of previous devices. It may be accurately set to a desired height without auxiliary measuring devices, there is no lost motion in the movement of the upper block, and the resolution is improved.

3.6.3. Vernier Instruments

The Reading of Verniers. Am Mach v25 Apr 3 1902 p 474–5 5 figs. An explanatory article.

The Reading of Verniers. Am Mach v30 Mar 7 1907 p 349–51 5 figs. Explains the reading of verniers.

Inside and Outside Caliper Gage, H. E. CURTIS. Am Mach v32–2 Nov 4 1909 p 786. A vernier beam caliper having inside measuring jaws.

Vernier Height Gage, Machy (N.Y.) v23 Feb 1917 p 546.

Slide Gage. Jeweler's Circular Jan 7 1920 p 143. A vernier caliper having special features is described.

Brown & Sharpe Nos. 465A and 465B Height Gage Instruments. Am Mach v69 Aug 30 1928 p 374–5.

Die Genauigkeit der Ablesung an einem Nonius bei feinen Kreisteilungen (Exactitude in Reading of Vernier on Small Circular Divisions), K, LÜDEMANN. Zeit InstrumKde v49 n5 May 1929 p 238–48. Tabulation of observations on reading with and without magnifying glass ; summary of existing literature. Bibliography.

British Standard Specification for Vernier Calipers. Brit Stand Instn—BS Specification n887—1940 14 p. Specification applies to calipers, with internal and external measuring faces, and having ranges of measurement in inch units up to 48 in., graduated to read 0.001 in., in metric units up to 1 mm, graduated to read 0.02 mm, and in both inch and metric units with above graduations.

Choix et Détermination d'un Vernier, A. LABORDE, C. TURLAN. Technique Mod v38 n9–10 May 1–15 1946 p 106–11. Study of theory of vernier, its intervals and method of observation ; circular verniers ; charts and tables presented.

Some Variables Influencing Vernier Acuity, I. Illumination and Exposure Time. II. Wave-length of Illumination, K. E. BAKER. J Opt Soc Am v39 p 567–76 July 1949. Functions relating vernier acuity to illumination have been obtained for two different exposure times and at 3 regions of the visible spectrum. An apparatus providing the necessary stimulus controls has been described in detail and the procedure is fully explained.

Single Element Verniers Reading Two or Three Dimensions, R. E. LEWIS. Rev Sci Instrum v21 p 647–9 July 1950. By superimposing concentric radial elements on rectangular co-ordinate rulings, vernier systems may be constructed reading in two or three dimensions without the necessity of any particular angular orientation. A two-dimensional vernier may consist of one transparent element ruled with concentric circles. The observed tangencies of the circles, with regard to a rectangular grid placed in contact, provide the reading of the additional decimal of the co-ordinates of the fiducial centre of the circles on the grid. A three-dimensional vernier system may be established by means of a binocular optical system presenting images of spheres concentric with the locating point and images of co-ordinate boxes in the same space. The tangency of a vernier sphere and co-ordinate plane indicates the last decimal of the reading. Angular orientation may be indicated by radial lines near the points of tangency.

Precision Vernier Calipers. TESA, Ltd., Switzerland Bul 21 Feb 1951 4 p 15 figs. Discusses important factors in manufacture and use of vernier calipers, including accuracy of graduation, thickness of lines, errors of interpretation, influence of the measuring pressure, deformation of beam and jaws, and objective and subjective influences on measuring accuracy.

Modernized Slide Gauge. L. D. SHCHUKIN. Meas Techns 1962 n1 June 1962 p 18 2 figs. Translated from Izmer Tekh n1 p 15 Jan 1962. Modified vernier caliper for measuring internal dimensions.

Making Parts for Vernier Calipers, P. A. SIDDERS. Machy (London) v101 n2604, 2606 Oct 10, 1962 p 800–8, Oct 24 p 924–32. Methods employed for production of new instrument, type 600 calipers, developed by James Chesterman & Co., Sheffield ; it was designed to meet need for relatively inexpensive calipers with acceptable standard of accuracy ; operation ; induction hardening jaws ; grinding external measuring jaw ; finish broaching operation ; milling operations on beam ; surface grinding operations ; operations on triggers ; inspection trolley specially built to facilitate inspection work ; grinding ends of scales and ends of depth gage blades.

Chesterman-Sogenique Electronic Height Gauge. Machy (Lond) v105 n2706 Sept 23 1964 p 761–2. Gage described has dial indicator to ensure predetermined stylus pressure and digital indicating equipment ; it is designed to enable accurate measurements to be made rapidly, and to eliminate possibility of slight errors in reading instruments of vernier type.

3.6.4. Dial and Test Indicators

New Micrometers, W. WEICHOLDT. Zeit InstrumKde v6 Mar 15 1902 p 53–5. These are made with wheel and lever motions, and the length is given by the reading of a pointer and circular scale, the instruments reading directly from 0.02 mm to 0.0001 mm.

The "Just It" Lathe Test Indicator. Machy (N.Y.) v13 Dec 1906 p 225 2 figs. Pivoted-finger type of test indicator.

Toolmakers Universal Test Indicators, J. D. STRYKER, Am Mach v30 Sept 19 1907 p 411–2 9 figs. A test indicator of the plunger-pin type.

Inspecting Tools with the Test Indicator, J. H. BOULET. Am Mach v30 Oct 17 1907 p 537–41, Nov 14 1907 p 773. Illustrates and describes a number of methods of testing and measuring various classes of tools by means of indicator of the author's invention.

Dial Gages for Accurate Measurements. Machy (N.Y.) v14 Dec 1907 p 264–5 3 figs.

A Test Indicator and Some of Its Applications. Am Mach v31 Aug 27 1908 p 303–5 9 figs. An instrument of plunger-pin type, for setting and testing lathe, miller, shaper, and surface plate work. Made by Henry Koch and Son. Various applications are illustrated.

Compact Form of Dial Indicator, L. HAAS. Machy (N.Y.) v15 Aug 1909 p 966–7. Plunger-pin type indicator using spiral and multiplying lever combinations.

Dial Indicators. Zeit Practische Maschinenbau v45 1910 p 2059–60.

A Novel Fine-Measuring Machine—"Hirth Minimeter", A. GRADENWITZ. Am Mach v33–1 Apr 14 1910 p 696–7 8 figs. Various adaptations of "Hirth" Minimeter for gaging are illustrated. Fig 1, the minimeter lever, pointer, and scale ; Figs. 2, 4, and 8, the minimeter mounted as an amplifying comparator ; Figs. 3, 5, 6, and 7, the minimeter mounted to gage rings.

Automatic Micrometer Calipers. Mech Engr v26 Aug 26 1910 p 248–51 17 figs. Describes a series of dial micrometers, or auto calipers, made in England.

A Test Indicator and Comparator, H. F. ATKINS. Am Mach v34 Aug 31 1911 p 407–9 19 figs. Illustrated description of a simple indicator of almost universal applicability. The principle on which the indicator depends is the magnifying of the movement of a plane surface by transferring it to a roller, held between the movable plane and a fixed plane, and causing the roller to swing a pointer over a graduated sector.

Test Indicators and Their Uses, G. W. BURLEY. Mech Wld Dec 1 1911. Explains uses to which they are applied and illustrates and describes types.

A Universal Indicator, H. V. PURMAN. Machy (N.Y.) v18 Jan 1912 p 341–2 4 figs. Diagrams and descriptions of indicator of pivoted-finger type, designed by F. A. Turner.

Test Indicator. Machy (N.Y.) v18 Apr 1912 p 648–9. Pivoted finger type of indicator made by American Watch Tool Co.

Universal Test Indicator. Machy (N.Y.) v18 July 1912 p 898. Pivoted-finger type of indicator made by Alvan Mfg. Co.

Lowe "Last Word" Indicator. Machy (N.Y.) v20 Mar 1914 p 610 2 figs. Fig. 1 shows Lowe test indicator carried on ball-joint toolpost shank; Fig. 2 shows Lowe indicator mounted on the needle of a surface gage. Also Machy (N.Y.) v22 Nov 1915 p 248 3 figs. Contact point is provided with a friction joint at the pivot.

Toolmakers' Test Indicator, D. BAKER. Machy (N.Y.) v23 Nov 1916 p 246–7 3 figs. Pivoted finger type of indicator designed by Warren Dunbrack.

Ausbau der Fühlhebelmessung (Development of Lever-Gage Measurement), M. KURREIN. Werkstattstechnik v16 Oct 15 1922 p 613–6 8 figs. Describes new measuring tools of the Fortuna Works, Stuttgart-Cannstatt, Germany, exhibiting at Leipzig Exhibition.

A Study of Commercial Dial Micrometers for Measuring the Thickness of Paper, P. L. HOUSTON, D. R. MILLER. Tech Papers NBS n226 Dec 29 1922 p 125–52. For abstract see Subsection 5.4.

Federal Micrometer Dial Gage. Am Mach v58 Apr 26 1923 p 643. See also p 889. Consists of a bench stand for holding dial indicator at any desired angle and a pair of micrometer jaws.

Federal Dial Indicators, Models D and DD. Am Mach v58 June 14 1923 p 889. Show 0.04 in. per revolution.

D–10 "Last Word" Test Indicator. Am Mach v61 July 31 1924 p 211. For specially accurate work. Range 0.016 in. Magnifies 300 times.

Toleranzmesser, Flächen und Winkelprüfer (Tolerance Measurer, Surface and Angle Measurer), W. EWALD. Deutsche Opt Wochenschrift v12 n36 Sept 1926 p 466 4 figs; v12 n34 Aug 1926 p 441 1 fig. Describes mechanical indicating instrument for measuring thicknesses and angle deviations. Produced by Askania.

A Convenient Indicating Device for Dividers, Calipers and Compasses. Instrum v1 Mar 1928 p 165–6 1 fig. Device designed to eliminate tiresome and slow operation of taking measurements directly from scale or rule; disk is graduated in $1/64$ and $1/100$ in.; dial performs function of vernier; can be provided with dial for direct indication of any desired units.

Ames Dial Micrometer. Am Mach v72 Feb 6 1930 p 281. Easier reading to thousandths by means of widely spaced dial graduations is the chief feature of this dial indicator micrometer. Two dials are employed. The smaller indicates the revolutions of the larger pointer, each graduation of the small dial representing 0.1 in. The large dial has 100 widely spaced graduations around the dial, each representing 0.001 in. The range is to 1 inch. By operating the spindle lock, the tool may be used as an adjustable snap gage.

Apparatus for Measurement of Very Small Displacements, H. WHITAKER. J Sci Instrum v8 n8 Aug 1931 p 251–8 6 figs. Apparatus consisting of accessory device, which can be fitted to standard type of microscope; method consists in using fine quartz pointer as lever which multiples small displacement to be measured.

Japanese Scientists Develop Simple Optical Indicator, P. N. HELDT. Automotive Industries v70 n26 June 30 1934 p 813–4. Details of optical indicator developed by F. Nakanishi, M. Ito, and K. Katamura.

Frictional Forces in Dial Gauges, C. F. BRUCE. Eng v167 n4335 Feb 25 1949 p 169–71. Investigation of "stickiness" in movement of plunger on anvil of gages for dial indicators of type which are mounted on surface gage and used mainly for leveling of surfaces; frictional forces in gage may amount to as much as 50% of max operating force on gage, as measured when gage is lightly tapped; photographs, charts.

How to Get Your Money's Worth Out of Dial Indicators, I. A. HUNT. Am Mach v93 n12 June 12 1949 p 93–100. Construction and maintenance recommendations including standard dimensions and types of dials; checking of indicators; their correct mounting; when and how to use indicators.

Les Défauts des Comparateurs à Cadran, G. MICHALET. Pratique des Indus Mecaniques v32 n9, 10, 11, Sept 1949 p 279–87, Oct p 318–21, Nov p 359–63. Defects in dial comparators of $1/100$ mm; results of study conducted at Laboratoire Central de l'Armement; discussion of different defects, their causes and remedies; degree of accuracy which can be expected; different types of comparators; illustrations.

The Deming Test Indicator. Precision Measurement in the Metal Working Industry. 1952 ed. Syracuse Univ. Press. Described on p 108 and illustrated in Figs. 164 and 165. (No other published description has been found, but it was very popular during the First World War and subsequently.) Is graduated to 0.0005 in. It has a spring-pivoted compound lever system and a number of replaceable ball points for reaching into small holes, slots, and recesses.

Messuhren, G. BERNDT. Dresden. Technische Hochschule Wiss Zeit v3 n1 1953–4 p 63–70. Dial gages; formulation of standards and determination of errors.

New Dial Indicator Design Features Only Four Moving Parts, R. C. SOUERS. Machine & Tool Blue Book v49 n5 May 1954 p 193–200, 202. Nilcoid indicator now in stage of production at Nilsson Gage Co., Poughkeepsie, N.Y. will reduce disadvantages of gear train indicator without sacrificing any of advantages; design details of indicator which is claimed to retain its accuracy longer than gear train type.

Stable Wide-Range DC Amplifier, F. F. OFFNER. Rev Sci Instrum v25 n6 June 1954 p 579–86. Versatile high gain amplifier for biological applications; features include differential push pull operation with rejection ratio greater than 1000; response from zero to beyond 30 kc has maximum gain of about 2.5×10^6; optical control of

high and low frequency cutoff is provided; other features; circuit diagram.

Dial Gauge, H. W. BAKER. Eng v186 n4841 Dec 19 1958 p 804–6. Investigations carried out to obtain precise information about reliability of both new and nearly new gages, and to shed light upon factors which should receive special attention from manufacturers or users.

Fully Transistorised Frequency Modulated Indicator for Field Tests, R. S. ROBSON, A. GOODIER, R. G. PENN. Engr v207 n5380, 5381 Mar 6 1959 p 374–7, Mar 13 p 412–14. Indicator for translating mechanical parameters into electrical ones, developed by Thornton Research Centre, Chester; thermionic valves have been replaced by transistors and crystal diodes; it will replace most indicators used by Shell Research.

The Accuracy of the Dial Indicators of D-Type Shore Hardness Testers, K. YAMAMOTO, K. IIZUKA. Report of the Central Inspection Institute of Weights and Measures, Japan, v11 n1 report 28 1962 in Japanese. A method for testing the accuracy of the dial indicators of D-type Shore hardness testers is devised. By means of this method 10 indicators are inspected: two made by Shore Instrument & Manufacturing Co., U.S.A. and eight by domestic manufacturers. The results show that one division of the scales of the indicators does not correspond to the height of rebound of 0.1238 mm which would be the standard value when the same definition as C-type testers is applied to the scale of D-type testers but corresponds to about 0.13 mm, and show that most of the indicators have a periodic deviation of 0.020–0.045 mm and random deviations of 0.025–0.040 mm from the mean pitch of the graduation. The cause of the periodic and random

errors is investigated and it is concluded that the former error arises from the eccentricities of both the scale plate and the pinion to the center of rotation of the pinion and can be cancelled out by adjusting the magnitudes and phases of two eccentricities, whereas the latter one is due to the error of teeth form of the rack and pinion and determines the ultimate accuracy of the hardness readings, which is assumed to be 0.2–0.3 units in Shore scale for the testers.

4-m-Endmasskomparator (4-Meter End-Measure Comparator), M. DÜHMKE in collaboration with G. GEORGI and W. FISCHER. Feinwerktechnik v66 1962 p 369–72 3 figs 4 refs. With this comparator parallel end measures over 200 to 4000 mm in length are compared with standards of equal length by mechanical contact. The measures lie on two-dimensionally applied ball bearings and are hydraulically controlled from the outside of a temperature shield surrounding the measuring apparatus.

Device for Checking Dial Gauges and Indicating Hole Gauges, E. M. EVICH. Meas Techns 1962 n6 Dec 1962 p 463–4 1 fig. Translated from Izmer Tekh p6 15 June 1962. Equipment was made from an old height gage; its measuring device consists of a zero class micrometer, and a collet chuck is used for fixing the dial gauge or bending limiter of a hole gauge tubular stem.

More Reliable Testing of the Precision of Dial-Type Gauges, A. N. KARTASHOVA. Meas Techns 1963 n3 Sept 1963 p 185–8 1 fig 5 refs. Translated from Izmer Tekh n3 p 4–7 Mar 1963. Describes a newly-developed testing technique for dial gages which provides higher reliability of testing with lower expenditure of labor.

Addendum to Section 3

3.2. End Measuring Rods and Measurement of Long Lengths

Combined Micrometer and Sensitive Indicator Unit, W. F. ATKINS. Machy (London) v105 n2697 July 22 1964 p 271–2; Machine Shop v25 n8 Aug 1964 p 398–400. To overcome difficulty when measuring work pieces of large diameter, design was produced at National Physical Lab-

oratory in which micrometer and fiducial indicator are combined in single unit that can be mounted on machine; external and sectional views of unit are described; unit was fitted to diameter measuring machine used at NPL for checking API screw plug gages.

3.3. External Diameters by Mechanical Methods

Superposition Spherometer Type IZS–8, S. D. GOLOD, V. A. NIKITIN. Meas Techns n8 Mar 1965 p 679–81 2 figs. Translated from Izmer Tekh n8 p 19–21 Aug 1964. The new superposition spherometer IZS–8 is suitable for measuring convex and concave spherical surface radii in the range of 80 to 40 000 mm. As compared with spherometers made abroad the IZS–8 spherometer has several advantages which are: high precision provided by large-diameter carrier rings for measuring the radii of curvature in large components, the replacement of supporting bands used in foreign spherometers by ball bearings over which the carrier rings can be turned as they become worn, direct measurement of the spherical segment curvature deflection by comparing it with a certified instrument scale, as against indirect measurement used in foreign spherometers which require reference glass spheres.

A Study of Errors in the Measurement of Microscopic Spheres, C. P. SAYLOR, NBS. App Optics v4 n4 Apr 1965 p 477–86 11 figs 6 refs. Uncertainties in the microscopical measurement of small spheres as influenced by index of refraction of the mount, focus, aperture, and resolution have been variously reported and denied. The present study was conducted with large spheres in order to disclose the basic phenomena, but with such optical conditions as would ordinarily be used for much smaller objects. The reality of each reported error is verified. The principal uncertainties originate in the geometrical optics of thick bodies, but these effects tend to be confused by limitations in resolving power. See also F. Ehrenhaft, p. 10.

3.4. Internal Diameters by Mechanical Methods

Investigation of Contact Methods for Measuring Internal Sizes of Components with Stationary Instruments, G. B. KAINER. Meas Techns n11 Apr 1965 p 945–9 4 figs 1 ref. Translated from Izmer Tekh n11 p 8–11, Nov 1964. The research revealed the basic components of the error produced in measuring internal sizes with stationary instru-

ments. The process was investigated by means of a recorder with induction transducer which was mounted on an instrument with a metering device (for instance, an optimeter) in such a manner that all the displacements of the component together with support table could be recorded in the course of measurements.

Section 4. Calibration of Line Standards of Length, Including Tapes

CONTENTS

4.1. Line Standards, General

Comparaisons des Mètres dans L'Air a la Température Ambiante (Comparisons of Meters in Air at Ambient Temperature), M. J. PERNET. Trav et Mém du BIPM v4 1884 273 p 10 figs. Description of Brunner transverse comparator; measurement of temperatures; calibration of thermometers; measurement of lengths; calibration of optical micrometers; method of comparisons and reduction of data; results; tables; observations.

Standard Measures, E. A. GIESELER. J. Franklin Inst Aug 1888 p 115–33; Eng News Sept 8 1888. Gives brief history of the development of standards of length, describes the present standards of the United States, and methods adopted to compare them with other standards.

The New Standards of Weight and Measure. The Nation Oct 24 1889. An interesting letter from Paris, describing the methods used in preparing the standard meter bars and standard kilograms for the International Bureau of Weights and Measures.

Nouvelles Déterminations des Mètres Étalons du Bureau International (New Determinations of the Meter Standards of the International Bureau), C. E. GUILLAUME. Trav et Mém du BIPM v11 1895 87 p. Discusses comparisons of several standards made in 1884, 1892, 1894 and other years by various observers; derives equations for their temperature coefficients; defects of the microscopes of the Brunner comparator; observations.

On the Comparison of Line and End Standards, L. A. FISCHER. Bul Phil Soc Washington v13 p 241–50. Read before the Phil. Soc. of Washington May 28, 1898.

Precision in Determinations of Length, J. R. BENOIT. Int Phys Congress at Paris Rept 1 1900, p 30–77. A résumé of the practice and progress in different countries as to the standard and measurement of length. France, England, Russia, and Germany are dealt with, and the extension of the metric system noted. The best form for standards of length is discussed and the tests they should bear are described. The probable error of a single comparison in comparing 30 standard meter bars is calculated to be ±0.12μ. The permanence of the standards and their variations with temperature are also treated.

Methods of Testing Flat-End Gages and Standards. Great Britain NPL Rept 1906 p 39–42. Flat-end gages are tested by an optical method, involving the reflection of light from them. A method of measuring an end standard by means of a line standard is to apply two or more end standards (preferably flat ends) and draw a line near the middle of each. All possible combinations with a line standard are measured.

Standards of Length, H. T. WADE. Sci Am Mar 10 1906. Information concerning the two meter bars in the custody of the National Bureau of Standards at Washington, and the care given them. Also the uses to which they are applied.

Methods of Comparing Standard Measure Bars, L. A. FISCHER, NBS. Am Mach v29 Oct 25 1906 p 547–8. Describes a simple process for deriving the yard from the meter bar.

Verification of International Meter Standards, C. E. GUILLAUME. CR Acad Sci v173 Dec 27 1921 p 1438–43. Results of recomparison of various national standard meters with the international protype meter.

Über Metermasstäbe mit Strichteilung und ihre Genauigkeit (Regarding Meter Measures having Line Division and their Accuracy), K. LÜDEMANN. Der Betrieb v4 n9 Feb 11 1922 p 292–8 13 figs. Proposal for a standard meter measure with line divisions required in mechanical metrology.

Matters of Special Interest in Precision Metrology, A. PERARD. Rev Opt v2 Dec 1923 p 506–11. Precise definition of the exact method of making a setting with a microscope on a line graduation might be "to set the microscope so as to obtain equality of the luminous area between the line of the microscope graticule and the edges of the line upon which the setting is made". Discusses personal errors, fogging of objectives and torsional forces on bars.

Testing of Line Standards of Length. NBS Cir n332 May 13 1927 22 p 2 figs. Method used in comparison and standardization of line standards of length and basis of such measurements in United States; apparatus used and precautions necessary for precise work; information regarding testing of line standards and of metal tapes, including shipping directions.

Optical Instrument Demands Unusual Precision, H. SIMON. Am Mach v68 Mar 8 1928 p 421–3 6 figs. Scribing and checking of half-inch line on blade used in Zeiss measuring microscope; accuracy within plus or minus 0.00002 in. must be maintained; high-precision dividing engine and apparatus used to check its work; testing device permits readings to be made correct within limits of about 0.000008 in., plus or minus.

Skalen fuer Messgeraete (Scales for Measuring Instruments), G. KEINATH. Archiv fuer Tech Messen v3 n32 Feb 1934 p T20–1 (4 p). Scales for measuring equipment; comparative study of various standard types; illustrations.

Gestaltung von Instrumenten zum Zwecke der Vereinfachung Messtechnischer Aufgaben (Design of Instruments for the Purpose of the Simplification of Technical Measurement Problems), R. SEWIG. Zeit Instrumkde v56 n9 Sept 1936 p 349–57. Design of instruments with view to simplifying practical problems of measurements; psychotechnical and phototechnical form and character of scales discussed.

Homogeneous Scales for Pointer Instruments, H. MAURER. Zeit InstrumKde v57 Jan 1937 p 26–9. In certain types of pointer instruments it is necessary to read the position of the pointer in terms of divisions of a non-homogeneous scale, owing to the mode of operation of the measuring device. Thus a similar change of the measured quantity a at different parts of the scale corresponds to dissimilar changes of angular position w of the pointer, where w is some non-linear function of a. It is possible to find curves on which the lengths of the intercepts between two positions of the pointer are linearly proportional to the difference between the corresponding indicated quantities, so that accurate linear interpolation between scale divisions becomes possible. For practical purposes a scale of circular form is retained but the fiducial marks are shown on a zig-zag line.

Improvements in Definition of International Standards of Length and in Comparison of Standards, A. PERARD, C. VOLET. CR Acad Sci v208 Jan 23 1939 p 263–5. An account of the state of certain copies of the standard metre. It was decided to renew the scales on five of these, and this was done satisfactorily as regards definition, thickness of the lines reduced to 3.5μ and other points of improvement. There has taken place also an improvement in the observing instruments. The redrawn standards will be compared with the international metre and its latest copy.

Permanence of Standards of Length, T. H. FIELD. Can J Res v17 Sec A May 1939 p 71–6. A few reasons are presented for believing that the fundamental standards for the metre and the yard, and also the legal Dominion standards of length, are not changing appreciably. On the other hand, measurements of a number of laboratory nickel-iron rules show progressive shortening which is still taking place, through periods up to 20 years.

Comparaison au Prototype metrique de ses Témoins et des Mères d'Usage du Bureau International des Poids et Measures, A. PERARD, C. VOLET. CR Acad Sci v212 n2 Jan 13 1941 p 71–3. Comparison of metric standard with its reference replica and with meters used by International Bureau of Weights and Measures; report on comparisons made by four independent observers, with improved optical comparator.

Comparison of Etalons of Length, C. VOLET. Rev Opt (Theor Instrum) v21 1942 p 168–75 in French. Analyses the systematic errors liable to be encountered in the comparison of standard metres, etc., when observations are made on grooves or scratches. The effects of the shape of the groove and of the illumination are discussed. The method of comparison by means of reversible microscopes is advocated and a Société Genevoise instrument of this type is described.

Première Vérification Périodique des Mètres Prototypes Nationaux et Détermination de Quelques Nouveaux Prototypes (The First Periodical Verification of the National Prototype Meters and Determination of some New Prototypes), A. PERARD, L. MAUDET, C. VOLET. Trav et Mém du BIPM v20 1944 86 p 7 figs. 7 refs. Characteristics of the Prototype Meters; revision of the early measures,— actual values of dilatations and equations; instruments and methods,—Brunner comparator, thermometers and temperature, manner of checking a line, organization of the measurements; periodic verification,—the prototype of the Bureau, the national prototype meters, prototype meters verified several times, table of results, conclusions; determination of changing prototype meters.

An Adjustable Scale for Measuring Instruments, W. KOCH. J Sci Instrum v22 May 1945 p 94–5. A method is described for constructing and using a scale which compensates for calibration errors. The principle involves the use of 3 fixed points; the appropriate scale reading is determined by the intersection of a movable line with an arc passing through each point of the scale. The line is adjusted by reference to the fixed points.

Metres and Comparators, C. VOLET. Microtecnic v2 n4 Aug 1948 p 138–43. Comments on substitution and displacement methods used for comparison of graduated length standards; description of improvement which made it possible to avoid instrument errors when using substitution method; construction principles and choice of good standard discussed.

Measuring Instruments—the Division on Glass of Graduated Areas of Instruments, F. DELHOMME, J. MARTIN, CR Acad Sci Paris v227 Aug 2 1948 p 335–7 in French. The technique of making scales on glass by depositing by evaporation of thin homogeneous layer of Pb or Al, ruling with a dividing engine, and coating with a protecting layer of varnish is fully described.

New Method for the Calibration of Line Standards. Soc Gen d'Inst Phys May 31 1950.

Micrometer Eyepieces, H. BECKER. Microtecnic v5 n2, 3 Mar–Apr 1951 p 59–65, May–June p 108–13. Limitations of eye in respect to its optical resolution in reading very fine scale division; problems connected with use of magnifying eyepiece or microscopes on micrometer instruments; reference made to some German patents in this field; typical optical systems for precision readings; factors important in manufacture of micrometer eyepieces.

Human Factor in Instrument Design, L. S. BEALS, JR. Instrum v24 n11 Nov 1951 p 1290–1, 1337–9. How aviation or other instrument dials and control knobs can be improved and made more useful by careful analysis and design of size, resistance to motion, grouping, direction of motion, numbers, letters, pointers, and scale division. Bibliography.

New Comparator of High Precision for Measurement of Line Standards of Length, J. S. CLARK, L. O. C. JOHNSON, V. W. STANLEY. J Sci Instrum v28 n12 Dec 1951 p 357–64. 1-m comparator having two heat insulated tanks designed to contain line standards of length and to bring them in turn under pair of micrometer microscopes rigidly fixed at distance apart equal to nominal length of standards to be compared; instrument can be used to compare lengths of two standards or to determine their coefficients of thermal expansion.

Les Mètres Prototypes du Bureau International. Notes Historiques. Renovation. Etude. (The Prototype Meter of the International Bureau. Historical Notes. Restoration. Study), A. PERARD, C. VOLET. Trav et Mém du BIPM v21 1952 156 p 36 figs. 46 p of historical notes. Review of measurements prior to 1937. Study of new sources of errors. Restoration of the meter and the Brunner comparator. Determination of the meter retraced. Examination of the progress realized. Conclusion. Note on a study of the subdivisions.

Graticules for Engineer Optical Measuring Instruments, A. G. THOMSON. Mech Wld v133 n3402 Jan 1953 p 26–7. Processes developed by Brit Sci Instrum Res Assn, which have enabled graticules for optical instruments to be made with accuracy which, in general, enhances precision of instrument; graticules are produced by photography and etching on glass, and by vacuum evaporation of films of chromium, aluminum, platinum, palladium, rhodium, etc.

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The Possibility of Comparing Line Standards of Length Photographically, A. H. COOK. Proc Roy Soc A v219 Oct 7 1953 p 500–15. Line standards can be compared visually to about one in ten millions. It seems possible that in a photographic comparison appreciably higher precision could be attained with less labour. Photographs of the lines on some line standards have been examined with a densitometer to determine the accuracy with which the distance between two photographic images of such lines could be measured. With suitable definition of line position a single measurement of this distance should have a standard deviation corresponding to less than 0.05μ. Provided the temperature of the bars is known with sufficient accuracy it should be possible to compare two line standards to much better than one in ten millions in less than half the time taken by present visual methods. A machine for measuring the photographs is suggested. The characteristics of photographs of some lines are given in an appendix.

Novel Devices for Checking Graduated Scales and Tapes, C. HOFFROGGE, Microtecnic v9 n5 1955 p 247–52 7 figs. Devices are described which make possible the checking of graduated scales and tapes with an uncertainty of some ± 0.01 mm. The standard can be moved longitudinally in order that coincidence readings can be carried out on the graduations to be compared. The displacement is given by a dial comparator or a micro-indicator. The devices can be used with particular advantage for tolerance measurements.

Calibration of Meter Line Standards of Length at the National Bureau of Standards, B. L. PAGE. J Res NBS v54 n1 Jan 1955 p 1–14. The results of the intercomparisons of the total lengths of several meter bars and of calibrations of the subintervals of some of these bars for the past twenty years are reported. Information both on the degree of stability of these standards and on the precision with which such measurements can be repeated was obtained. The results are critically analyzed and comments made as to the precautions necessary in the precision comparisons of line standards of length.

Machine Tool Scales with Optical Reading Devices, C. GODFREY, S. C. BOTTOMLEY. Microtecnic v13 n4 Aug 1959 p 154–61. Use of precision scales on machine tools, especially when viewed by optical projection, has many advantages; they are unaffected by wear, can be magnified, and permit subdivision of main scale; review of various types covers micrometer projectors, vernier projectors, circular scales, and "microptic" scale reader; photographs.

The Manufacture, Testing, and Application of Precision Glass Scales, G. MEISTER, J. CICHON. (Zeiss, Jena) 1960. An example of automation in precision-measuring technology by means of photoelectronic methods. Contents: On the state of dividing techniques; basic methods for the objective photoelectronic localization of graduation marks; instrument technology; application of glass scales; automation of photoelectronic reading of glass scales.

De l'Importance de la Qualité d'une Regel-Étalon, P. MARTIN. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 57–62 8 figs. The coming change in the definition of the meter and its consequences; line standards on glass and on metal, advantages and disadvantages; factors of errors; precision; definition of the line; factors influencing the good definition of the line; appropriate materials for good scales; lines with round edges; the Volet effect; the retracing of the prototypes.

Survey of Development of Line Standard Metrology, J. PETAVEL. Microtecnic v14 n1 Feb 1960 p 1–13. Methods used by Bureau of Weights & Measures, and standards Laboratories for intercomparison of line standards and their comparison with international standard; micrometer microscopes enable meter to be defined with relative un-

certainty of one part in 10^7; photoelectric microscopes have enabled uncertainty to be reduced to one part in 10^8.

Calibration of Line Standards of Length and Measuring Tapes at National Bureau of Standards, L. V. JUDSON. NBS Monogr n15 May 1960 11 p. Methods used in calibrating line standards of length and measuring tapes submitted for standardization; equipment used is described briefly; there is discussion of some considerations that should be given as to whether or not standard should be submitted to Bureau; instructions are given for submitting items to Bureau for calibration; appendix contains useful information on use of steel tapes.

Unmittelbarer Anschuss von Strichmassen an Lichtwellenlängen (An Instrument for Direct Comparison of Line Standards with Wavelengths of Light), C. HOFFROGGE, Amtsblatt PTB 1961 n2 p 192–5. See abstract under 2.4.6.

An Automatic Fringe Counting Interferometer for Use in Calibration of Line Scales, H. D. COOK, L. A. MARZETTA. J Res NBS v65C n2 Apr–June 1961 p 129–40. A reversible fringe counting interferometer is described in which mechanical, optical and electronic adjustments are maintained stable by servomechanism control or by balancing. An electronic fringe counter and interpolator permits recording of the count in digital form to 0.01 fringe. Design factors and details are discussed.

On an Instrument for Calibrating Graduated Scales up to 1 Meter in Terms of Wavelength of Light, Y. SAKURAI. Global Technol Apr 1961 (Digest of original Japanese article). Description of an interferometric line standard comparator. The principal components are a photoelectric microscope and an interferometer employing a Koester's double prism and corner-cube reflectors. A reversible fringe counter and interpolator is used to determine the order of interference.

Interference Comparator for the Calibration of Line Standards Directly in Terms of Standard Wavelengths, K. M. BAIRD. Rev Sci Instrum v32 n5 May 1961 p 549–54. An interference comparator for routine calibration of line standards or scales by direct reference to the vacuum wavelength of Kr^{86}. Principles of construction and performance characteristics are given. Method of exact fractions used to determine the order of interference.

Case Histories of Methods to Achieve Cost Reduction Through Optical Tooling, A. W. YOUNG. ASTME Creative Mfg Seminars Tech Paper SP63–120 Feb 1963 7 p. Eleven examples are described dealing with alignment of machine tools, checking out rotational error of rotary tables, transfer of angular measurement in shops, use of telescope and clinometer mounted in one fixture, etc.

The Calibration of Linear Scales by the Method of Hansen-Pérard. E. G. THWAITE, R. T. LESLIE. Austral J Phys v16 n1 Mar 1963 p 82–107. The exact least-squares solutions are obtained by matrix inversion. These sets of equations correspond to the "simple calibration" and the "cross calibration," of linear scales by the method of Hansen-Pérard. Tables are given of the inverses of the coefficient matrices of the normal equations for most practical cases and expressions are derived for the variance to be associated with any interval between calibrated scale graduations.

Positioning System Spaces Lines to Within $\frac{1}{10}$ Microinch, E. G. LOEWEN. Control Eng v10 n5 May 1963 p 95–8. Author, associated with Bausch & Lomb Inc., explains operation and control of ruling engine that scribes up to 100,000 uniformly spaced lines per inch on diffraction grating.

Magneto-Optic Positioning, R. J. MELTZER. IEEE Trans Indus Electronics vIE–10 n1 May 1963 p 46–56. For accurate production of scales and grids it was necessary to

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develop device which could locate lines with precision better than 1µin.; system is described that accomplishes this by forming image of line with polarized light, whose angle of polarization varies with position of line.

High-Precision Linear Scales. Firm of Dr. Johannes Heidenhain, Traunreut. Oct 1963 19 p 21 figs. Describes advantages of scales manufactured by the patented Diadur process. Describes detail features of high-precision glass rules, metal rules, grating bars, and coded rules.

Recommendations for Design of Scales and Indexes. Brit Standards Instn—Brit Standard 1449 pt 1 1964 44 p. Recommendations in this part are intended to be generally applicable to quantitative instruments of bold presentation and designed for rapid reading, intended to be read to resolution of about 1 to 2% of scale range and are particularly concerned with relating scale dimensions to maximum reading distance; they are only applicable to single scale instruments having dials with full circle, part circle or straight scales as defined.

4.2. Calibration of Subintervals

NOTE. The more important articles are indicated by an asterisk (*)

*Traité de Thermomètre (Treatise on Thermometry), HENNERT, 1758 (Book.) Chwolson in his Traité de Physique v3 p 42 states that the method generally ascribed to Gay-Lussac was first given by Hennert. Gay-Lussac is credited by very many writers on this subject with having given the first method of calibration. Some have, however, given evidence to prove that he did not originate the method. An outline of the method of Gay-Lussac is given in many treatises on experimental physics and in books on thermometry but without reference to Gay-Lussac's description of his method.

Anmerkningar angående thermometrars förtfärdigande och Bruk. Hallström, G. GABRIEL, Åbo, 1823 Akad Dissertation. A very early method of calibration, concerning which there seems to be considerable difference of opinion, although the Hallström method is often referred to in the literature. In a footnote to an article by Hallström in the Ann Phys Chem in 1836, Poggendorf states that, as the method is the same as that already published by Bessel, to save space it is not repeated, although included in Hallström's manuscript of the article. Rudberg later pointed out some slight differences. The committee of the British Association (see under Stewart) put the method in an entirely different classification from that of Bessel. The original dissertation unfortunately has not been available for consultation in the preparation of this bibliography.

Methode die Thermometer zu berichtigen (Method of Correcting the Thermometer), F. W. BESSEL. Pogg An Phys v6 1826 p 287–308. A method of calibration in which the various lengths used are not multiples of the smallest or unit interval.

Untersuchungen über das Thermometer: V. Die stereometrischen Verhältnisse der Glassrohre (Investigations of the Thermometer: V. The Stereometric Proportions of the Glass Tube), P. N. C. EGEN. Pogg An Phys und Chemie v11 p 529–36 1827. A method of calibration which is a slight modification of that of Bessel. Allusions are sometimes found in the literature to Egen's method without any journal reference being given.

Über die Konstruktion des Thermometers (Regarding the Construction of the Thermometer), F. RUDBERG. Pogg An Phys v40 1837 p 562–82. A method of repeated subdivision; for instance, first divide the total length in half, then compare the three-thirds of the total length, then divide the total into twelfths, etc.

*Bestimmung der Teilungsfehler eines gradlinigen Massstabes (Determination of the Graduation Errors of a Rectilinear Scale), P. A. HANSEN. Abhandlungen der Mathematisch-Physikalischen Klasse der Königlich Sächsischen Gesellschaft der Wissenschaften v15 1879 p 525–667. The basic memoir on which present-day methods of calibration of scales are founded. It discusses the calibration of a single scale. Methods of double calibration are a later development.

Über das Kalibrieren von Thermometern (Regarding the Calibration of Thermometers), M. THIESEN. Carl's Repertorium für Experimental-Physik v15 1879 p 235–99. The author points out that Lambert in his "Pyrometrie" published in 1779 had used (p 31, 43) the method of calibration commonly attributed to Gay-Lussac, and that it was known even earlier. An application to thermometry of this method is briefly outlined by Thiesen. It is stated that Rudberg's method is only a special case of Hallstrom's, but that it has the disadvantage that the corrections to the divisions obtained in the component parts of the calibration are not well coordinated to make a unified system of corrections.

*Über die Anwendung der Methode der Kleinsten Quadrate auf die Kalibrirung der Thermometer (Regarding the Application of the Method of Least Squares to the Calibration of the Thermometer), W. J. MAREK. Carl's Repertorium für Experimental-Physik v15 1879 p 300–19. Method of calibration of a thermometer (applicable also to a scale) for cases of division into 2, 3, 4, 5, and 6 parts with a brief statement of the general case. Corrections to the intervals are obtained by the solution of the normal equations obtained by least squares methods. These equations are given a form especially applicable for ready numerical solution. Numerical examples exemplifying the method in the calibration of thermometers are given, together with formulas for obtaining the probable error of the results. See also reference to article by Benoit, p 121.

Über das Kalibrieren von Thermometern, inbesondere über die wahrscheinlichen Fehler der Kaliberkorrektion (Regarding the Calibration of Thermometers, Especially Regarding the Probable Error of the Calibration Correction), M. THIESEN. Carl's Repertorium für Experimental Phys v15 1879 p 677–81. By a consideration of the probable errors, the feasibility of an abbreviated method of calibration is shown. There is a saving of time compared with the rigorous least squares method proposed by Marek. The artifice used by Thiesen had been proposed by F. E. Neumann in the case of another set of equations similar to those involved in this work, and the method of calibration is sometimes known as the Neumann-Thiesen method.

Report of the Committee Appointed for the Purpose of Reporting on the Methods Employed in the Calibration of Mercurial Thermometers. B. STEWART; RÜCKER; T. E. THORPE. Report of the Brit Assn for 1882 p 145–204. Discussion with illustrative examples using the following methods: Gay-Lussac, Hallstrom, Rudberg, Thiesen, Marek, Bessel (as modified by von Ottingen and improved by Thorpe and Rücker). These methods are also applicable, with certain modifications to the calibration of divided scales. Four classes of methods are distinguished by this committee. (1) "Step by step," example, Gay-Lussac's method; (2) "Principal points," examples, Hallstrom, Thiesen, Marek; (3) "Repeated division," example, Rudberg; (4) "Distributed points," examples, Bessel and the modification by von Ottingen.

*Calibration of Thermometer Green 5280 by Hansen's Method, C. C. BROWN. Van Nostrand's Eng Mag v29 1883 p 1–7. One of the few expositions in the English language of Hansen's method.

Mesures de Dilatation et Comparaisons de Règles Métrique. 13 Thermometres-Corrections de Calibrage (Measurement of Dilation and Comparison of Metric Scales. 13 Calibration Corrections of Thermometers), J. R. BENOIT. Travaux et Mem du BIPM v2 1883 p C35–C48. Method of Marek as used in the calibration of thermometers. This article is in French; Marek's original article was in German.

*Études Thermométriques (A Study of Thermometry), C. E. GUILLAUME. Trav et Mém du BIPM v5 1886 92 p 5 figs. Comprises study of thermometers, variations of thermometers, and concordance of thermometers.

Note sur l'Étalonnage des Sous-Divisions d'une Règle, sur l'étude des Erreurs Progressives d'une Vis Micrométrique, et Sur le Calibrage des Thermomètres (Note on the Calibration of the Subdivisions of a Scale, on the Study of Progressive Errors of a Micrometer, and on the Calibration of Thermometers), O. J. BROCH. Travaux et Mémoires du BIPM v5 1886 p 1–82. Development of the method of Hansen for the calibration of a single scale. Computation forms. Applications to calibration of line standards, micrometer screws, and thermometers.

Weinstein Handbuch der Physikalischen Maasbestimmung v2 1888 p 274–82. Method of Hansen for single scales and method of Thiesen for a double calibration.

On the Determination of Errors of Graduation Without Cumulative Errors and the Application of the Method to the Scales of the Cape Heliometer, D. GILL. Monthly notices of the Royal Astron Soc v49 1889 p 105–18. (See also the errata on p 241 of the same volume.) A method is outlined of calibrating two scales simultaneously. This method is essentially that of Lorentzen. No general formulas are given and no computation system outlined. It is to be noted that Gill considered all intervals to be calibrated with the same weight, whereas, as Jacoby pointed out, weight factors given by Lorentzen must be used.

*Traité Pratique de la Thermométrie de Précision (Treatise on the Practice of Precision Thermometry), C. E. GUILLAUME. Gauthier-Villars et Fils, Imprimeurs-Libraires 1889 336 p 4 plates 45 figs refs. Methods of calibration of thermometer scales with illustrative examples are given on p 43–99: Gay-Lussac's method; Neumann-Thiesen method; complete least squares method.

The Cumulative Errors of a Graduated Scale, W. A. ROGERS. Proc. ASME v15 1893 p 127–46. The method of Broch and the method of summing the corrections found for the unit lengths are each discussed and illustrated. Rather undue emphasis is placed on the possibilities of simple summing the corrections found for the individual intervals; Mr. Rogers was an experienced and careful observer; repetition of length measurements to a certain precision is no proof of their accuracy to that degree.

*Über die Untersuchung der Scalen eines Heliometers I (Regarding the Investigation of the Scales of a Heliometer), G. LORENTZEN. Astron Nachr v131 n3134 1893 p 217–38. This is a method of double calibration which differs only slightly from a least squares solution.

Über die Untersuchung der Scalen eines Heliometers II (Regarding the Investigation of the Scales of a Heliometer), G. LORENTZEN. Astron Nachr v135 n3236 1894 p 353–66. This is an application of the method of double calibration described by the same author in a previous paper to the calibration of two heliometer scales, each a decimeter in length.

Note on the Division Errors of a Standard Scale, H. JACOBY. Astron Nachr v137 n3285 1895 p 357–60. Jacoby points out the advance made by Lorentzen over Hansen and also the practical identity of Lorentzen's method with that used and described by D. Gill. The fact that Lorentzen gives a weight factor for the several intervals is emphasized. Jacoby suggests repeating the observations on the first and last comparisons of the two scales in the usual order of measurement four times. The final results would then be more uniformly weighed. The possibility of computing the number of times to repeat each separate observation in order to produce a weight of unity for all points is suggested by Jacoby as of some possible theoretical importance.

On the Determination of the Division Errors of a Straight Scale, H. JACOBY. Am J Sci v151 May 1896 p 333–42. Gill's method, an improvement on Hansen's and Lorentzen's formula, are both explained and discussed. A modification of Gill's method, by the author, follows, whereby accuracy within 0.00002 inch is obtained. A method of calibration of two scales in which the various observations are repeated such number of times as to secure a unit weight for the final result for the correction to each interval. An application to the calibration of screws is included, whereby the nonperiodic errors of a screw are determined without assumption of any law of error.

Über die Ermittelung der inneren Theilungsfehler zweier Masstäbe nach der Methode des Durchschiebens (Regarding the Investigation of the Inner Division Errors of Two Scales by the Method of Translation), DZIOBEK. Wiss Abh der Kaisarlichen Normal-Aichungs-Kommission v4 1903 p 1–56. A least squares solution for a double calibration with comparisons with the method of Thiesen; numerical examples.

Über die gleichseitige Bestimmung der Theilungsfehler zweier Maszstabe durch die Methode des Durchschiebens (Regarding the Congruent Determination of the Division Errors of Two Scales by the Method of Translation), A. LEMAN. Wiss Abh der Kaisarlichen Normal-Aichungs-Kommission v6 1906 p 1–75. A method of double calibration.

*Standardization of Divided Scales, C. E. GUILLAUME. Ann des Poids et Mesures, v13 1907 p 1–54. There are three factors in a complete determination: (1) The formula of thermal expansion; (2) the total length; (3) the calibration of the divisions, i.e., the differences in the distances between successive divisions. The theory is fully investigated and certain examples are given. The author considers that the third factor above need not introduce a greater error than 0.1μ throughout the meter scale, but uncertainties in temperature and in the expansion formula bring up the error to 0.2μ or 0.3μ. Both a method of single and one of double calibration are given, each with examples.

Note sur le Calcul des Etalonnages de Grandeurs en Progression Arithmetique (Note on the Calculation of the Calibration of Size by Arithmetical Progression), A. PÉRARD, Trav Mém du BIPM v16 1917 p 1–77. A method of single calibration and a method of double calibration. The method given in this circular is a variation of the method of single calibration described by Pérard.

Calibration of a Divided Scale. NBS Cir n329 May 13 1927 15 p 1 fig. Method used at NBS for calibrating equal subintervals of length on a line standard; apparatus, observing procedure, and mathematical reduction of data. Bibliography.

Calibrations of Line Standards of Length of National Bureau of Standards, L. V. JUDSON, B. L. PAGE. J Res NBS v13 n6 Dec 1934 p 757–72. Results of intercompar-

ison of total lengths of meter and of decimeter bars, and results of calibrations of subintervals of several of them are given.

Instrument Scale Distribution and Its Effect on Observational Errors, R. G. JEWELL. Instrum v8 n3 Mar 1935 p 58–60, 79. Certain electric indicating instruments have uniformly divided scales while others have scales which are open over one portion and constricted over another portion; purpose of paper is to show what factors affect distribution and to determine what effect distribution has upon observational errors. Bibliography.

The New Graduated Prototype of the International Bureau of Weights and Measures for the Subdivisions of the Metre, H. MOREAU, N. CABRERA. Rev Opt (Theor Instrum) v23 Oct–Dec 1944 p 255–60 in French. The difficulties originally encountered in working with Pt-Ir (poor polish, difficulty in marking, etc.) meant that some of the older prototypes were not entirely satisfactory. One of these (T4) has now been renovated, markings removed, surface planed and repolished, and regraduated. Two independent examinations have now been made of this new prototype and it is found that the error for any graduation rarely exceeds a micron. The length is given as 1 m—1.14μ at 0°C.

Adjustable Scale for Measuring Instruments, W. KOCH. J Sci Instrum v22 n5 May 1945 p 94–5. Method described for constructing and using scale which compensates fairly well for calibration errors; principle involves use of three fixed points; appropriate scale reading is determined by intersection of movable line with arc passing through each point on scale; line is adjusted by reference to fixed points.

Choix et Determination d'un Vernier, A. LABORDE, C. TURLAN. Techn Mod v38 n9–10 May 1–15 1946 p 106–11. Study of theory of vernier, its intervals and method of observation; circular verniers; charts and tables presented.

Manufacturer's Viewpoint on Instrument Calibration, H. BERRING. ISA J v1 n4 Apr 1954 p 32–4; Steel Processing v40 n1 Jan 1954 p 33–7, 51. Problems relating to correct positioning of pointer on calibrated scale, from viewpoint of manufacturer responsible for original dial calibration; extent to which manufacturer's equipment, required for calibration of large numbers of instruments, may differ from that employed by testing laboratories and industrial instrument departments; mechanics of calibration; scale division and layout.

Photoelectric Microscope for Measurement of Linear Scales, J. S. CLARK, A. H. COOK. J Sci Instrum v33 n9 Sept 1956 p 341–7. Apparatus for accurate measurement of scales of high precision; real image of graduation line, formed by microscope objective, is caused to oscillate across fixed slit in front of photocell; phase sensitive rectifier determines when mean position of line image coincides with center line of slit; short scales were measured directly in wavelengths with standard deviation of about 0.1μ.

Automatic Measurement of Small Deviations in Periodic Structures, H. T. CLOSSON, W. E. DANIELSON, R. J. NIELSEN. Rev Sci Instrum v29 n10 Oct 1958 p 855–9. Special optical, mechanical, and electronic techniques have been combined in a new instrument, the microdeviometer—originally developed for measuring and recording the pitch uniformity of helices in travelling wave tubes—in which a beam of light and two optical gratings are used to obtain a very accurate scale of distance. The location, with respect to this distance scale, of the salient periodic features in the structure being measured is established through the interception of a second light beam by the structure. Electronic circuitry automatically stores and processes the position information and feeds the processed information, in the form of deviations from the corresponding ideal structure, to a pen recorder. A measuring accuracy of $\pm 1\mu$ has been consistently obtained, and measurements which formerly required nearly 2 man-days are accomplished in less than 10 min.

Wiederholbarkeit und Richtigkeit der Messwerte beim Zusammenwirken von Optischen Ablesegeräten und Strichteilungen (Repeatability and Accuracy of Measured Values with Coordinate Action of Optical Reading Apparatus and graduations), K. RÄNTSCH, Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 50–6. Proposes the proportion of the scale value to the average error of the individual measurement as the reading quality characteristic, for which a simple formula is indicated.

Calibration of Line Standards of Length and Measuring Tapes at the National Bureau of Standards, L. V. JUDSON. NBS Monogr 15 1960 p 11. See 4.1 for abstract.

General Theory of Verniers; Verniers for Nonuniform Scales, P. M. PEPPER. Ohio State Univ—Eng Experiment Station—Bul v30 n2 Mar 1961 55 p. Novel means of applying verniers to nonuniform scales; mathematical principles on which vernier depends are treated; rudimentary error theory for verniers; and approximate methods for construction of generalized verniers; concept of acceptability for approximate verniers is defined and employed in treating several examples of generalized verniers.

Selection of the Number of Check Points on an Instrument Scale, A. S. NEMIROVSKII, V. A. VOLKONSKII. Meas Techns 1961 n1 Sept 1961 p 6–13 1 fig 3 refs. Translated from Izmer Tekh 1961 n1 p 5–10 Jan 1961. Article describes the selection of an optimum number of check points on an instrument scale. This solution could be applied to developing or improving methods of checking a wide range of instruments.

Calibration of Linear Scales by Method of Hansen-Pérard, E. G. THWAITE, R. T. LESLIE. Austral J Phys v16 n1 Mar 1963 p 82–101. See 4.1 for abstract.

4.3. Calibration of Tapes

Measuring a Steel Tape, W. GRIBBEN. Am Mach Mar 19 1896. A good illustrated description of a job quite out of the usual run of machine shop work.

Über eine Anreihevorrichtung für Genaue Messungen mit dem Stahlbande (Details of a Series of Precise Measurements with Steel Tapes). Zeit Oesterreichische Ing und Architektonische Verein Feb 12 1897. An account of a series of experimental measurements to determine the probable error and limit of precision of steel tape measurements. Gives useful practical details.

Steel Measuring-Tape Apparatus, A. E. BURTON, J. F. HAYFORD. Eng Record v45 Jan 25 1902 p 80–1. Outline is given of the development of this instrument at M.I.T. since 1888 and of tests to which it was submitted by the US Coast Survey.

The Bureau of Standards and Its Relation to the United States Coast and Geodetic Survey, S. W. STRATTON. Reprinted by the Government Printing Office from the "Centennial Celebration of the United States Coast and Geodetic Survey" Apr 5–6 1916 18 p 11 figs. This is largely a review of F. R. Hassler's work in procuring instruments for a coast survey and in providing and comparing physical standards.

The Measurement of Tapes and Wires at the Reichsanstalt, P. A. THOMAS. Zeit InstrumKde v39 Nov 1919 p 321–32. A description of the 30 m. measuring track used for the most accurate measurement of invar and other tapes and wires. A description is given of the sledge

carrying the travelling microscope and of the procedure involved in a complete test of length.

Standardization of Measures of Length at the Laboratory of the Dominion Land Surveys. Bul 44, Dept of the Interior, Canada, Topographical Surveys Branch 1921 33 p 32 figs. Description of equipment for calibrating tapes.

Effect of Concentrated Loads on the Length of Measuring Tapes, L. V. JUDSON. Sci Papers NBS v21 nS–534 Apr 15 1926 p 385–93. Formulas are given for computing the change in length of a tape when concentrated loads such as thermometers are added to the tape. Experimental data confirming the formulas are given.

Testing of Measuring Tapes at the Bureau of Standards, L. V. JUDSON. NBS Cir n328 Mar 1927. Description of steel tape and invar geodetic tape calibration at NBS.

Nomographic Chart for Steel Tapes, C. D. SHEPARD. Civ Eng v2 July 1932 p 440–2 4 figs. Elimination of corrections to tape measurements made possible by determination of tension of accuracy.

The 24 m interference comparator of the Potsdam Geodetic Institute, F. MÜHLIG. Deutsch Akad Wiss Berlin. Veröff Geodat Inst Potsdam n2 50 p 1949 in German. An instrument for standardizing invar tapes for geodetic base measurements in terms of the red Cd line. The distance between mirrors 12.5 cm apart is compared with the distance between the mirrors of a Fabry-Perot etalon by establishing interference between white-light beams which have undergone one reflection at the 12.5 cm mirrors and two reflections at the etalon. A wedge is inserted into the combined beams to produce white-light fringes and the difference between the longer interval and twice the shorter interval is equal to the thickness of the wedge at the point where the white-light fringes occur. Similarly the 12.5 cm interval is compared with a 1 m interval, that with a 6 m interval and the latter with the 24 m interval. The length of the etalon and the thickness of the wedge are obtained in terms of the red Cd line. The apparatus is arranged so that for convenience in field work the comparisons between the different stages can be made simultaneously, and with two observers the etalon can also be standardized at the same time. The influence of optical aberrations is discussed, the use of the instrument is described and some measurements are reported.

50-Metre Mural Comparator at N.P.L., J. S. CLARK. Engr. v189 n4908 Feb 17 1950 p 201–3, Feb 24 p 228–30. Method used at National Physical laboratory to standardize precision tapes and wires used by geodetic surveyors and for other measurements of length ; micrometer microscopes and other equipment are attached to brick wall 164 ft long, whole forming comparator of sufficient short term stability for comparisons of necessary accuracy ; description of improved equipment and technique supplements article in "Glazebrook's Dictionary of Applied Physics", Vol. 3, 1923 ; illustrations.

Standardisation of Steel Surveying Tapes, J. S. CLARK, L. O. C. JOHNSON. Empire Survey Rev v11 n81 1951 p 118–28 4 figs 7 refs. Surveying tapes of steel are much more satisfactory mechanically than those of invar, and are less subject to secular changes of length, but the magnitude of their coefficient of thermal expansion demands a closer knowledge of their temperature than can be obtained with ordinary thermometers suspended near the tapes. The measurement of steel tapes in terms of their electrical resistance has therefore been investigated. The history of this work is traced. The use of resistance methods has proved satisfactory in the field, and under Laboratory conditions at the NPL the accuracy of 1 part in 2 millions in the measurement of the lengths of 24-metre and 100-foot tapes of steel is attained. Such steel tapes appear to have

remained stable on the average within about 2 parts in a million in 25 years.

A New Method for Determining Linear Thermal Expansion of Invar Geodetic Surveying Tapes, P. HIDNERT, R. K. KIRBY. J Res NBS (RP–2407), v50 n4 Apr 1953 p 179–85. An electrical method for measurement of linear thermal expansion is described. A direct current is passed through the tape for heating. Observations of changes in length and electrical resistance are taken at different constant temperatures of the tape. Temperature of the tape is determined from its different resistances and the temperature coefficient of resistance. This method has several advantages over the old method of measuring the change in length of the tape at different ambient temperatures of the laboratory.

Neues Prüfungsverfahren fur die Eichung von Messbandern (New Testing Method for the Calibration of Tapes), C. HOFFROGGE. Special reprint from the Amtsblatt n 4/56 of PTB, Deutscher Eich-Verlag, Berlin W 30 1955 p 320–1 2 figs.

Meteranschluss von Invardrähten für Basismessungen (Meter Reference of Invar Wires for Base Line Measurements), C. HOFFROGGE, H. RUMMERT. Veröffentlichung der Deutschen Geodätischen Kommission, ser B n71 1958 11 p 7 figs 6 refs. A part of 1958 was spent by the PTB in the calibration against the prototype meter of the invar wires used in the measurement of the 8-km baseline in the Ebersberger Forest near Munich. The arrangements and measuring methods applied are described and the possible sources of error are quantitatively investigated.

Berechnung der Messlänge bei frei durch hängenden Bandmassen (Calculation of Length of Freely Suspended Tapes), M. GARY. Zeit für Vermessungswesen v84 n6 1959 p 188. Discusses calibration of tapes.

Universal Device for the Inspection of Direct-Reading Gages, M. A. ADADUROVA. Meas Techns 1959 n1 Mar 1960 p 7 1 fig. Translated from Izmer Tekh n1 Jan 1959 p 6. Describes a comparator having a 1 meter base with which every meter division of measuring devices of any length are compared with it in turn. In checking a tape measure its free front end is connected to the lead tape of the right-hand reel, passed over the guide rollers and, together with its case, placed onto the left-hand reel. Thus placed, the divisions of the tape being inspected are opposite the divisions edge of the master tape. The error of each meter is determined after placing the first graduation of the tape being inspected against the corresponding mark of the master tape, by reading the error on the other end.

Calibration of Line Standards of Length and Measuring Tapes at the National Bureau of Standards, L. V. JUDSON. NBS Monogr 15 May 20, 1960. Description of tape calibration methods at NBS. Appendix on the use of steel tapes including Young's Modulus of Elasticity, corrections for sag, and tension of accuracy.

4.4. Measuring Microscopes and Line Comparators

See also Subsection 1.2.3

Measuring Objects in the Microscope, F. E. IVES, J Franklin Inst v154 July 1902 p 73–6. The image of an illuminated scale is projected in the plane of the object by means of the substage condenser. In the author's arrangement a Welsbach light, with ground-glass chimney and hood, illuminates a jeweller's saw set up, on a block of wood, at a suitable distance from the condenser. The distance between two teeth was equivalent to 0.02 mm on the stage micrometer.

A Microscope for Measuring Screw Threads. Eng v76 Nov 13 1903 p 660 9 figs; Am Mach v27–1 Jan 21 1904 p 78–9 7 figs; Machy (N.Y.) v24 Feb 1918 p 494–5 4 figs. The instrument was made by the Cambridge Scientific Instrument Co. for the Small Screw Gage Committee of the British Association by whom it was placed in the custody of the National Physical Laboratory. Figures show different views of the instrument and the arrangement of cross wires and various adjustments.

Comparator, A. J. COX. Zeit InstrumKde v22 Nov 15 1907 p 229–31. Bureau of Science, Manila, Philippines. A solid base carries two vertical guide bars rigidly connected at the top by a cross piece, from the middle of which two scales to be compared are hung. The suspensions for both are provided with an adjusting screw, so that the scale zeros can be set together. The bottom of each scale is secured to the base by a suitable clip. The reading microscope (magnification=60 diams.) has horizontal traverse on the edge of the plate, capable of adjustment, which is carried on a slide having vertical motion on the guide bars. With the aid of a scale in the eyepiece of the microscope, readings can easily be obtained correct to 0.01 mm. For greater accuracy the most costly method of the German Imperial Commission of Standards is recommended. See also Deutsche Mech Ztg 1907 p 230–1 and Phil J Sci v2 Manila 1907 p 139–43.

The Transversal Comparator, A. BLASCHKE. Zeit InstrumKde v27 Dec 1907 p 361–9. Communication from the Phys Tech Reichsanstalt. Improvements in the comparator, including details as to thermostats.

Über einige Neueinrichtungen für Längen- und Kriesteilungen mit Mikroskop-Ablesung (New Length-measuring Instrument), C. PULFRICH. Zeit Instrumkde v27 Dec 1907 p 369–73. Communication from the Optical Workshops of C. Zeiss. The instrument is called the stereocomparator. Rough readings are taken by the eye alone to 0.1 mm on a metal scale. Fine readings are taken on a glass scale to .01 mm. A series of mirrors is used to send the light onto the scale and then horizontally to the eye. The principle is also applied to the measurement of angles.

The Microscope in the Tool Room, F. A. STANLEY. Am Mach v30 Dec 12 1907 p 887–92 and 916. An illustrated article showing how a great variety of operations in connection with tool work may be facilitated by the use of the microscope. A comprehensive article.

The Microscope in the Manufacturing Plant, F. A. STANLEY. Am Mach v31 Jan 16 1908 p 77–8. Illustrates and describes some of the advantages of the microscope in connection with manufacturing processes. Includes the description of a microscope having two micrometers at right angles to each other mounted in the base of the instrument and actuating the work-supporting table.

Registration Micrometer for Spectra, O. LOHSE. Zeit InstrumKde v30 June 1910 p 169–73. Description of a new measuring micrometer for spectra, with a series of registration keys for recording the readings directly as observed.

Der grosse Komparator der Kaiserlichen Normal-Eichungs-Kommission (Large Line Comparator of K. N. E. Komm), W. KÖSTERS. Zeit InstrumKde v33 Aug 1913 p 233–47 9 figs. Describes a new comparator for the finest length measurements and for comparison of meter bars. Describes the room in which it is installed; the system of interchange of the standards; the pier and microscope; the rail, turntable, and carriage; the troughs of the one-meter comparator and its length-standard supporting table; special features of the one-meter comparator; and the troughs of the four-meter comparator.

Micrometer Microscopes, A. W. GRAY. NBS Sci Paper 215 Bul 10 1914 p 375–90. Discusses some errors affecting

measuring microscopes, methods of applying corrections to a group of micrometers and of determining the corrections of micrometer microscopes.

Measuring Templets and Screw Threads with a Microscopic Measuring Machine. Machy (N.Y.) v24 May 1918 p 791–3 5 figs; Am Mach v53 July 22 1920 p 187; Eng Prod v2 Jan 13 1921 p 4–44 12 figs. Construction and adjustment of Alfred Herbert design of measuring microscope and application for testing accuracy of templets or contour gages and screw threads. The machine has a table capable of 12-in. longitudinal movement by accurate amounts by insertion and removal of hardened steel measuring rods between flat contact pieces. The table carries a pair of centers, one of which can be adjusted crosswise to enable accurate alignment of work. A microscope fitted with two crosshairs, one rotating with the outside tube and the other rotating with the eyepiece, is mounted on a compound slide controlled by micrometer screws. The outer tube of the microscope has a dial reading to half degrees and the eyepiece has a vernier reading to one minute. A light projector is fixed to the machine and will project parallel rays of light past the work.

Use of Microscopes in the Gage Section, Bureau of Standards, R. L. RANKIN. Am Mach v51 Sept 18 1919 p 581–2. Discusses use of microscope in linear measurements on gages, etc.

Note on a Handy Form of Measuring Microscope, T. F. CONNOLLY. Opt Soc Trans v22 n1920–21 p 194–8. The instrument comprises a microscope system of relatively low power; a double-image prism traverses the object-space, and is controlled by the rotation of a milled band operating a spiral slot. Exit pupil discs of telescopes or other optical instruments and Brinell impressions can be measured by a single contact setting of the edges of the duplicated discs. The range is from 1 to 6 mm. and the accuracy with fixed focus ±0.02 mm. The reading scale is divided to 0.1 mm. No vernier is used.

A New Ocular Micrometer, H. KELLNER. J Opt Soc Am v7 Oct 1923 p 889–91 4 figs. Describes micrometer employing sliding measuring wedge in place of micrometer screw. Presents the advantages but not the defects of both the micrometer screw and the glass scale. A glass scale is adjusted by a sliding wedge and readings then taken to three places of decimals.

On the Limit of Accuracy in Optical Measurement, A. A. MICHELSON. J Opt Soc Am and Rev Sci Instrum v8 321–8 Feb 1924. The limits of accuracy obtainable in observations with the telescope, microscope, interferometer, and spectroscope are discussed.

Société Genevoise Combined Measuring and Drilling Machine. Am Mach v66 June 30 1924 p 1112. Adapted for measuring in polar coordinates. Has circular table permitting angular measurements, table lead screw of 4 in. range, and a microscope.

Zeiss Thread-measuring Instruments. Am Mach v62 May 28 1925 p 861–2 5 figs. A toolmakers' microscope is shown in fig. 5. Work may be mounted on V-blocks or centers that are placed on a compound table provided with a swivel movement. For inspecting thread profiles the instrument is provided with an accurate optical templet, containing the profiles of standard threads, as shown at C, fig. 13, which is located at the upper portion of the magnifying lens and turned by hand until the desired profile is brought into view.

Microscopic Measuring Machine, C. M. GOOTSCHAU. Machy (N.Y.) v31 June 1925 p 791–2 3 figs. A binocular measuring microscope for inspecting and measuring the faces on type and embossing punches and for determining their position relative to bodies and shanks. One micro-

scope is focused on a scale and the other on the work, the images being blended when seen through the binoculars.

Principles and Advantages of Optical Methods for Measuring Machine Parts, H. F. KURTZ. Mech Eng v47 mid-Nov 1925 p 987–92 16 figs. Fig. 4 shows an erecting tool-makers' microscope, that is, one giving the image the same aspect and motion as that of the object. The cross-slide stage is actuated by micrometers reading to 0.0001 in. Fig. 5 shows a special screw-measuring stage, and Fig. 6 a goniometer eyepiece for the tool-makers' microscope.

A New Measuring Micrometer, J. H. DOWELL. Opt Convention Proc. Part II p 991–8; Disc. 998–9 1926. A new micrometer measuring up to 6 in. is described, and the theoretical considerations controlling its design are discussed. The main features are a carriage with geometric bearings, which can be released from the nut to line up the specimen, an enclosed screw and slide, and a microscope of geometric design adapted to take a wide range of objectives.

Société Genevoise Measuring Microscope. Am Mach v64 Jan 28 1926 p 177–8. Measuring microscope suitable for the measurement of small machine parts, fibers, mesh of textiles, pitch and diameters of small screws. Performs both angular and linear measurements. The microscope is mounted in a slide, the ways of which are part of the rotating table. The angular position of the table is read by means of a graduated circle and vernier. The slide is moved by means of a micrometer.

Ein Universalmessmikroskop (Universal Measuring Microscope), A. STEINLE. Maschinenbau v5 May 20 1926 p 445–9 16 figs. Discusses optical measurement of threads, and progress attained in increased precision with projection method.

Bausch and Lomb Toolmakers' Microscope. Am Mach v65 Oct 14 1926 p 652–3 2 figs. Microscope having base with micrometer adjustment, illuminator attachment, lead-measuring attachment, protractor eyepiece, etc.

Zeiss Universal Measuring Microscope. Am Mach v66 May 26 1927 p 913–4. Has wider range than toolmakers' microscope and is designed to measure pitch diameter of screw threads, using knife edges.

Société Genevoise Two-Coordinate Measuring Machine. Am Mach v69 Nov 1 1928 p 706–7. Also Machy (N.Y.) Nov 1928. The object to be measured is placed on a table which moves in one direction on V and flat ways under the action of a precision micrometer screw which causes motion of the table through 16 in. The microscope is carried on a slide by which it is moved across the table by a similar micrometer screw through a range of 4 in. Has a variety of useful features.

Zeiss Improved 1x3-in. Toolmakers' Microscope. Am Mach v73 Nov 20 1930 p 832–3 2 figs. This model retains the features of previous designs, such as: the dial templet; smooth table movement guided by balls; a free swiveling table top, and a quick-acting micrometer crank. The general design has been made more massive and sturdy, and longitudinal movement of table of 3 in. permits the use of gage blocks. The cradle for the centers and V-blocks can be clamped to the table. The box-type column can be swiveled for bringing the microscope tube and illumination jointly into angular position for projecting the helix angle of a thread. Measurement of pitch diameter to within the limits of 0.0002 in. can be made. Specifications: Cross travel of table, 1 in.; longitudinal travel of table, 3 in.; magnification, 30 times; range of micrometers, 1 in.; graduation of micrometers, 0.0001 in.; reading of angles on universal ocular, 1 min.; reading of angles on dial templet, 10 min. A special projection attachment, for converting the Zeiss toolmaker's microscope into a pro-

jector is available, making observation visible to both eyes from an image on the screen.

Société Genevoise Micrometer Microscope. Am Mach v75 July 30 1931 p 221–2. Model 281–D may be used for checking the profiles of small gears or screw threads. The micrometer screw is fitted and lapped into the bronze nut, while the thrust bearing of the screw is a sapphire ground optically flat to eliminate periodic error. Micrometer-drum divisions permit estimates of a tenth of a division, or 0.000005 in. To obtain the complete reading it is merely necessary to set down successively the numbers indicated on the turn counter and the micrometer head. The eye-piece can be placed over the center of the desired field to reduce the distortion of the image. Total magnification is 41.5, 63 or 96 times.

Optical Measuring Machine. Eng v133 Mar 4 1932 p 294. Machine patented by R. Douglas, installed in Orthological Institute, London; measures small wire and like, to accuracy of 0.00005 in.; method of measurement; though originally designed for measurement of very fine filaments or of very small holes, same method is applicable to ordinary workshop measurements.

Measuring Microscope for Rubber Specimens, R. E. LOFTON. Indus and Eng Chem (Analytical Ed) v4 Oct 15 1932 p 439–40. Microscope provided with six-times micrometer eyepiece and objectives of 32 and 48 mm focal length is suitable for measuring cross-sectional dimensions of rubber test specimens; width of specimens is usually greater than that of die with which they were cut; thickness of soft compounds as determined by microscope is greater than that indicated by gage of plunger type.

Improved Toolmakers' Microscope. Engr v166 n4320 Oct 28 1938 p 477–8; Eng v146 n3799 Nov 4 1938 p 547. Illustrated description of Zeiss microscope for measurement of gages, templets, form tools, screw threads, gears, and similar parts.

"Home-made" Toolmakers' Microscope, E. W. PENNINGTON, Am Mach v84 n13 June 26 1940 p 460–1. Illustrated description of conversion job done on contour projector which widened its usefulness without sacrificing any of its original functions.

Direct-Reading Measuring Microscope, J. E. SEARS, JR., A. TURNER. J Sci Instrum v43 n17 Feb 1941. The article describes a travelling microscope designed for measuring by direct readings Debye-Scherrer X-ray powder photographs. With this instrument measurements are made by direct reference to a glass scale which can be traversed, together with the photographic film, beneath a low-power microscope in which the scale and film can be viewed together. A fixed vernier also of glass, is viewed at the same time and readings may be made to 0.01 mm. The scale and film are traversed by hand, enabling rapid movements to be made throughout the length of the film. A fine traverse is provided for adjusting the film image to the cross wire in the microscope.

Measuring Microscope, G. H. WAGNER, G. C. MAILEY, W. G. EVERSOLE. Indus and Eng Chem (Analytical Ed) v13 n9 Sept 15 1941 p 658–9. Technique for measuring vertical distances up to several centimeters with precision of 0.00005 cm; illustrated description of microscope which has range of 16 cm and can be read to 0.000058 cm; difficulties that were encountered and solved in constructing and calibrating instrument to this precision.

Taylor, Taylor and Hobson Toolmakers' Microscope. Machy (London) v61 n1558 Aug 20 1942 p 217; Automobile Engr v32 n480 Nov 1942 p 497–8. Illustrated description of microscope for use in toolroom and standards room, mainly intended for examination and measurement of screw threads, thread cutting tools and grinding wheels and for measurement of lengths and angles on small components, form tools, and gages.

Cooke Toolroom Microscope. Machy (London) v61 n1559 Aug 27 1942 p 235–7. Illustrated description of microscope developed by Cooke, Troughton and Simms, intended to serve as comprehensive measuring instrument in both factory and laboratory.

The Toolmaker Microscope as Optical Comparator, F. KOENIG. Screw Mach Eng June 1944 p 40–3 5 figs. Deals primarily with the adaptability of the toolmaker microscope as a comparator.

Optical Locating System Takes Guesswork Out of Positioning, G. C. BECKER. Am Mach v90 n1 Jan 3 1946 p 83–6. Developed for graduating curved gunsight elevating bars, optical indexing fixtures use $40\times$ toolmakers microscope and specially engraved master scale; air clamps assure uniform pressure, permit operator to check setting with microscope while applying pressure, and allow quick release of work; construction, operating details, performance and working results; modifications of fixture discussed in which same principle is applied to other close tolerance machine work.

The Measurement with the Microscope of Inaccessible Dimensions of Macroscopic Bodies, G. SCHENDELL. Archiv fuer Tech Messen n178 (Ref. V1121–8) Nov 1950 p T120 in German. Two arrangements are described. They are suitable for measurements of, for example, electrode dimensions or spacings which are inaccessible due to enclosure in glass envelopes or are at high potentials.

Parasitic Vertical Movement of a Symmetrical System of Guided Rods, J. E. PLAINEVAUX. Nuovo Cimento v11 June 1954 p 626–38 in French. A brief historical review of mechanical arrangements for the rectilinear guidance of elastic rods is followed by an approximate theoretical treatment of a particular compensation system which is used in microscope travelling stages. The treatment is based on the principle of the superposition of small deformations.

Das Mikroskop, A. METZ. Archiv fuer Tech Messen n223 Aug 1954 p 185–8. Microscope for length measurement and contour control; ocular micrometer; measuring microscope with tube displacement; applications.

Semi-Automatic Recorder for Filar Micrometer Eyepiece and Its Application to Track Measurement, B. STILLER, F. I. LOUCKES, JR. Nuovo Cimento (Ser. 10) v4 n3 Sept 1956 p 642–7. A differential transformer has been mounted on a filar micrometer eyepiece and has been coupled to a recording circuit, to make possible automatic recording of the hairline positions. The apparatus greatly reduces the time required to make measurements with a filar eyepiece; e.g., as when measuring the multiple Coulomb scattering of tracks in nuclear emulsions.

A Photoelectric Microscope for the Measurement of Linear Scales, J. S. CLARK, A. H. COOK. J Sci Instrum v33 n9 Sept 1956 p 341–7. A description is given of a photoelectric microscope which is suitable for the accurate measurement of linear scales of high precision. A real image of a graduation line, formed by means of an ordinary microscope objective, is caused to oscillate across a fixed slit in front of a photoelectric cell. A phase-sensitive rectifier determines when the mean position of the line image coincides with the center line of the slit. When this is so, the d.c. output of the rectifier is zero and for small displacements of the mean position of the line gage, the d.c. output—which is measured on a microammeter—is proportional to the displacement. The standard deviation of a single setting of the microscope is about 0.03μ and by associating the microscope with an interferometer, short linear scales have been measured directly in wavelengths with a standard deviation of about 0.1μ. It is thought that, with a properly designed interferometer to measure the displacement of a scale with respect to a fixed photoelectric microscope a standard deviation of 0.05μ would be achieved.

Measurement of the Diameter of Opaque Cylinder by Scanning Microscopy, J. A. DOBROWOLSKI, W. GODFREY, P. N. SLATER, W. WEINSTEIN. J Opt Soc Am v47 n2 Feb 1957 p 186–90. Experiments have been carried out to determine the systematic errors in the measurement of the diameters of opaque cylinders by scanning microscopy. It was found that for cylinders of diameter near the optical resolution limit, the scanning microscope gives too large a size estimate. The variation of the error with aberrations and numerical aperture of the scanning objective, and with the wavelength and state of polarization of the light were determined. Optimum conditions for size determination are suggested.

Modifications to a Travelling Microscope Used for Measuring X-ray Powder Photographs, W. E. ARMSTRONG, R. J. DAVIS. J Sci Instrum v35 n2 Feb 1958 p 59–61. The cross-hairs in the microscope eyepiece were removed and the reference mark was obtained from a light spot thrown on the photograph from a projector clamped to the barrel of the microscope. Cross-hairs seen in silhouette tend to obscure faint lines on the photograph and prevent their measurement. The light spot eliminates this effect, allows change of magnification for measuring different lines without moving the reference mark, eliminates parallax and allows the use of a binocular eyepiece. These features reduce eyestrain while measuring a photograph, and improve the accuracy of measurement of faint or diffuse lines. The photograph is illuminated by a short fluorescent tube, the light of which is cooler and "harder" in quality than that of filament lamps. Means are described of adjusting the light intensity of the tube over a wide range.

Microscope Mechanical Object Stage for the Study of the Tracks of Charged Particles in Photographic Emulsions or Other Objects in Transparent Media, H. SLÄTIS. Rev Sci Instrum v29 n11 Nov 1958 p 968–70. In addition to the usual arrangements for measurements of the x and y coordinates for nuclear tracks in photographic emulsions, the stage is rotatable about the optical axis of the microscope as well as about an axis perpendicular to the optical axis. The angles of rotation can be read off scales. Through these arrangements and by the use of an eyepiece micrometer the orientation and the length of nuclear tracks can be measured directly.

La Dispersion de Lecture dans les Microscopes Micrometriques, J. PETTAVEL. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 63–72 12 figs 2 refs. Discusses measuring accuracy of micrometer microscopes having projection screens. The reading dispersion is the sole factor affected by the design of the micrometer. Comparison of dispersion curves for different types. The reading dispersion is less on projection screens than in microscope eyepieces provided that the surface is devoid of granulation.

Length Measurement at the Optical Resolution Limit by Scanning Microscopy, W. T. WELFORD. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 85–91 4 figs 6 refs. The image of an edge object in a scanning microscope with full-cone illumination is calculated, and it is shown that the half-intensity point does not occur at the position of the geometric image, resulting in a systematic error in determination of the position of the edge.

A Precision Microscope for the Measurement of Small Dimensions, V. E. KOSTIN. Meas Techns 1959 n6 June 1960 p 412–3 1 fig. Translated from Izmer Tekh n6 June 1959 p 18. The measurement of dimensions with the precision measuring microscope is performed by absolute and comparative methods. The first method is used with the ocular micrometer, and in the second, the measurements

are performed by comparison with a length standard placed between supports.

A Semi-Automatic Analyser for Bubble Chamber Photographs, O. R. FRISCH, A. J. OXLEY. Nuclear Instrum and Methods (Int) v9 n1 Oct 1960 p 92–6. Photographs of nuclear particle tracks can be accumulated rapidly with fast-cycling bubble chambers. This article describes a machine for measuring the photographs quickly so that the subsequent computation can be done with an electronic computer. The films are projected onto a ground glass screen bearing a reference mark, and moved by hand through a pantograph to bring interesting points onto the mark. The pantograph carries a plate with a fine square lattice of dots, and four photocells serve to digitize its X and Y coordinates. The two stereoscopic images of a point can be merged by moving one of the projection lenses; this motion also is digitized photoelectrically. After setting each point, the measured data are punched on tape, to be fed later to an electronic computer. The design, operation, and performance of the machine are described in some detail, together with the principles of measurement and some proposed improvements.

A New Micrometer Microscope, R. BARER. Nature (London) v188 Oct 29 1960 p 398–9. Measurement of the size of particles in a microscope against an eyepiece scale is tedious and often inaccurate. A new system is described in which two images are seen, sheared by a known amount. Particles whose diameter equals the shear will just touch, those smaller will appear as two distinct objects, while layer particles will overlap. An attachment to a standard microscope is described. This allows the shear to be controlled in amount and direction, so allowing the measurement of irregular shaped objects.

Photoelectric Microscopes for Comparing Graduated Linear Measures, L. K. KAYAK, S. I. TOROPIN. Meas Techns 1960 n2 Nov 1960 p 90–2 2 figs 3 refs. Translated from Izmer Tekh n2 Feb 1960. The developed experimental photoelectric microscope, applied to a four meter comparator, is suitable not only for sighting graduations, but also for direct measurement of length differences read off a comparator by the objective method.

Measurement of Object-Micrometer Type Scales, N. A. KLIENTOV. Meas Techns 1960 n2 Nov 1960 p 93–4 1 fig. Translated from Izmer Tekh n2 Feb 1960. A specialized instrument for measuring object-micrometer type scales has now been installed in a production shop. By means of this instrument rapid and efficient measurements of object-micrometers are made according to the specification of GOST 7513–55.

Checking MPB–2 Measuring Microscopes, F. P. VOLOSEVICH. Meas Techns 1960 n2 Nov 1960 p 95–6. Translated from Izmer Tekh n2 Feb 1960. Describes a modified horizontal comparator IZA–2 for checking the readings of measuring microscopes MPB–2 used with hardness testers TSh.

Modernized Horizontal Comparator, E. I. FINKEL'-SHTEIN. Meas Techns 1961 n1 Sept 1961 p 16–20 4 figs 2 refs. Translated from Izmer Tekh 1961 n1 p 12–4 Jan 1961. Describes an improved comparator for testing reference linear scales.

Method for Determining Comparator Screw Errors with Precision, J. M. BENNETT. J Opt Soc Am v51 n10 p 1133–8 Oct 1961. A method is described for determining with precision the relative cumulative error and the periodic error of a comparator screw. Measured curves of these errors shown for two comparators. The method also gives the relative lengths of the intervals on the scales used in the measurements.

The SIP Type CLP–10 Photoelectric Longitudinal Comparator, A. W. ASTROP. Machy (London) v99 Oct 25 1961 p 944–62 19 figs. Details of new length-measuring and comparing equipment. The basic principle as proposed by M. Volet; features of the mechanical design; the traversing carriage; traversing the carriage; drive to the carriage and microscopes; the photoelectric microscope; measurement and comparison without interferometry; the interferometry equipment; using the Fabry-Perot etalon; special permises.

A Photoelectric Setting Device for a Measuring Microscope, H. GOLLNOW. Monthly Notices Roy Astron Soc (GB) v123 n5 1962 p 391–7. A photoelectric setting device for the measurement of emission and absorption lines is described. Its special advantages for the case of ill-defined and asymmetrical stellar lines is discussed. The probable error for one setting is well under half a micron and is independent of line definition; systematic errors between different observers are practically eliminated.

Setting Accuracy of Graduation Lines, W. LOTMAR. Microtecnic v16 n2 Apr 1962 p 55–60. Comparative investigations concerning setting accuracy of graduation lines between 2 straddling reference lines have shown that method of image formation has no manifest influence on standard deviation, providing comparable optical equipment is used.

A Device for Accurate Linear Measurements of Chart Traces and Graphs, M. D. ROGERS. J Sci Instrum v39 n6 June 1962 p 317 1 fig. Measures to within 0.002 in. the position of x-ray diffraction peaks obtained on a chart recorder.

A Cathetometer with Automatic Levelling, J. GIELES-SEN, K. STEINER. Zeit Angew Phys (Germany) v14 n12 Dec 1962 p 715–7 in German. An optical device eliminates the need for levelling the cathetometer telescope each time it is displaced.

Microscope for Measuring Small Diameter Holes and Their Concentricity, S. L. GONDIK. Meas Techns 1962 n8 Feb 1963 p 648–9 2 figs. Translated from Izmer Tekh n8 Aug 1962 p 23–4. See abstract in subsection 7.4.

Test Measurements in Comparators and Tolerances for Such Instruments, B. P. HALLERT. Photogrammetric Eng v29 n2 Mar 1963 p 301–14. Comparator tests are assumed made with aid of measurements of grid coordinates of high and known geometrical quality; tolerances of regular errors, residuals and standard errors of unit weight are determined according to confidence limits from statistics; practical examples; certain regular errors of grid coordinates can be distinguished from errors of comparator; tests of some different glass scales are shown.

Magneto-Optic Positioning, R. J. MELTZER. IEEE Trans Ind Electronics vIE–10 May 1963 p 46–56 27 figs. The system described permits production of accurate scales and grids, with a precision better than one μ in, by forming an image of the line with polarized light whose angle of polarization varies with the position of the line. A combination of position sensitive polarization of Faraday modulation produces a signal whose phase depends on the sense and whose amplitude depends on the amount of displacement of the line image from the optic axis. Sensitivities of one microampere per microinch displacement can be achieved with unit magnification.

Cathetometer KM–8, F. M. DANILEVICH, V. A. NIKITIN. Measurement Techniques (English translation of Izmeritel'naya Teknika) n7 July 1963 p 544–6. Cathetometer described is intended for measuring vertical segments up to 500 mm in length, at distance of 280–1810 mm from protective glass of telescope (with lens attachments) and in range of 1810 to infinity (without attachments); as compared to its Western counterparts, instrument is claimed to have higher precision in measuring vertical linear segments, smaller error in its reading device, and

higher efficiency and ease in operation, since image of object, millimeters scales, and level bubbles are seen simultaneously in eye piece field of vision.

Measure to Millionths-in Seconds, C. STEAD. Am Mach/Metalworking Mfg v107 n19 Sept 16 1963 p 109–11. Carl Zeiss Universal Measuring Microscope employed by Taft-Peirce Manufacturing Co, Woonsocket, RI measures all kinds of contour gages, threads of any shape, cutting tools, templets, chasing tools, and similar parts; with attachment it can measure eccentricity and helix angle on threads, worms, gear shaper cutters, and gear and thread hobs; direct readings can be made to 50 millionths of in. and 1 min of arc; measuring time cut 85%.

Development and Applications of Photo-Electric Microscopes, A. MOTTU, J. PETTAVEL. Proc Mach Tool Design and Res, Pergamon Press 1964 p 455–71 18 figs. Principle of photo-electric microscope is discussed, together with applications in calibrating divided scales, determining the position of a movable member of a machine or instrument, and positioning manually or automatically a movable member of a machine or instrument.

An Improved Temperature-Controlled Bath for the Comparison of Line Standards, E. G. THWAITE. Microtecnic v18 n1 Feb 1964 p 2–7 7 figs 3 refs. The interrelationship of uncertainty of temperature, material of standards, and inaccuracy of linear measurement is discussed together with the special requirements of a temperature-control system to allow temperature to be measured to the accuracy required in very precisely comparing reference line standards. A description is given of a temperature-controlled bath, having a stability of ±0.003 °C at 20 °C for periods of 15 minutes, developed for use on a 1-meter line standards comparator.

Photo-Electric Microscope for Precise Setting on Scale Lines, J. L. GOLDBERG, H. J. RITTER, Microtecnic v18 n2, 3 Apr 1964 p 54–67, June p 117–24. Description of photoelectric miscroscope designed for use in transferring from optical wavelength standards to mechanical linear standards; instrument provides indicator to permit im-

personal settings to be made on line standard consistent to 0.01 μ as compared with 0.2 μ for visual microscope; deviations of up to plus or minus 0.2 μ from set position can be measured; lineal magnification of displacement is 350,000 times; electronic system uses semiconductor circuits which meet all requirements of stability for instrument of this type.

Measurement of Microscope Magnification, D. H. FREEMAN. App Optics v3 n9 Sept 1964 p 1005–8. Procedure of calibrating ruled scale and of measuring magnification of visible light microscope is described; measurement techniques include use of movable hairline micrometer, image-splitting ocular, photoelectric scanning of photomicrographic plates, and photoelectric scanning of image plane; empirical treatment of magnification measurements, including effects of optical distortion, is employed, so that residual errors are assigned to imperfections in measuring screw plus random contributions.

Classification of Photoelectric Microscopes, A. M. DUBINOVSKII. Meas Techns n3 Oct 1964 p 205–8 8 refs. Translated from Izmer Tekh n3 p 13–5 Mar 1964. Photoelectric microscopes can be divided by the principle of their conversion of the measured quantity into an electrical signal into three groups, of amplitude, pulse-position, and modulated types. Each type has a characteristic functional circuit from which it is easy to determine the relationship between their measurement error and their circuit component parameters. Pulsed photoelectric microscopes are superior to others in their quality characteristics, such as stability of readings, range, etc. The amplitude and modulated photoelectric microscopes are mainly used as null detectors, whereas it is possible by means of pulsed photoelectric microscopes to measure the position of graduation lines, as well as distances between them. An analysis made by means of the information theory has shown that it is possible to evaluate the properties of photoelectric devices by means of information characteristics, such as the flow of useful information and the capacity of the reading unit. These characteristics are suitable for finding such parameters of microscopes as precision and speed of operation.

Addendum to Section 4

4.1.   Line Standards, General

Untersuchungen und Maasregeln zur Herstellung der Einheit des preussischen Längenmaases (Experiments and Measurement Control for the Production of the Prussian Length Standard), F. W. BESSEL, Berlin 1839 148 p.

On the Measurement of the Base Lines at Holton, Indiana and at St. Albans, W. Va., 1891–2, A. T. MOSMAN, R. S. WOODWARD, O. H. TITTMANN. Appendix 8, Report for 1892, U.S. Coast and Geodetic Survey, Government

Printing Office 1893 p 329–503. Contents: Description of iced bar base apparatus and its application to the measurement of base lines; length of iced bar B_{17}; measurements made with iced bar apparatus; the metallic tape base apparatus; measurements of bases made with the tape apparatus; method of computing correction for flexure of 5-meter bar B_{17}; and mathematical theory of metallic tapes, including changes in length due to variable parameters.

Section 5. Dimensional Measuring Instrument Design Features

CONTENTS

5.1. Measuring Instruments, Design Principles

The Parallel Motion of Sarrut and Some Allied Mechanisms, G. T. BENNETT. London, Edinburgh and Dublin Phil Mag v9 June 1905 p 803–10. A link mechanism for exact parallel motion is described. See also Dunkerley's Mechanics, page 386.

Design and Construction of Scientific Instruments, R. S. WHIPPLE. Opt Soc Trans v22 1920–21 p 35–52; Eng v111 May 27 1921 p 659–62. A general résumé of the principles underlying the design of scientific instruments.

The Mechanical Design of Scientific Instruments, A. F. C. POLLARD, J Roy Soc Arts v70 Sept 29, Oct 6 and 13 1922 p 769–80, 783–94, and 797–808 43 figs; Eng v113 June 9 16 23 and 30 1922 p 729–30 763–64 794 and 828–9 24 figs. Consideration in design of qualitative and quantitative instruments used in many branches of physical, engineering and chemical sciences. Abstract of three Cantor Lectures delivered before Royal Soc of Arts.

Notes Upon the Mechanical Design of Some Instruments Shown at the Exhibition of the Physical and Optical Societies, 1928, A. F. C. POLLARD. J Sci Instrum v5 Mar 1928 p 88–92 5 figs. Ross kinematograph projector; Maltese cross movement; W. Ottway and Co. screw measuring machine; Laby X-ray spectograph; goniometer fitting of Muller's X-ray goniometer spectrograph.

Konstruktionsgrundlagen der feinmechanischen Technik (Principles of Instrument and Apparatus Design), W. KNIEHAHN. VDI Zeit v72 n49 Dec 8 1928 p 1773–5 34 figs. Discussion of standard structural elements, joints, bearings, gearing, etc., of mechanical, electric, optical, and acoustic apparatus.

The Geometric Design of Scientific Instruments, J. A. TOMKINS. Instrum Wld v1 Dec 1928 p 229–31. Considers degrees of freedom and gives examples showing the result of the imposition of successive constraints on a rigid body, each constraint being imposed by causing one point of the body to touch a fixed surface. Examples of geometrical slides and geometrical clamps. Lists authorities.

Notes on Design of Measuring Instruments, F. H. ROLT. Ch. 14 of Gauges and Fine Measurements, Vol. II. Macmillan and Co. Ltd, 1929. Discusses geometric location, geometric slides, the principle of alinement, form and flexure of measuring machine beds, the thrust of micrometer screws, the use of flexible steel strips, micrometer screws, and fine adjustments.

Grundlagen und Geraete Technischer Laengenmessungen, G. BERNDT. 2d ed. Berlin, Julius Springer 1929 374 p illus diagrs tables. Survey of scientific principles of measurement and instruments for practical use; evolution of usual standards is described, and methods by which shop and control standards of length are made and calibrated are discussed; application of various types of gages and other measuring instruments; physiological errors in measurement and reference of meter to wavelength of light are discussed in appendixes. Eng. Soc. Library, N.Y. H. SCHULZ was coauthor of 1st ed 1921.

Zwei Messtechnische Grundsaetze und ihre Befolgung (Two Fundamental Rules of Measuring Techniques and Their Observation), G. BERNDT. Werkstattstechnik v24 Sept 1 1930 p 461–7 22 figs and Sept 15 1930 p 495–8 10 figs. Sept 1: Example of comparators shows that to avoid errors of first order, object and not measuring instrument should be moved; it is further made apparent that for longitudinal comparator standard and object must be located on same axis (Abbe's principle); observation of these rules in principal measuring instruments and methods is investigated. Sept. 15: Technical measuring methods and instruments based on principle of transversal comparator.

Works of Messrs. Cambridge Instrument Co., Ltd., Eng v132 n3416 July 3 1931 p 1–5 21 figs partly on p 16 and supp plate. In design of instruments, geometric principle, of which late Darwin was perhaps greatest exponent, is largely employed; examples of effective application of geometric principle of instrument designs; layout and equipment of works; research; work organization.

Zeiss Optical Cam Checking Device. Am Mach v75 Sept 3 1931 p 397. The outfit consists of a scraped surface plate with two parallel T-slots, an optical dividing head and tailstock and a measuring microscope. The camshaft is taken between centers, and the angular setting secured from the optical dividing head. The reading

may be taken directly to one minute of arc. Rise and fall of the cam for each angular setting is secured by means of the measuring microscope. The reading is obtained directly from a scale. Distance between centers can be up to 60 in.

Daempfung von Messgeraeten (Damping of measuring instruments), W. HOFMANN. Archiv fuer Tech Messen v1 Mar 1932 p T38–9, and Apr p T54 ; Veroeffentlichungen aus dem Gebiete der Nachrichtentechnik 2 n2 1932 p 103–6. Mar : Fundamentals, theory and determining values ; theoretical mathematical analysis and curves. April : Calculation of air damping devices for measuring instruments. Bibliography.

Luftdaempfungen fuer Messgeraete (Air damping of measuring instruments), F. EICHLER. Archiv fuer Tech Messen v1 Apr 1932 p T55. Application and design of air damping devices for measuring instruments.

Some Industrial Applications of Metrology. M. F. TURRETTINI. Machy (London) v50 n1299 Sept 2 1937 p 692–5. Fundamental conditions that must govern design of precision instrument or machine, in order to ensure best chances of success ; example given of causes of error which may arise in operating screw cutting lathe. Before École Nationale Besancon.

Measuring and Gauging Contacts for Modern Production, F. HORNER. Can Machy v48 n12 Dec 1937 p 192–5, 202 and 220. Production methods demand great accuracy which can only be obtained by suitable measuring devices equipped with surface of contacts of special design, some of which are briefly described ; solid and adjustable gages ; micrometer calipers ; internal micrometers ; screw gaging and measuring ; contacts for indicating.

Design Factors Controlling Dynamic Performance of Instruments, C. S. DRAPER, G. P. BENTLEY. ASME Paper n30 mtg Dec 4–8 1939 9 p. Generalized treatment of instruments which have single movable index, controlled by magnitude of single actuating quantity ; such instruments act as system with 1° of freedom ; properties can be specified in terms of range, scale sensitivity calibration and environmental error and uncertainty ; definitions and use of each of these quantities discussed. Bibliography.

Use, Care and Maintenance of Laboratory Instruments, H. N. HAYWARD. J Eng Education v30 n5 Jan 1940 p 506–10. If accuracy is to be maintained and known, frequent checking of test instruments with reliable working standards is essential ; if possible, correct type of instrument should be used in every application ; cause of errors in instruments ; calibration and checking of instruments.

Instruments for Measuring Dimensions, O. W. BOSTON. Metal Progr v48 n4 Oct 1945 p 991–6. Linear dimension measuring instruments and gages discussed in relation to design, principles and applications as quality control tools. General review, O. W. Boston ; Rules, Micrometers and Calipers, H. D. Hiatt ; Comparators, W. H. Baker.

Geometrical Measurement, C. H. H. FRANKLIN. Eng Inspection v11 n2 summer 1946 p 9–23. In principles set forth engineering production is considered mainly as art of controlled production of geometrical forms in agreed relation to standard units of size and shape ; standards of length measurement ; accuracy and limits ; systems of geometrical measurement ; complex measurements ; apparatus characteristics ; geometrical construction of measuring appliances ; sources of error in geometrical methods ; use of interferometer. Before Instn Eng Inspection.

Precis of a discussion on "Practical considerations in instrument design"—London, 1948. J Sci Instrum Phys Ind v25, Apr 1948, p 122–4.

New Optical Precision Measuring Instruments for the Workshop, A. METZ. Trans Instrum Meas Conf Stockholm 1949 p 182–5 1950 in German. A brief illustrated description of new Leitz instruments. These include an instrument for the control of sizes of workpieces, a coordinate drilling machine with a precision measuring ocular, a telescope with a magnification of 32 and a range of 1–50 metres, and the "Perflektometer," an instrument for the measurement of end gap and other gauges.

Laboratory Instruments, Their Design and Application, A. ELLIOTT, J. H. DICKSON. Chemical Publ Co, New York, 1953 414 p. Principles of good design necessary for construction for instruments in laboratory workshop ; separate chapters discuss properties, treatment, and use of various materials ; methods of construction to meet special requirements ; Kinematic design of instruments ; optical instruments and glass ; use of photography in research. Eng Soc Library, N.Y.

Discussion on Kinematic Design Applied to Instruments. Soc Instrum Technol Trans v6 n2 June 1954 p 66–82. Views of various participants on advantages of instrument design based on kinematic principles ; such practice is of value in improvisation of research apparatus to be put together without specially good workmanship, construction of apparatus which is precise in function without imposing close dimensional limits, and design of equipment for metrology applications ; particular instrument designs.

Instrument Linkages, W. O. DAVIS. Soc Instrum Technol Trans v7 n1 Mar 1955 p 1–9. Design of linkages which have to operate accurately in indicating or computing instrument mechanisms under conditions of vibration and abnormal acceleration ; return springs and counterpoises ; relationship of number of kinds of calibration adjustment to number of null error points obtainable in calibration curves ; examples of linkages for providing linear, square-law, and log-law approximations in translation-to-rotation mechanism.

Some Principles of Measurement and Control, J. F. COALES. J Sci Instrum v33 n12 Dec 1956 p 457–64. Two classes of measurement are those which only have to be observed and recorded and those which are used to control ; limitations from which all measuring instruments suffer, e.g. they all disturb physical system on which measurements are being made and they all have inertia and damping to some degree, also no measuring instrument is completely stable ; these limitations are discussed ; simple theory of linear control systems is developed.

New Comparator for Measuring Pitch Errors of Fir-Tree Root Serrations in Gas Turbine Discs, L. W. NICKOLS. Machy (London) v19 n11 Nov 1957 p 450–4. Comparator described is complementary to instrument reported in Engineering Index 1955 p 202 ; new comparator rapidly measures pitch errors to desired accuracy by comparison with composite slip gage standard, with errors recorded on chart ; design and principle of operation ; measuring head and turret ; workholder and indexing mechanism ; setting comparator ; interpretation of chart record.

Aperture Corrective Systems, J. OTTERMAN. IRE Trans Instrum vI–8 n1 Mar 1959 p 8–19. Corrective networks for improving performance of certain instrumentation systems ; desired correction serves to offset averaging effect common to such sensing devices as deflection plates of oscilloscope, scanning beam of television camera, networks particularly useful when aperture small enough to provide essentially flat response up to desired frequency is not technically feasible.

Mesure et Instrument de Mesure (Measurement and Measuring Instruments), J. IDRAC, 4th ed. Dunod, Paris 1960

125 p. Basic principles of measurement; areas of measurement and sensitivity; accuracy; velocity; statistical distributions.

La Mesure dans l'Automatisme, l'Automatisation des Mesures (Measurement in automatization, and automatization of measurements), U. ZELBSTEIN. Genie Chim v83 n1 Jan 1960 p 1–14. Automatization of measurement is essential when manual observation and control is impossible (for example, at high speeds) or when standard arrangements have reached limit of their possibilities.

Universal Mechanical Assembly for Laboratory Purposes, Particularly for Optical and Semi-Automatic Measurements, J. BAKOS, Z. ERDÖKÜRI, K. KANTOR Magyar Tudomanyos Akad Központi Fiz Kutato Intézetének Közlemenyei (Hungary), v9 n3 p 171–80 1961 in Hungarian. Describes a versatile mechanical unit and driving mechanism both easily assembled from universal elements. The driving mechanism can be remote controlled. The two assemblies are suitable either for individual or for joint use. The various elements are provided with connections to optical and precision mechanical tools, and in this way their usefulness may be considerably extended.

Logarithmische Verstaerker mit VDR-Widerstaenden (Logarithmic amplifiers with voltage dependent resistor resistances), R. ROEHLER, H. P. POPP. Zeit InstrumKde v70 n1 Jan 1962 p 15–16. It is found that certain ceramic resistances have logarithmic characteristic within wide range which is made use of in construction of logarithmic amplifier; deviation of amplifier-characteristic from logarithmic scale is maximum of 2% within 3.5 decades; amplifier is used for direct indication of emulsion densities, but its range of application is much larger.

Grundbegriffe der Messtechnik (Fundamentals of Measuring Practice). DIN 1319 15p Jan 1962. German standard available in both German and English from ASA. price $2.50. Covers basic principles governing the use of measuring instruments and fundamentals of errors arising in measuring practice. Applies to measuring instruments in which an index associated with the instrument is set, or sets itself, to a position on a scale belonging to the instrument.

Kontakteinrichtungen fuer empfindliche Zeigermessgeraete (Contact devices for sensitive indicating instruments), K. H. ZEITZ. Archiv Tech Messen n313 315 Feb 1962 p 33–6, Apr p 87–90. Principles of operation and design of devices for wide range of instruments used for chemical processes, industrial temperature measurement, etc., 23 refs.

Non-Contact Dimensional Measurements by Optical and Electronic Techniques, C. D. BRYANT. IRE Trans on Indus Electronics vIE–9 n1 May 1962 p 1–6. Accurate dimensional measurements of products during processing are major requirement in many industries; because of high heat radiation, rapid motion, or other factors noncontact measurement system is desirable; systems which have been developed using combination of closed circuit television and special optical techniques together with special purpose computers and associated readout devices.

Some Uses of Elasticity in Instrument Design, R. V. JONES, J Sci Instrum v39 n5 May 1962 p 193–203. Discussion of anti-distortion instrument mountings, elastic movements for rotation and translation, movement magnifying and reducing devices, elastic averaging schemes, simple harmonic force and constant force systems, elastic energy stores, and slow relaxation device for transmitting rapid displacements only. 45 refs.

Graticules and Fine Scales: Their Production and Application in Modern Measuring Systems, E. BOVEY. J Sci Instrum (GB) v39 n8 Aug 1962 p 405–13. After a historical survey an account is given of a wide range of processes employed for graticule manufacture. Optical, photographic and mechanical requirements together with their respective limitations are discussed. Finally, some special high-quality graticules and scales employed in modern measuring systems are described.

Classification of Automatic Measuring Instruments, V. M. SHLYANDIN. Meas. Techns 1962 n6 Dec 1962 p 456–7. Translated from Izmer Tekh n6 p 9–11 June 1962. Develops the definition that an automatic measuring instrument is a device which evaluates objectively the measured quantity by balancing it automatically with a compensating quantity, and which uses for this purpose an auxiliary power source.

5.2. Amplification

5.2.1. General

Measurement of Small Displacements, A. RIGHI. N Cimento v6 1897 p 349–52 in Italian. The author describes a simple method of measuring small displacements, such as the motion of a point on an expanding bar. It consists essentially of a short lever supported at two close points on the same side of its centre of gravity by two very fine stretched fibres, one of which runs in an upward direction, and the other downward. The directions of the fibres will intersect on the vertical through the centre of gravity of the lever. The lower end of the lower fibre is fixed, and the upper end of the upper one is attached to the moving point. When the point moves upward or downward, the lever is tilted, and the angle of tilt is measured by a telescope, or lamp, and scale. In the actual instrument the suspension is bifilar; a thread of three cocoon-fibres is formed into a rectangle, the two upper corners of which are fastened to a rod connected with the moving point, and the two lower corners to a similar rod connected with the fixed point. The thread passes between two jaws at each end of a crosspiece attached horizontally at right angles to the lever. By this means errors due to torsion of the fibre are avoided; and by using short fibres changes in length due to humidity of the air do not cause any ap-

preciable error. The author has succeeded in magnifying a small motion twenty thousand fold by this apparatus.

Empfindlichkeit von Instrumenten, G. KEINATH. Archiv Tech Messen v1 Feb 1932 p T22. Sensitivity of measuring instruments; rules outlined are applicable primarily to electric instruments and also to great extent to other types; definitions; value of high sensitivity; sensitivity of various types; current, voltage and energy sensitivity; numerical data. Bibliography.

Recent Progress in Making of Precision Instruments, A. J. PHILPOT. J Roy Soc Arts v96 n4764 Mar 12 1948 p 213–22 (discusssion) 222–4; Mech Wld v 123 n3187 Feb 13 1948 p 193–4; Metal Industry v72 n8 Feb 20 1948 p 151–2; Machy Market n2474, 2475, Apr 16 1948 p 195–6. Apr 23 p 205. Discussion of means by which increased accuracy of instruments is obtained; examples of optical and surveying instruments accuracy of which has been increased by magnification; magnification by conversion applied to conversion of small temperature changes into large pressure changes; data on recently developed instrument in which small changes in linear dimensions are converted into changes of frequency; discussion of magnification by electronics.

Primary Detectors for Measurements, E. E. LYNCH, A. J. CORSON. Elec Eng v67 n9 Sept 1948 p 849–59. Basic elements of any measurement system may be classified into three functional groups known as primary detectors, intermediate means, and end devices; by classifying primary detectors for both electrical and non-electrical quantities, convenient selection of suitable detector may be made when quantity to be measured together with range over which it will vary is known. Paper 48–104 before Am Inst Elec Engrs.

Is There a Science of Instrumentation?, E. U. CONDON. Sci v110 n2858 Oct 7 1949 p 339–42. Rules governing classification of instruments; characteristics of transducer; transforming and amplifying elements of instrument; present demands for instrumentation improvement are essentially higher sensitivity and faster response.

Theory of Mechanical, Electrical, Electronics and Air Gaging, W. F. ALLER. ASME Paper n52—A–89 for meeting Nov 30–Dec 5 1952 16 p. Characteristics of mechanical, electrical, electronic and air gages that have made possible separation of inch into smaller and smaller divisions; descriptions of dial indicator, mechanical comparator, reed gage mechanism, electric transducers, gaging circuits, limit type gage head, flow type gage, Venturi type gage, back pressure gage and differential gaging circuit.

Sensitivity of a Vibrating Reed Null Indicator, L. J. SOMERVAILLE. J Sci Instrum v31 n12 Dec 1954 p 439–40. A simple vibrating reed null detector is described. The sensitivity of the instrument has been studied by two methods. In each case consecutive readings were obtained within $\pm 2 \times 10^{-6}$ in.

Mechanic-Electric Transducer, K. S. LION. Rev Sci Instrum v27 n4 p 225–5 Apr 1956. Description of a transducer system which permits the conversion of mechanical displacements into electrical signals. The system is based upon a high-frequency discharge in a gas under reduced pressure. Different modifications permit the detection of either very small movements (<1 mm) or large movements (several cm), or small changes of capacitance (fraction of a micro-microfarad).

A Mechanical-Electric Transducer of Simple Design, M. MANZOTTI. J Sci Instrum v33 n8 Aug 1956 p 314–15. A probe electrode plunged into a current field experiences a potential which is a function of its position in the field; when it is moved, the variation of potential is also a function of the displacement. This principle makes possible the design of mechanical-electrical transducers of simple construction and easy assemblage. An application to pressure recording is here described. The sensitivity (5 cm of water per full deflection) and speed of response (no distortion for variation of pressure up to 220 cm of water per second) can, if necessary, be easily improved.

Six Transducers for Precision Position Measurement, J. O. MORIN. Control Eng v7 n5 May 1960 p 107–12. Review of high precision transducers, with measurement capabilities up to one part in quarter million, includes pin-and-pawl mechanism, magnetic bench-mark system, resolver-type transducers, electrostatic transducers, and diffraction gratings.

A Recording Extensometer, A. D. MARTYNOV. Meas Techns 1959 n3 May 1960 p 163–4 1 fig. Translated from Izmer Tekh n3 Mar 1959 p 7. Discusses inclusion of electrical recorder into amplifying devices.

Screening Micrometer—New Principle for Measuring Small Movements. B. E. NOLTINGK. Brit Communications & Electronics v7 n6 June 1960 p 430–5. Limitations of conventional resistive, capacitive, inductance, and photoelectric pickups for measuring small movements are reviewed; new type of transducer is described in which coupling between coils is varied by screen moving between them; sensitivity of device is such that movements of 1μ and less can be readily measured.

Hydraulic Method of Measuring Length, V. G. SHTEIN. Meas Techns 1959 n12 Sept 1960 p 934–8 3 figs. Translated from Izmer Tekh n12 Dec 1959 p 10. The instrument described proves the possibility of using the hydraulic method for linear measurements and the production of commercial instruments operating on this principle and capable of wide application in different devices, including those used in various methods of automatic control.

Electromechanical Transducer for Small Displacements and Forces, G. S. BERLIN. Pribory i Tekh Eksper (USSR) 1961 n5 p 152–7 Sept–Oct in Russian. The design, characteristics, and parameters of an electromechanical transducer (mechanotron) for small displacements and forces, and of a simple, highly sensitive mechanotron micrometer and dynamometer with a potentiometer recorder are described. [Eng. translation in: Instrum exper Tech (USA) n5 Sept–Oct 1961 p 973–7; publ. April 1962.]

Investigating the Kinematic Error in a Hydraulic Comparator, V. V. MATVEEV. Meas Techns 1961 n10 Mar 1962 p 784–8 4 figs 6 refs. Translated from Izmer Tekh n10 p 11–4 Oct 1961. The kinematic error in hydraulic comparators plays an important part in determining the final judgment on the advisability of using the hydraulic method and on selecting a suitable arrangement for the instrument. In order to eliminate the kinetic error and raise factor, and hence raise the sensitivity of the instrument, it is necessary to use hydraulic comparators which provide a constant pressure on the diaphragm due to the liquid head independently of the displacement of the instrument's measuring rod.

Barium Titanate Ceramics for Fine-Movement Control, J. V. RAMSAY, E. G. V. MUGRIDGE. J Sci Instrum v39 n12 Dec 1962 p 636–9. Barium titanate transducers are described for use in automatic control of Fabry-Perot interferometer, to achieve parallel displacements of plate to accuracy required in interferometry.

High Precision Linear Electro-Mechanical Transducers, F. BROUWER. Int Production Eng Research Conference Proc Sept 9–12 1963 p 592–600. Published by ASME. Various types of transducers for linear positioning and measuring problems in machine tool and gages are analyzed, including mechanical linkages and leadscrews, rack and pinion drives, diffraction graftings, digital scales, linear inductosyn. Steward-Warner linear position transducer etc. of which only digital scale gives absolute machine position directly; final choice of system for particular application depends to large extent on individual factors determined by environment in which measuring systems shall be used, and on magnitude of allowable errors.

Extensometer Calibrator, G. E. RICKWOOD, Canada, Nat Research Council-Mech Eng Report MH–102 Aug 1963 p 3 plates. Arrangement suitable for producing and measuring linear extensions of order of 1 μin. over range of plus or minus 0.0035 in. is described; provision is made for referring measurements to gage blocks; originally designed to permit calibrating vibrating wire strain gages, it is readily adaptable to calibrating other types of extensometers and strain gages by addition of suitable mounting blocks.

5.2.2. Electrical

An Electric Micrometer, P. E. SHAW. Proc Phys Soc London v17 Mar 23 1900 p 431–59 16 figs; Phil Mag v50 Dec 1900 p 536–62 6 figs; Abstract, Electrician v44 Apr 6

1900 p 854–5. Describes a method, said to be reliable, of measuring small distances by electric contact.

Electric Contacts, H. ROHMANN. Phys Zeit v21 Aug 15 1920 p 417–23. A torsion arrangement is described by means of which displacements of the order of $1\mu\mu$ could be determined. With this apparatus the variations of current, due to closer approach of the electrodes of a contact, could be followed. The "contact distance" for different materials was of the order of magnitude of $1–50\mu\mu$. The results made it possible to produce an efficient metal microphone and a reliable coherer.

A Method of Measuring the Periodic Error of a Mechanism, G. A. TOMLINSON. J Sci Instrum v6 n5 May 1929 p 152–3 3 figs; Mech Eng v51 n12 Dec 1929 p 955. Simple apparatus devised in the Metrology Department of National Physical Laboratory for determining periodic error in motion transmitted by kinematic pair; consists of two similar electromagnetic markers connected in series so as to produce series of simultaneous kicks on smoked-plate records attached to two components of kinematic pair; mechanism is allowed to move at very slow rate.

The Electric Gage, A. V. MERSHON, J. W. MATTHEWS, B. C. WAITE, JR. Gen Elec Rev v32 n12 Dec 1929 p 674–5 3 figs; West Machy Wld v21 n1 Jan 1930 p 10 30 3 figs. Instrument is independent of human sense of touch; simple and rapid to manipulate; amplification factor is 10,000; electric gage has been developed to meet need for accurate gaging device that has but minimum of moving parts and that will permit routine gaging operations to be conducted with great rapidity.

Electric Precision Gage of Great Accuracy. Machy (N.Y.) v36 n6 Feb 1930 p 435–6 3 figs. Description of electric gage designed to meet demand for accurate gaging device that has minimum of moving parts and that will permit routine gaging operations to be conducted with greater rapidity; with amplification factor of 10,000, this gage, independent of human touch, makes possible measurements to 0.00005 in., gage may be used for both inside and outside measuring.

General Electric Magnifying Electric Gage. Am Mach v74 Feb 19 1931 p 340. An electric gage that measures one one hundred thousandth of an inch, and then magnifies that dimension 10,000 times, has been developed. This type of gage is suitable for almost any kind of measurement with certain changes in set-up. The gage consists essentially of a contact point supported to move through a limited distance in the direction of measurement, say 0.0005 in. This movement causes a pointer to travel 5 in. over a scale of an indicating instrument. The diamond contact point is fitted in the gage spindle, which is made to suit the work.

Piezo-Electric Gage and Amplifier, R. A. WEBSTER. J Franklin Inst v211 n5 May 1931 p 607–16 7 figs. Pressure gage using cartridge of pure bakelite; within this was placed pile of 21 quartz crystals, each 0.69 in. sq. by 0.053 in. thick, being separated by platinum electrodes; screwed brass ends held them in cartridge which was then sealed with beeswax; gage has given good service, and although few of crystals cracked, no loss in sensitivity has been noticed.

Grid Glow Micrometer, R. W. CARSON. Am Mach v75 n11 Sept 10 1931 p 407 2 figs. Operating principles and hook-up of instrument using vacuum tube to avoid errors resulting from contact pressure.

New Electric Arrangement for the Measurement of Small Displacements, S. REISCH. Zeit für Hochfrequenztechnik v38 Sept 1931 p 101–11. A brief description is given of various electric micrometer arrangements, with a full bibliography. The various arrangements are criticized, and then a new type of capacitative displacement meas-

uring apparatus is described which is based on the potential distribution across condensers arranged in series. The theoretical capacity sensitivity is 2.5×10^{-8}.

Precision Measurements of Mechanical Dimensions by Electrical Measuring Devices, A. V. MERSHON. Gen Elec Rev v35 Mar 1932 p 139–44. Electric gages for measuring diameters; combination electric gages for making two or more measurements at same time; electric sizing control used to automatically machine parts to given dimension; electric matching control used to machine parts to existing masters; strain gage used to measure change in length of structural member, etc.

Korkeajaksointerferenssiin Perustuva Rekisteroeivae Mitrometri, P. E. KUOKKANEN, A. BAECKSTROEM. Teknillinen Aikakauslehti n12 Dec 1934 p 388–95. High frequency interference recording micrometer invented by authors for measuring and recording diameter variations of thin wires used for manufacturing of glow lamps; variation of 0.0001 mm in wire diameter will cause deflection of 1 or 3 mm respectively on recording paper of instruments. (Brief abstract in English p 395.)

Elektrisches Ultra-Mikrometer zur Messung des Waermeausdehnungskoeffizienten keramischer stoffe (Electric micrometer for measuring coefficients of thermal expansion of various ceramic materials), A. HEINZ, H. KOTTAS. Sprechsall v68 n4 and 5 Jan 24 1935 p 49–51 and Jan 31 p 65–7. Details of procedure; illustrations.

Galvanomagnetic Measurement of Small Displacements, S. REISCH. Akad Wiss Wien Ber v145 2a 9–10 1936 p 725–52. The method depends on the variation of the resistance of Bi with the magnetic field in which it is placed. To obtain a high sensitivity and good temperature compensation four Bi resistance coils, connected so as to form a Wheatstone bridge, move in the gaps of two permanent magnets. In order that correction may be applied for the temperature of the whole network, this forms the arm of another bridge enabling the total resistance to be measured. Theoretical considerations lead to the calculation of a calibration curve and give information concerning the constancy of the zero, and the limit of sensitivity. Two practical designs are given, together with their experimentally-determined sensitivities. These, expressed as fractional changes of resistance for 1 mm of movement, were 1.6×10^{-2}.

Measuring Millionths of an Inch, R. W. CARSON. Elec J v33 n2 Feb 1936 p 106. After several years of experimental work, entirely new method of measuring spring deflections was developed, using electronic micrometer; device used electronic means of indicating point of contact between hand micrometer and test specimen in form of small cantilever beam.

Electric Gage, C. M. HATHAWAY, E. S. LEE. Mech Eng v59 n9 and 12 Sept 1937 p 653–8 and (discussion) Dec 1937 p 963. Mechanical measurements involving displacements as small as 0.00001 in. and even 0.000001 in. can be made with electric gage described; displacements being measured can be amplified 10,000 or 100,000 times on indicator without introducing frictional effects; four methods of electric gaging, capacitance, bridge, saturation, and eddy current, are described. Bibliography. Before Am Soc Mech Engrs.

Elektrische Messung kleinter Laengenunterschiede (Electric measurement of small differences in length), E. FROBOESE K. SCHOENBACHER. Archiv fuer Elektrotechnik v33 n5 May 12 1939 p 341–6. Fundamental operation of electric measuring gage discussed; special reference made to sources of error and their correction; examples of practical application.

Convenient Electrical Micrometer and Its Use in Mechanical Measurements, R. GUNN. ASME Advance Paper n34

meeting Dec 4–8 1939 4 p. Simple micrometer of mechanical and electrical stability developed; electric current output from micrometer is accurately proportional to impressed mechanical displacement; zero drift, hysteresis, temperature, and pressure variations reduced to less than 1%; special circuits described which permit indication of sums, difference, ratios, or products of mechanical displacements and are useful in mechanical measurements.

Note on Electromagnetic Induction Micrometers, Including Novel Circuit, Incorporating Metal Rectifier, R. J. COX. J Sci Instrum v 19 n8 Aug 1942 p 117–20. Convenient method of measuring displacements of order of few thousandths of inch is one which utilizes changes in inductance of iron cored coil produced by changes in lengths of airgaps in its magnetic circuit; methods of indicating these changes in inductance are discussed; new circuit is described which incorporates metal rectifiers and microammeter or galvanometer as indicator.

Electric Gauges, H. P. KUEHNI. Gen Elec Rev v45 p 533–6 Sept 1942. The gage is an a.c. bridge circuit in which one or more impedance branches are acted upon by the quantity to be measured. The calibrated amount of brdige unbalance is indicated on an instrument which may be remotely installed at any convenient location.

Detecting Small Mechanical Movements, J. C. FROMMER. Electronics v16 p 104–5 July 1943. A valve circuit for detecting movements of 10^{-6} in. is described. These movements are converted into capacitance changes of the order of $0.01\mu\mu$ F. Variations in oscillator and cable characteristics are nullified by the insertion of a displacement unit between the oscillator and amplifier. The amplifier has been used successfully for measuring blood-pressure curves.

Elektrische Verfahren zur Messung kleiner Laengen (Electrical methods of measuring small lengths), W. REDEPENNING. Archiv Tech Messen n150 Dec 1943 p T145 (2 p) (J112–4). Illutrated description of electric methods at measuring short linear dimensions with aid of induction or contact instruments; both types described and illustrated.

Measurement of Displacement and Strain by Capacity Methods, B. C. CARTER, J. F. SHANNON, J. R. FORSHAW, Engr v177 n4602 Mar 24 1944 p 237–8. Account of some developments for which authors and colleagues at Royal Aircraft Establishment have been responsible; authors have found it advisable to employ electronic equipment that is adaptable to any class of pick-up, e.g., resistance, electromagnetic, capacity, or induction, with associated pre-circuits. Abstract from Symposium before Instn Mech Engrs.

Electric Gaging Methods for Strain, Movement, Pressure and Vibration, H. C. ROBERTS. Instrum v17 n4, 5, 6, 7, 8, 9, 10, 11, 12, Apr 1944 p 192–6, May p 260–5, 284, 286, 288, June p 334–9, July p 398–403, 414, 416, 418, 420, 422, 424, Aug p 475, 484, 486, 488, 490, Sept p 534–4, 544, 546, 548, 550, 552, 554, Oct p 603–5, 626, 628, Nov p 668–70, 684, 686, 688, Dec p 742–4, 755. Apr–May: Principles of operation; auxiliary circuits and recording devices; operating techniques; gaging methods based on variations of capacitance; sensitivity, stability, and accuracy discussed. June–Aug: Gaging methods based on variation of inductance. Sept–Dec: Gaging methods based on variation of resistance.

A Change-of-Capacitance Method for the Measurement of Mechanical Displacements, E. BRADSHAW. J Sci Instrum v22 June 1944 p 112–4 2 figs 2 refs. Method is suitable for the measurement of static or alternating displacements. The circuit includes two radio-frequency oscillators feeding a mixer valve. Variation in the frequency of one of the oscillators, and therefore in the frequency of the mixer output, is effected by the changing capacitance. A frequency-amplitude converter circuit produces a direct voltage which is proportional to the change of capacitance.

Use of Radio-Frequency Apparatus in Inspection, J. CORNELIUS. Machy (London) v66 n1699 May 3 1945 p 473–6. Details of construction and operation of apparatus which measures such mixture variations as one thousandth part of millionth of inch; comprising measuring and indicating units, physical units in inspection are translated into electrical units which are amplified by external power on indicator; electronic arrangement and radio circuit employed are explained, and economics and advantages of its application discussed.

The Use of Frequency Modulation in a Sensitive Micrometer, G. M. FOLEY. Am Phys Soc Proc June 1945. Abstr. in Phys Rev v68 p 101 Aug 1 and 15 1945. To measure the unimpeded displacement of an object, one plate of a small air capacitor is attached to the object. The other plate is fixed close to the moving plate, and the capacitor is used to tune a r.f. oscillator. The change in frequency resulting from motion of the object is converted into proportional d.c. voltage by a receiver similar to a radio receiver. Voltages of ±300 V are obtained from small displacements, and a magnification of the motion 10^4–10^5 times can be obtained, permitting detection of displacement of 10^{-6} in. The apparatus is robust and stable and requires no electrical connection with the object. Two such micrometers were placed at rt. angles to measure the rotation of a precision lathe spindle in its bearings, the outputs of the two micrometers being applied to two axes of a c.r.o. A similar micrometer was used as a high-speed recording dilatometer to follow the allotropic transformation of steel on heating and cooling.

Electric Gaging Methods, H. C. ROBERTS. Instrum v18 n9, 10, 12, Sept 1945 p 616–7, 624, 626, 628, 630, 632, 634, 636, Oct p 685–9, 706, 708. Dec p 882–9, 912–4, 916–8, 920. Sept: Calibrating devices. Oct: Calibration checking circuits and oscillographs. Nov: Power supplies. See earlier parts of series listed above.

Capacitance Micrometer, R. W. DAYTON, G. M. FOLEY. Electronics v19 n9 Sept 1946 p 106–11. Variations in oscillator frequency caused by minute movements of capacitive circuit element are converted to output voltage changes in electronic gage; using principle which has been successfully used for dilatometer, monometer, roughness gage and hardness testing apparatus; device uses limiting amplifier to free instrument from errors which might be caused by amplitude variations; design details.

Electronic Gaging, P. H. HUNTER. Electronic Indus v5 n9 Sept 1946 p 68–71. New standards of accuracy and speed in dimensional inspection made possible by precision electronic instruments, is exemplified by two micrometer developments; Carson Electronic micrometer employs screw of high lead accuracy with electronic circuit facilitating interpolations to 25 microinches or less; Wilmotte "Visi-Limit" micrometer features sensitivity not dependent on size of material being measured, and accuracy of ±0.0002 in.

Indicateur de Contact Electrostatique à Battements (Electrostatic oscillating contact indicator), P. FAYOLLE. Rev Gén de Elec v56 n3 Mar 1947 p 124–8. Application to comparator for ultra-micrométric recording; illustrated description of screw comparator combined with electric contact indicator, claimed to give very accurate results.

Les Ultra-Micromètres Electrostatiques (Electrostatic ultra micrometers), A. PARNET. Machines et Métaux v31 n343 Mar 1947 p 107–9. Principle of apparatus and comparison of two different solutions; illustrated description of 150-mm and 250-mm comparator and micrometer used for internal measurements.

A Variable Capacitor for Measurements of Pressure and Mechanical Displacement; A Theoretical Analysis and Its Experimental Evaluation. J. C. LILY, V. LEGALLAIS, and R. CHERRY, J App Phys v18 n7 July 1947 p 613–28. A variable capacitor is described for measuring small displacements, small volume changes, and pressure differences. The capacitor consists of a deflectable diaphragm and a fixed electrode. The diaphragm is metallic, plane-parallel, clamped at the edges, and at earth potential; the electrode, at an a.c. potential, has a plane surface parallel to the undeflected plate across an air gap. For use in displacement measurements, the diaphragm's center is deflected by a point contact from a mechanical link to the observed system, or by a uniform pressure load from a fluid link to the system. The plate deflection results in a change in the air gap, and thus generates a capacitance signal, which is measured by electrical methods. The theory of the device is analyzed and sensitivity and alinearity factors are derived.

Cathode-Ray Recording Micrometer and Force Gauge, J. EWLES, C. CURRY. J Sci Instrum v24 n10 Oct 1947 p 261–5. Features of device using oscillograph with moving coil system to record and measure rapidly varying movements of order of 3 mm to accuracy of 0.0025 mm; by attaching moving coil to specially designed force gage of natural period of about $\frac{1}{5000}$ sec, device has been applied to record and measure rapidly varying forces and preliminary study of rapid shear.

Electronic Gauges, J. SCHWARTZ. Microtecnic v2 n5, 6 Oct 1948 p 199–206, Dec p 267–74, v3 n1 Jan–Feb 1949 p 10–8. Systems for transformation of mechanical dimensions into voltages such as piezoelectric gaging heads for measurements of pressure, resistance extensometers for measurements of strains and stresses; study of types of gaging heads suitable as sensitive part of electronic comparators; gaging heads utilizing variations of capacity or of selfinductance can be adapted for accurate measurements of lengths.

Mesure et Amplification de Faibles Déplacements par Modulation de Fréquence (Measurement and amplification of small displacements by frequency modulation), P. BRICOUT, M. BOISVERT. Rev Gén de l'Elec v58 n10 Oct 1949 p 402–4. Use of manometric capsule as variable gap in capacitor in tuned circuit; frequency modulation resulting from pressure changes are determined using Bradley discriminator and output is read on calibrated milliammeter; equipment is suitable for manometer, vibrometer, or seismograph.

Electronic Developments in Instrumentation, D. ED-MUNDSON. Soc Instrum Techn Trans v1 n5 Dec 1949 p 8–17 (discussion) 18–9. Use of amplifiers for indicating instruments applied to measurement of physical quantities; consideration of a-c amplifier in instrument form, a-c bridge detector, negative feedback amplifier, d-c amplifiers, chopper amplifier, self balancing potentiometers and photoelectric amplifiers; questions of reliability and maintenance.

Measurement and Amplification of Minute Displacements by Frequency Modulation, P. A. BRICOUT. M. BOIS-VERT. Rev Sci Instrum v21 p 98–9 Jan 1950 2 figs. All functions are performed using only two tubes, an oscillator and a discriminator. Describes apparatus and discusses principle, characteristics, and applications of same.

Kleinstwegmessung mit induktivem Geber (Measurement of Very Small Movements by Means of an Inductive Pickup), F. STEJSKAL. Electrotech Zeit v71 n5 Mar 1 1950 p 115–6 6 figs 5 refs in German. Mechanical vibrations, as they occur in the testing of vehicles or stationary machines are converted by means of small pickup coils into a compensation circuit in electrical voltage fluctuations and shown on a loop oscillator. The pickup elements and circuits are described.

Differential Transformer as Applied to Measurement of Substantially Straight Line Motion, W. D. MacGEORGE. Instrum v23 n6 June 1950 p 610–4. Methods for determining displacement of bellows or diaphragm, motion of float, tip travel of Bourdon tube and tilt of weigh beam; discussion of basic design of differential transformers and circuits which permit their application to measurement of instrumentation variables such as pressure, flow, force, etc.; schematic diagrams.

A Micro-Inch Micrometer of One-tenth Inch Range, E. B. BAKER. Rev Sci Instrum v22 p 373–5 June 1951. Many instruments exist which will magnify small displacements to almost any degree desired but always at the expense of range. The micrometer screw is a notable exception, but does not give an electrical output nor will it measure distance directly and continuously without extra equipment. The present device combines a lever, a micrometer screw, a sensing element and a servometer to achieve this purpose.

Improvements in Null Indicator Electromagnetic Gauges, E. B. BROWN. J Sci Instrum v28 p 272–4 Sept 1951. The conditions for elimination of errors due to mains fluctuations are discussed, and an improved form of null setter is described, which in itself is a useful piece of laboratory equipment since it may be used as an a.c. potentiometer, having a small and nearly constant phase defect less than $\frac{1}{2}°$. The null setter was originally designed by the author for use as a counterbalance for a diaphragm operated moving coil gauge, but in this paper its application is shown to an a.c. mains operated gauge for remote indication with magnification of small angular deflections.

Inductance-type Transducer and its Applications, J. YAMAGUCHI, Y. SAKURAI. Tech. Rept Osaka Univ v1 p 201–12 Oct 1951. The "variable-gap" inductance-type transducer is used as the pick-up in measurement of length, pressure and mechanical vibration. In this paper fundamental considerations and practical applications of this transducer are described. The sensitivity of source which is applied to the transducer and the acting current of inductance coil, and the adequate values of these are shown in the case of a micrometer. Next, in the measurement of dynamic pressure or acceleration the relation between these mechanical quantities and gap length is discussed theoretically. As practical applications the ultra-micrometer, pressure recorder and acceleration meter are described. By the ultra-micrometer the diameter of a steel ball can be measured with sensitivity $\frac{1}{20}\mu$. The pressure recorder is applied to the measurement of dynamic pressure between pantograph and trolley wire and as an acceleration meter for vehicles. These instruments are stable, use light transducers of small size and robust construction, and are suitable for telemetering. They are thus suitable for field testing.

Micrometer Dilatometer, E. J. VANDERMAN. Rev Sci Instrum v22 Oct 1951 p 757–60. The construction, calibration, and use of a dilatometer that is ideally suited for use with radioactive materials is described. Expansion measurements are made electrically with a linear variable transformer.

Electronic Ultramicrometer, W. ALEXANDER. Electronic Eng v 23 n286 Dec 1951 p 479–80. Micrometer utilizing single octode tube and particularly adapted to measuring small changes of length; circuit makes use of change of anode voltage when resonant frequencies of two grid oscillator circuits are separated progressively from common value; change of length measured is applied to capacitor plates in one grid circuit.

Electronic Measuring Instrument for Small Displacements, L. A. GONCHARSKII. Elektrichestvo 1952 n6 p 62–5 in Russian. The theory of the input diode of a thermionic measuring instrument for small mechanical displacements using a moving electrode is presented. A

method for determining the current and voltage sensitivities of the instrument is found. It is seen that a diode with flat parallel electrodes is the most sensitive input element for such purposes, as far as current sensitivity is concerned, whereas the possibilities for improving voltage sensitivity are rather limited.

Die Electronic im Dienste der Messtechnik (Electronics in the Service of Measurement Technique), F. TURRETTINI. Ind Organisation v21 n6 1952 p 166–72.

Electronic Device for Measuring Small Transient Displacements, J. J. TROTT. J Sci Instrum v29 n7 July 1952 p 212–4. Micrometer device for measuring displacements down to 10 micro in., being suitable whenever it is possible for equipment to be mounted on stable support; use for measuring relative and absolute movements of concrete road slabs under wheel loads of vehicles; device is based upon variation of output of h-f oscillator due to movement of metal disk near tuning coil.

A Linear Transducer for the Electrical Measurement of Displacement, M. J. TUCKER. Electronic Eng v24 Sept 1952 p 420–2. This device depends upon the change in coupling between two coils with linear displacement. The primary is wound round the centre limb of a stack of Permalloy gate stampings. It extends almost halfway up this limb and above it is located the movable secondary coil. This latter coil is connected through a bridge rectifier to a d.c. indicating instrument. Over the linear operating range, corresponding to a displacement of approx. 1 cm, the output current varies from 1.3 to 2.7 mA. Accordingly, sensitivity can be improved by backing off some of this current, and two circuits intended for this purpose are shown. The circuit as used has to work off a 250c/s supply, but the advantages of a high frequency, e.g. 2 kc/s, are pointed out. Over the 1 cm range, linearity within the accuracy of measurement, approx. 0.005 cm, is achieved.

Electronic Dimensional Gaging, C. W. WILLIAMS. ASME Paper n52 A–98 for meeting Nov 30–Dec 5 1952 12 p. Features of gaging devices where displacement of measuring tip which engages piece to be measured is magnified by vacuum tube or amplifier to permit user to read displacement on scale, or to furnish impulse to control automatic gaging and handling equipment, use of recorders driven by amplifier where permanent records are useful.

Electronic Circuitry for Instruments and Equipment, M. H. ARONSON. Instrum Pub Co, Pittsburgh, 1953 310 p. Nonmathematical presentation of basic circuits and fundamental techniques with examples and application covering broad scope; resistance, capacitance, inductance and signal shaping, vacuum tube and gas tube fundamentals, amplification, rectification, and oscillation circuits dealt with. Eng Soc Library, N.Y.

Comparateur Électromécanique (Electromechanical Comparator), J. HUETZ. Techn Mod v45 n2 Feb 1953 p 47–50. Principles and characteristics; apparatus described has characteristics of strain gage, such as high degree of stability and fidelity.

The Photodianode, G. DELOFFRE E. PIERRE, J. ROIG. CR Acad Sci [Paris] v237 p1507–9 Dec 9 1953 in French. The use of the two anodes in a vacuum phototube with suitable geometry enables the relative anode currents to be used as a measurement of the displacement of a light spot on the cathode. The tube is of use for the precision measurement of small displacements or rotations.

Direct Reading Instrument for Measurement of Small Displacements, W. C. CORNER. G. H. HUNT. J Sci Instrum v31 n12 Dec 1954 p 445–7. Arrangement whereby differential condenser forms part of a-c bridge network; displacement of central plate causes proportional off balance voltage; small displacements can be measured to accuracy of 10^{-7} cm; applicability to measurement of magnetostriction of small crystals of nickel, maximum change in length being 85×10^{-6} cm.

A Simple Circuit for Use With Condenser Strain Gauges, D. M. MAURICE. J Sci Instrum v31 n12 Dec 1954 p 442–4. A one-valve circuit operating at 200 Mc/s is described which gives a stable output proportional to the strain and sufficient to drive directly a low-impedance recording milliammeter. It may be used with a wide range of recording capacitance down to 3pF. The connecting cable to the recording condenser acts as a transmission line and may be long without affecting seriously the working of the circuit.

Electronic Indicators of Mechanical Quantities, L. A. GONCHARSKII. Uspekhi fiz Nauk v55 n1 1955 p 81–100 17 refs in Russian. A survey, including material on the electronic micrometer, vibrometer, dynamometers, manometers.

History of Electrical Devices for Measuring Strains and Small Movements, B. E. NOLTINGK. J Sci Instrum v32 n5 May 1955 p 157–8. The development of apparatus for measuring strains and small movements by transduction into electrical signals is traced over the past hundred years. Instruments depending on resistive, capacitive, inductive, piezoelectric, acoustic and photoelectric systems are considered, and the chief contributors to the introduction of different techniques are enumerated.

Electronics: New Answer to Shop Gaging Problems, D. M. GASKILL. Am Mach v99 n25 Nov 21 1955 p 134–6. Design and functioning of electronic gaging system; gages can be made sufficiently sensitive to measure deviations in dimensions as small as 0.000010 in., 0.000001 in., or even 0.0000005 in.; other applications; examples of checking dimensions on lapped hydraulic motor pistons, high precision gears and armature shafts.

Apports de l'Électronique à la Métrologie (Contributions of Electronics to Metrology), J. AVRIL. Soc. Francaise des Mécaniciens Bul v6 n20 1956 p 22–4. Different methods enabling physical quantities to be transformed into electrical variables, irrespective of use made of them; examples.

A Magneto-Resistance Displacement Gauge, I. M. ROSS, E. W. SAKER. Nature (London) v178 Nov 24 1956 p 1196. The displacement to be measured causes a small strip of InSb to change its position relative to a permanent magnet the poles of which are shaped to give a strong field gradient in the direction of movement. The mean field over the crystal and hence its resistance are then a function of position. In practice two crystals rigidly connected are used to overcome temperature errors.

Instrument Transducers, J. THOMSON. J Sci Instrum v34 n6 June 1957 p 217–21. After dividing the problems of instrumentation into two categories (1) the determination of what is to be measured, and (2) the investigation of how to make the measurements, the importance of energy transformations to problems in the second category is established. The attempt is made to define the forms of energy in a manner suitable for instrument research and a chart is presented showing important physical and chemical phenomena as transformations between these forms of energy. Particular attention is paid to those transducers which provide an electric signal. In conclusion, recent developments of transducers are considered from the point of view of instrumentation and the significance of solid state science is underlined.

Use of Piezoresistive Materials in the Measurement of Displacement, Force, and Torque, W. P. MASON, R. N. THURSTON. J Acoust Soc Am v29 n10 Oct 1957 p 1096–

101. The use of piezoresistive materials as strain gauges and in the measurement of displacement, force and torque is discussed generally. A torsional transducer, which was constructed from n-type Ge, is described, and the experimentally obtained voltage-torque characteristic is given.

Der heutige Stand der Entwicklung elektrischer Messgeraete fuer mechanische und waermetechnische Grossen (Present status in development of electric instruments for measuring mechanical and thermotechnical values), G. BECK. Werkstattstechnik und Maschinenbau v48 n3 Mar 1958 p 169–78. Survey of indicating, amplifying and recording instruments.

A Sensitive Micrometer for Measuring Small Displacements, J. NORBURY, D. SHEWRING. J Sci Instrum v35 n6 June 1958 p 217–20. A variable parallel-plate capacitor associated with an oscillating circuit forms the basis of an apparatus which can measure displacements of the order of 200A. The apparatus is so designed as to combine robustness with sensitivity, ease of calibration and reproducibility. The use of a diode pump integrator circuit makes the sensitivity independent of the gain of the a.c. amplifier. The capacitor is of simple construction and standard electronic components are used throughout.

The Measurement of Small Displacements by Electrical Screening, B. E. NOLTINGK. Inst of Phys Stress Analysis Group Conf, Delft, 1959. A conducting screen interposed between two coils affects their electrical coupling. It is shown how the dependence of this effect at the exact position of the screen can be made the basis of a transducer converting mechanical displacements to electrical scale. Such a system needs only a small element attached to the moving part to be measured; it is insensitive to movements in directions other than those studied; and it can allow an indefinite travel of the moving element. A small instrument is described, used on this principle, which has a linear range of 10 mm and a stability of a fraction of a micron, allowing displacements to be observed on any scale between millimetres and hundreds of Angstrom units.

Inductance Bridge for Sensitive Displacement Measurements Over Long Periods, D. MURRAY. J Sci Instrum v36 n7 July 1959 p 312–15. An application of linear differential transformers in an ac. bridge that provides reproducible displacement measurements over long periods, extends the linear response while retaining high sensitivity, and can be readily adapted for automatic recording of displacement.

Modern Measuring Instruments—Electric and Electronic Gages, F. W. WITZKE. ASTME Tech. Papers 60 book 1 paper n245. Electronic gage heads now provide extreme precision and accuracy for standards laboratory use. Performance specifications are listed.

Application of Electronics to Industrial Metrology, J. QUENTIN. Microtecnic v14 n3 June 1960 p 125–35. Roles of electronics in solving metrological problems are reviewed; applications to high and low resolution instruments, equipment for remote measurements, and for automatic control based on small dimensional variations are discussed.

Application of Continuous Secondary Electron Multiplication for Amplifying Small Currents, P. K. OSHCHEPKOV, B. N. SKVORTSOV, B. A. OSANOV, I. V. SIPRIKOV. Instruments & Experimental Techns (English translation of Pribory i Tekhnika Eksperimenta) n4 July–Aug 1960 p 611–14. Electron multiplier developed at Metallurgical Inst of Acad of Sciences, USSR, operates on principle of continuous secondary electron amplification without central focusing electrode; approximate calculation of multiplying system; production technology and composition of one of versions of emitter material.

Novel Displacement Detector and its Application in a Recording Thermobalance, J. C. VAN DER BREEGGEN, H. J. WOUTERLOOD. J Sci Instrum v37 n8 Aug 1960 p 297–300. A transducer has been developed to detect changes in position of a balance beam. Its operation is based upon a differential capacitor. Variations in capacitance are made to produce directly a d.c. voltage corresponding in sign to the sense of deflection of the balance beam. The construction of the transducer is described, and its application in automatic apparatus for thermogravimetric analysis is illustrated by results obtained on the dehydration of copper sulphate and the decomposition of quinoline phosphomolybdate. The sensitivity of the instrument can be varied in nine steps to give full-scale deflections from 10 to 500 mg. An accuracy of about 1.5 mg or 0.75% of full scale was obtained for the 200 mg range.

Unicom Measuring System, S. RIGBY. Automatic Control v13 n6 Dec 1960 p 31–8. Mechanical inspection system developed by Adage, Inc., which employs linear variable differential transformers as input transducers to sense contours, and electronic system for processing transducer outputs and producing printed inspection reports; basic resolution of automatic gaging system of various types of components, is 0.001 in.

Sensitive Output Indicator for Differential Transformer Displacement Determinations, D. WOBSCHALL. Rev Sci Instrum (USA) v32 n1 Jan 1961 p 71–3. A transistorized circuit particularly designed as an output indicator for linear variable differential transformers for the measurements of small displacements is discussed. Resolution of the unit is about 0.05μ; the linearity is about $\frac{1}{4}\%$.

Refining Measurements by Capacitance Techniques. F. K. HARRIS, R. D. CUTKOSKY. ISA J v8 n2 Feb 1961 p 63–6 8 figs 1 ref. Through recent advances in the art of capacitance measurement, capacitance may be determined solely by a length, and vice versa. Accordingly capacitance bridges will be useful for measurement of mechanical displacement, film thickness, and dielectric constant, both as a spot check and as a continuously recording quality control technique.

Design and Construction of Device for Recording Small Displacements, P. R. JAMES. Mag Concrete Res v13 n37 Mar 1961 p 37–9. Design and construction of electromechanical device for remote, continuous recording of displacements of order of one mm in concrete structures; electronic potentiometer recorder is used in conjunction with bridge circuit of four resistance strain gages, variation in out-of-balance potential being used as measure of displacement; instrument developed to measure movement of sections of concrete road on either side of expansion joint.

Method for Adjusting Nominal Inductance of Transducers, B. E. KOSTICH. Meas Techns 1962 n3 Sept 1962 p 187 1 fig 2 refs. Translated from Izmer Tekh n3 p 9 Mar 1962. Describes a method for a smooth adjustment of the transducer's inductance by varying the reluctance of a hollow core by means of displacing inside it a screw of a high permeability.

Compensated Electrical Instrument for Remote Measurements of Displacements, M. I. BELYI. Meas Techns 1962 n8 Feb 1963 p 641–2 1 fig 2 refs. Translated from Izmer Tekh n8 p 17–9 Aug 1962. The author has developed an electrical instrument which uses a method of compensating two emfs for measuring large displacements with an error not exceeding 10μ. This instrument can be used as a transducer in devices for automatic control of displacements, especially of carriages and tables of metal-working machines.

Computation of an Inductive Transducer with an Adjustable Short-Circuited Turn, V. YA. EDUSH, M. A. NABIEV. Meas Techns 1962 n8 Feb 1963 p 684–90 3 figs 2

refs. Translated from Izmer Tekh n8 p 50–3 Aug 1962. An inductive transducer of linear displacements whose sensing element consists of a moving short-circuited turn.

Displacements Transducer with Electrical Recording, V. V. NIKIFOROV. Meas Techns 1962 n9 Apr 1963 p 733–4 1 fig. Translated from Izmer Tekh n9 p 17–8 Sept 1962. A transducer on the basis of a clock type indicator, provided with an electric-spark paper recorder for registering displacement of tenths or hundredths of a mm.

New Electrical Contact Head Type GK–3, F. M. DANILE-VICH, V. A. NIKITIN. Meas Techns 1963 n1 Aug 1963 p 19–21 2 figs. Translated from Izmer Tekh n1 p 14–6 Jan 1963. Describes an improved electric contact head used as an attachment to measuring or gaging devices for measuring 1 to 13.5 mm diameter holes either directly or by a differential method.

A Automatic Recording Differential Dilatometer, J. BAR-FORD. J Sci Instrum GB v40 n9 Sept 1963 p 444–5. The apparatus is suitable for the study of the kinetics of phase transformations and precipitation processes in the solid state. Relative length changes between a specimen and a control are measured by means of a variable inductance transducer. The differential system works to better than 1%, over temperature ranges of up to 1000°C.

Indicating Instrument for Measuring Very Small Displacements, K. I. ZABLONSKII, V. I. NASSAL'. Meas Techns 1963 n5 Nov 1963 p 381 1 fig. Translated from Izmer Tekh n5 p 13–4 May 1963. Describes a resistance wire transducer by which it is possible to record displacements of the order of 0.1μ by means of ordinary amplifying equipment.

Application of Induction Transducers for Measuring Displacements at High Temperatures, M. I. KORSUNSKII, A. S. LAGUNOV, L. P. BAIVEL. Meas Techns 1963 n8 Feb 1964 p 651–4 5 figs. Translated from Izmer Tekh n8 p 16–9 Aug 1963. The transducer can be used as a basis for designing an instrument for automatic checking and control of the starting and operating of powerful steam turbines. The temperature-compensated transducer can also be used for remote contactless measurements of clearances in other machines which operate at high temperatures. The method of temperature compensation can be used for induction transducer measurements of other quantities. There exists the possibility of increasing the temperature operating range of the transducer. However, for this purpose it may be necessary to use magnetic materials with higher Curie points, for instance, cobalt.

5.2.3. Mechanical

See also Subsection 3.6.4

The Minimeter for Fine Measuring, F. C. PERKINS. Can Machy v20 Nov 21 1918 p 592–93 5 figs. Principle and forms of Hirth apparatus for measuring threads, balls, cylindrical parts and grooves, also for inside measuring of various diameters.

The Determinateness of the Hysteresis of Indicating Instruments, F. J. SCHLINK. J Washington Acad Sci v9 Jan 19 1919 p 38–45 2 figs. Hysteresis determinations of non-integrating mechanical measuring instruments require no unusual care, and are fully reproducible.

The Concept of Resilience with Respect to Indicating Instruments, F. J. SCHLINK. J Franklin Inst v187 Feb 1919 p 147–69 2 figs. Deals particularly with instruments of index-and-scale and value-controlling types of class of non-integrating instruments, as distinguished from integrating instruments and those used for comparison purposes strictly.

Die Genauigkeit mehrfacher Fühlhebel (The Accuracy of Multiple Lever Gages), G. BERNDT. Werkstattstechnik v15 June 15 1921 p 347–50 2 figs. Comparison of accuracy of single and multiple levers. States that, when possible, instead of using several levers with smaller gear ratios, it is better to use a double or single lever with gear ten times as great.

A Study of Commercial Dial Micrometers for Measuring the Thickness of Paper, P. L. HOUSTON, D. R. MILLER. Tech Papers NBS n226 Dec 29 1922 p 125–52. The mechanisms were studied to determine the effect of the various designs on the contact pressure, the variation in contact pressure, and the accuracy and variance of the instruments. Specifications are given for a standard instrument.

Das Reibungsfreie Minimeter (Frictionless Minimeter), N. PFLEIDERER. Zeit für Feinmech v32 Feb 20 1924 p 38–9. Description of Hirth minimeter, with a sectional view showing the construction.

New Société Genevoise micro-indicator. Machy (London) v36 Apr 3 1930 p 19–20 2 figs. Embodies rocking plate and knife edges to give max amplification of 500. Spindle travel is approx. 0.03 in.

Precision Measuring Instrument. Eng v131 n3404 Apr 10 1931 p 500 2 figs. At Leipzig Fair, Fortuna-Werke Spezialmaschinen-fabrik A-G., of Stuttgart-Cannstadt, exhibited number of examples of their precision measuring instruments, many of which embody Hirth minimeter; interesting application of minimeter is shown in combination instrument for testing distance between gudgeon-pin hole and piston head or pistons of internal-combustion engines, as well as whether axes of this hole and of piston are truly at right angles.

Recent Developments in Design of Precision Measuring Instruments, M. A. ROBBIN. Mech Wld v91 Feb 5 1932 p 123–5. Operating principles and accuracy of Hirth-Minimeter, Krupp's Mikrotast gage, Zeiss optimeter and Werner's Microlux indicator.

Mechanische Fuehlhebel, G. BERNDT. Archiv fuer Tech Messen v1 May 1932 p T71 (2 p.). Operation of lever mechanisms of precision gages with data on accuracy and use of German and Swiss makes.

Fuehlhebelmessgeraete (Contact Lever Measuring Instrument), ALBRECHT. Werkzeugmaschine v40 n12 June 1936 p 299–304. Application of contact lever to various types of movements for mechanical, optical and electric measuring instruments.

Mechanical Amplification of Small Displacements, A. F. C. POLLARD. J Sci Instrum v15 n2 Feb 1938 p 37–55. Describes a number of the more satisfactory methods of amplifying small displacements and of accurately reducing large movements to small and corresponding displacements. The mechanisms described and discussed include levers, combined with optical means of increasing their sensitivity, the rolling cylinder of small diameter, gear trains of various types, the differential screw mechanisms, mechanisms depending on the bending, twisting or sagging of flexible elements, hydraulic and liquid indicating devices, including spirit levels, and a pneumatic micrometer. The paper concludes with a discussion of the natural limit to the sensitivity of all measuring instruments, and a short Bibliography.

Die Messeigenschaften der Messuhr und ihre Beruecksichtigung in der Werkstatt (Characteristics of clock dial micrometers and consideration of their use in work shops), E. BARZ. Werkstattstechnik und Werksleiter v32 n12 June 15 1938 p 287–9 and 291–5. Study of measuring errors and underlying fundamentals of standards for this type of micrometer.

Draft Standard Specification for Dial Gauges. Machy (London) v54 n1400 Aug 10 1939 p 594–5. Specification prepared under authority of Mechanical Industry Committee of British Standards Institution, in response to request received from Institution of Production Engineers; main purpose is to set up standard of accuracy for commoner types of dial gages now in use.

Dial-Gauge Research, G. SCHLESINGER. Eng v138 n 3859 Dec 29 1939 p 725–7. Review of report on dial gage and its use issued by Institution of Production Engineers, giving account of researches carried out at Loughborough College; examples of employment of instrument in acceptance tests for machine tools illustrated.

British Standard Specification for Dial Gauges for Linear Measurements (Excluding Back Plunger Type). Brit Stand Instn BS Specification n907 1940 19 p. Specification applies to gages having axis of plunger movement parallel to plane of dial; with dial diameters of 1¼ in. to 2 in. and having ranges of movements of plunger up to ½ in. or 12 mm and measuring by steps of 0.001 in., 0.0005 in. and 0.01 mm.

Levers of Constant Ratio, R. S. CLAY. J Sci Instrum v17 n3 Mar 1940 p 49–55. Theoretical discussion of simple lever, bent lever, and lever with connecting link; applications of levers of constant ratio.

A Fine Mechanical Adjustment of Variable Sensitivity, D. S. PERFECT. J Sci Instrum v21 p 123–4 July 1944. It was desired to adjust to a specific setting the tilt of a mirror to an accuracy of the order of 0.1 in. or better. A spring was encastered at one end and also constrained on one side near this end by an adjustable fixed ball. Near this ball a second ball presses against the other side of the spring. and is given minute displacement when the spring is flexed by a screw controlling the free end. The displacement can be used to give linear or angular adjustment to a suitably constrained body linked to the second ball. Adjustment of the longitudinal separation of the two balls controls the minification factor.

A Mechanical Arrangement for Measuring Small Changes in Length, G. LEIBFRIED. Zeit Phys v127 n5 p 580–7 1950 in German. An apparatus for measuring length changes such as are observed when plastic deformation begins in a single crystal is described. The linear movement is taken up by two fine wires rolling between plane surfaces, and the angular movement of the wires is recorded optically. A magnification of 3×10^5 is achieved, and an accuracy of about 10 A is claimed. Some results for single Al crystals are discussed.

New Johansson Measuring Instruments. Machy (London) v83 n2144 Dec 18 1953 p 1217–9. Feature of Mikrokator comparator, designed by Swedish Co., is that frictionless drive to pointer is provided by twisted metal strip; two designs of surface finish indicators developed which also employ twisted metal strips for operating pointers; Deltameter air operated automatic sizing unit which is available with measuring heads of various designs.

Ultra-Sensitive Mechanical Comparator. Eng v177 n4588 Jan 1 1954 p 23. Comparator with magnification of 200,-000 is production model from range of "Mikrakators" made by C. E. Johansson, Ltd; special Mikrakators made with range of plus or minus 0.00002 in. and graduations for each 0.000001 in.

Ein Neues Verfahren zur Messung kleiner Laengenaenderungen (New method for measuring small changes in length), D. KUHLMANN-WILSDORF. Zeit fuer Angew Phys v6 n4 Apr 1954 p 171–4. Differential method of measuring length by means of horizontal roller having two sections of different radii; movable bands attached to length being measured are fastened to perimeter of each roller section; rotation of roller is determined by mirror arrangement; apparatus construction and applications are included.

Basic Principles of Link and Lever Adjustment, N. A. ANDERSON. ISA J v3 n1 Jan 1956 p 10–12. Calibration steps for link and lever recorder or indicator which has pen or pointer connected to element or other power source by 4-bar linkage; adjustments for zero, multiplication and angularity; first covers angle between pen and pen lever; second, ratio of total pen or pointer motion to total element motion; last, unequal rates of pen or pointer travel for equal increments of rotation.

CEJ Mikrokator. Machy (London) v92 n2366–67 Mar 21 1958 p 658–66, Mar 28 p 713–6. Mikrokator produced by Aktiebolaget C. E. Johansson, Eskilstuna, Sweden is shock resistant, dial type measuring instrument capable of high amplification, which incorporates thin twisted metal strip design; its application to diameter, load and surface finish measurement; operations in production of Mikrokator methods employed in assembling amplifying mechanisms.

Adjusting Device Incorporating an Ultrafine Movement, H. M. KING, J. B. WEIR. J Sci Instrum (GB) v39 n1 p 31 Jan 1962. The primary screw thread is on the outside of a shaped hollow bar with a necked extension in which two slots are cut. A lapped contact button is at the end. The secondary screw is inside the bar and has a tapered extension. When this is pushed into the neck the outer bar expands and contracts. A maximum shrinkage of 0.0006 in. is obtained and a one-hundredth turn of the secondary screw gives a movement of two millionths of an inch.

New Instruments for Linear Measurements, G. B. KAINER, N. N. MARKOV, V. YA. EIDINOV. Meas Techns 1962 n3 Sept 1962 p 184–7 5 figs. Translated from Izmer Tekh n3 p 6–8 Mar 1962. Describes several types of mechanical indicators including an optical spring head; spring head having a bronze tape twisted helically from the middle; two gear and lever indicators; a head having moving electric contacts; waviness instrument for checking gears; and an indicating hole gage.

5.2.4. Optical

Photographic Registration of Sounds, D. C. MILLER. Phys Rev v28 n2 Feb 1909 p 151; Sci v29 p 471 1909; Eng v94 p 550 1912. A small steel cylinder, 1 mm in diameter, is arranged to receive angular motion, with a minimum of reaction effects, which is proportional to the displacement of a sensitive diaphragm. A minute mirror, with its plane parallel to the axis of the cylinder, reflects light to a special camera, and at a distance of 30 cm gives waves 15 cm wide which show great detail. See also The Science of Musical Sounds, D. C. Miller, Macmillan Co. N.Y. 1916. The Phonodeik p 78–88.

The National Physical Laboratory—Optical Lever Comparator. Eng v110 July 9 1920 p 56–8. Apparatus for measuring thermal expansion by tilt of a glass or quartz disc.

Optical Strain Gages and Extensometers, L. B. TUCKERMAN, NBS. Proc ASTM v23 pt II 1923 p 602–10, 10 figs 7 refs. Describes three optical lever observing and four mirror systems.

A Sensitive Optical Lever Method for Measuring the Thermal Expansion of Small Specimens, J. GUILD. J Sci Instrum v1 Apr 1924 p 198–204 3 figs. Method employed is comparative one in which two specimens of suitable form stand close together on flat reflecting surface and support second reflecting surface approximately parallel to first; inclination between two surfaces is measured by auto-collimating telescope system. Optical lever system

employed, magnification 390, corresponding to measurement of change in length of approximately λ/20 for green light.

Molecular Measurements by Optical Lever, W. N. BOND. Nature v122 Aug 4 1928 p 169–70. Optical lever giving very large magnification to test the accuracy with which a steel-to-steel contact will return after separation, and whether the thickness of a mica sheet can be detected as varying in multiples of the "molecular" length. Preliminary results are given.

Molecular Length Measurement by an Optical Lever, W. N. BOND. Phil Mag v7 June 1929 p 1163–82. Used in a series of penetration experiments on mica and steel. A periodicity is shown, viz, 10×10^{-8} for mica, and 6.8×10^{-8} for steel which agree with the lengths of the unit cells of mica and of cementite as determined by X-rays.

Optische Fuehlhebel (Optical Contact Levers), G. BERNDT. Archiv Tech Messen v2 July 1932 p T100 (2 p.). Optical systems by which limitations in length of mechanical feelers are extended by application of frictionless ray of light; details of Zeiss optometer, Sears feeler, Mikrolux, Optotest and interference feeler. Bibliography.

Der Lichstrahl als Zeiger in Technischen Messgeraeten (Light beam as pointer in technical measuring equipment), K. H. SIEKER. Zeit fuer Fernmeldetechnik v13 Dec 15 1932 p 186–90. Application of pointer is shown in series of examples; selection of examples made from practical standpoint and no critical analysis is given. Bibliography.

Geometry of Optical Indicators, K. J. DE JUHASZ. J Franklin Inst v229 n1 Jan 1940 p 53–80. Article describes term "optical indicator," embracing all kinds of instruments in which one or more optical levers are incorporated classification of optical indicators; optical lever; kinematic considerations; optical levers with one degree of freedom of rotation; application of theorem to particular cases; effect of deviations from assumed conditions; nonspherical screens; convergent light beams; mirror support.

A Multiple-Reflection Optical Lever, H. O. HOADLEY. Rev Sci Instrum v20 Jan 1949 p 30–41. A detailed description is given of an optical lever which secures increased sensitivity by means of multiple reflections from a single small mirror. It is of particular use where space is limited, or where the mirror must have minimum size and mass. Its limitations are an inherent restriction of the measurable range, and a comparatively rapid loss of light with increasing number of reflections. A model system was constructed, which demonstrates that no special difficulty is met with in making an optical lever according to these principles up to 7 reflections. Tests made with the fifth-order reflection proved the model to be quite satisfactory.

An Apparatus for Measuring Small Changes in Linear Dimensions, D. G. R. BONNELL, A. WATSON. J Sci Instrum v27 Jan 1950 p 10–12. During the study of the effect of freezing on certain building materials, it became necessary to develop an apparatus to measure small linear changes in two dimensions. In the apparatus described, movement of the specimen is magnified by the change in the angle of reflection of a beam of light incident on a system of rotating mirrors. A device is incorporated to translate horizontal movements of the specimen into vertical movements on the extensometer.

Some Points in the Design of Optical Levers and Amplifiers, R. V. JONES. Proc Phys Soc London B v64 June 1951 p 469–82. The design of optical levers with photoelectric amplifiers is examined and sources of instability are traced. Convection currents causing refraction variations are found in some circumstances to affect the light balance in the optical lever; they may be minimized by properly designed shrouds around the optical path. The better known causes of instability are discussed, and the appropriate remedies are described. The discussion is extended to the stability of galvanometers. The design of an optical lever and amplifier is given which can detect a change of 10^{-9} radian in a mirror 5 mm in diameter with an indication time of 1 sec and with a long-term drift of the order of 10^{-8} radian/hour.

Deflection Multiplier for Reflecting Galvanometers, T. M. DAUPHINEE. Rev Sci Instrum v26 n9 Sept 1955 p 873–5. A very simple multiple reflection system is described by which the effective sensitivity of a reflecting galvanometer can be increased by a factor of five or more without increasing the mirror-to-scale distance. The full width of the galvanometer mirror is used for each reflection, so that with a good quality mirror there is little reduction in the sharpness of the hairline image and only moderate reduction in the brightness of the spot. Use of a 2 m path distance and four or five reflections makes it possible to extend the useful sensitivity of a sensitive galvanometer close to the limit set by Brownian movement. The principle of this amplifying system can be applied directly to most forms of optical lever.

On a Light-Pointer Arrangement for Null Instruments, H. HAAS. Optik v15 n2–3 Feb–Mar 1958 p. 135–7 in German. The use of a porro-prism permits the light beam reflected from a mirror to be split into two beams which deflect in opposite directions for a mirror rotation. Thus the null position is shown as the only position for which there is a single beam.

Recording Optical Lever, R. V. JONES, J. C. S. RICHARDS. J Sci Instrum v36 n2 Feb 1959 p 90–4. A small optical lever is described which can detect a change of 10^{-10} rad in orientation of a 2 mm^2 mirror, with a response time of about 0.25 sec. A differential cadmium selenide photocell is used with a standard optical grid technique to detect the displacement of the reflected light beam from a 4V, 3.2W lamp. Transistors are used to stabilize the lamp current and to amplify the signals for a pen recorder. "Noise" arising from convection currents in the light beam and from the photocells appears not to exceed greatly the photon fluctuations in the light beam. Records illustrate the performance of the lever and amplifier in detecting changes in dimension of a crystal of a few times 10^{-10} cm and changes in refractive index of a gas by a few times 10^{-9}. The system has also been applied to an infrared detector using the linear expansion of a metallic strip, where the limit for a 5 x 0.2 mm strip is about 10^{-11} W for a 1 c/s bandwidth. For this purpose the signal can be differentiated with respect to time, and velocities of down to 30μ/annum can be observed. It appears that a displacement of 10^{-12} cm could be detected.

Some Developments and Applications of the Optical Lever, R. V. JONES. J Sci Instrum (GB) v38 n2 Feb 1961 p 37–45 22 refs. The history of the optical lever is briefly reviewed from its invention by Peggendorf in 1826 to the recognition by Ising in 1926 of Brownian fluctuations of a galvanometer in the records obtained by Moll and Burger in 1925 with their thermoelectric relay. The design of optical levers and amplifiers by the author and his collaborators is outlined; these give sensitivities of the 10^{-10} radian for a mirror 2.00 mm x 2.0 mm, and an observation bandwidth of 10 c/s. The effects of convection currents and photon fluctuations are indicated. The applications of optical levers to a range of measurements, including Brownian fluctuations, radiation pressure, linear expansion and infra-red detection are described. Optical and photoelectric systems similar to those developed for the optical lever can be used for alignment measurement; applications include refractometry for refractive index changes of order 10^{-9}, and a test of the constancy of the velocity of light in a transverse magnetic field.

An Optical Lever Gauge for Local Thickness Measurements on Fragile Crystal Plates, W. E. SPEAR, A. R. ADAMS. G. A. HENDERSON. J Sci Instrum (GB) v40 n6 June 1963 p 332. The design and use of a simple and inexpensive gauge is described which is suitable for thickness probing on fragile crystal platelets between 10μ and 500μ thick. It employs a miniature optical lever which gives an optical magnification of 10^5, and the local crystal thickness can be determined to within 0.5μ.

Ultraoptimeter IKP–2, V. A. NIKITIN, E. P. SMIRNOVA. Meas Techns 1963 n6 Nov 1963 p 461–3 2 figs. Translated from Izmer Tekh n6 p 6–8 June 1963. A new model of an ultroptimeter IKP–2 was developed in 1961 by the Leningrad association of optical-mechanical plants. The instrument is intended for contact measurements of external linear dimensions, and uses a relative method by comparing the measured article with block gauges, jigs, or sample components. The instrument's optical system is based on the autocollimation principle in combination with repeated reflections.

5.2.5. Pneumatic

High-Precision Measurement of Lengths and Thicknesses, M. MENNESSON. CR Acad Sci v194 Apr 25 1932 p 1459–61. The method consists essentially of a measurement of change of pressure in air when flowing through an orifice whose section is a function of the length or thickness to be measured. A supply of air at constant pressure, regulated to within 1 mm of water, flows through a calibrated orifice into a vessel and thence through a second orifice whose size has to be found. The object whose dimensions are required is placed on a movable base whose distance from the second orifice is known. The air pressure between the two orifices is a function of their sectional areas and is measured by a water manometer. The sensitivity can be varied by a suitable choice of the orifice diameters and the initial air pressure.

Groupe "Mécanique de Precision et Métrologie." Mécanique v21 n271 Mar–Apr 1937 p 69–83; English review in Engr v164, n4254 July 23 1937 p 106. Symposium before Société Francaise des Mécaniciens, as follows: Metrological Instrument of French Make, DUMANOIS; Pneumatic Amplification, L. WATTEBOT; Application of Solex Micrometer in Industrial Metrology, J. OUTIN; Application for Measuring Strength of Materials, H. DE LEIRIS; Application in Study of Metals Cutting, R. BENSIMON; Application in Measurement of Surface Conditions, P. NICOLAU.

Die praktische Verwendung des Solex-Messverfahrans (Practical application of Solex measuring method), O. NIEBERDING. Werkstattstechnik und Werksleiter v36 n23/24 Dec 1942 p 498–504. Air is used as measuring medium; testing of small nozzle openings and bores; early form of Solex plug gage; testing of calipers and external diameters; multiple test apparatus; testing of pistons.

Solution of Instrumentation Problems by Pneumatic Null Balance Method, C. B. MOORE. Instrum v18 n9 Sept 1945 p 598–603. Principal characteristics of pneumatic null balance method; description and summary of design factors including nozzle characteristics, effective area of flexible member, and materials of construction; typical examples of utilization of pneumatic null balance principle in solving instrumentation problems; automatic control. (Reprint with additions available from Moore Products Co.)

Nozzle Flow Characteristics in Pneumatic Force-Balance Circuits, D. B. KIRK. Moore Products Co. Outline of an illustrated lecture before Industrial Instruments and Regulators Div., ASME.

Pneumatic Gauges, H. NIEPEL. Mech Wld v119 n3098 May 17 1946 p 545–50. Principles and applications for measuring instruments. Translated from German journal Feinmechanik und Praezision v50 1946 p 255–60.

Pneumatic Length Measurement Principles, E. GÖTHEL. Archiv für Tech Messen Issue 152 (Ref. V1121–6) T3 July 1947 in German. The "Solex" pneumatic method of length measurement, invented by Marcel Menneson, gives an accurate indication of small length differences by using gas flow. Constant-pressure compressed air flows through an orifice into a closed chamber and through a second orifice, where it impinges on a surface at distance d. The pressure in the closed chamber then $\propto d$. The incoming air pressure is kept constant by an air-bubble overflow and the chamber pressure is measured by a water manometer. The theoretical air flow relations are deduced. Owing to moisture and orifice-bore roughness these relations are very approximate, and the instrument must be empirically calibrated.

Air Jets . . . Their Characteristics for Gaging Devices, R. S. ELBERTY. Mach Design v20 n1 Jan 1948 p 111–4. Discussion of air jets used for ultrasensitive gages; characteristics of air jet gaging devices are revealed in tests relating to pressure drop across air jet, sensitivity of pressure type air gage, sensitivity of air jet, and zone of greater sensitivity of pressure type air gage; data on pressure regulators and air gage circuits.

Évolution de la Métrologie Pneumatique (Evolution of pneumatic measuring apparatus), R. YRIBARREN. Machines et Métaux, v32 n356 Apr 1948 p 123–7. Principles: self control and quality control; pneumatic control of micrometers, internal cylindrical gages, "Solex" pneumatic vernier, and vertical scale; illustrations.

A New Pneumatic Method for Measuring Small Variations in Length and Some Applications of It. C. G. HARD. IVA, Stockholm, v20 n3 1949 p 107–19 in English. After a brief survey of other pneumatic measuring methods the principle and theory of the Delta system are described. The device consists of two measuring chambers fed with air at constant pressure through an intermediate chamber, the air passing from the intermediate to the measuring chambers and then out into the atmosphere through valves, all mounted on the same spindle, and designed for greatest sensitivity. The relation between the ratio of the chamber to the applied constant pressure, and the spindle position, is shown to be approximately linear. The merits of the system are listed. The Delta meter, a commercial form of instrument, utilizing the Delta system, and generally used as a comparator, is fully illustrated and described.

Les Lois de la Métrologie Pneumatique (Laws Governing Pneumatic Metrology), R. MOLLE. Rev. Gén de Mécanique v 34 n13 Jan 1950 p 26–30. Laws governing pneumatic metrology and their application to development of new apparatus in laboratories of Faculté Polytechnique de Mons; principle of Solex apparatus and various other types of pneumatic gages described and illustrated.

Versatile Pneumatic Instrument Based on Critical Flow, W. A. WILDHACK. Rev Sci Instrum v21 n1 Jan 1950 p 25–30. Principles of instrument for measurement and control of pressure, temperature, flow, humidity, gas composition, or mechanical displacement; in simplest form, critical flow is maintained through two nozzles in series; variation in flow through first nozzle, occurring with changes of pressure, temperature, etc., are reflected as change in absolute pressure at entrance to second nozzle.

Pneumatic Comparator of High Sensitivity, M. GRANEEK, J. C. EVANS. Machy (London) v79 n2016 July 5 1951 p 33–6; see also Engr v192 n4981 July 13 1951 p 62–4; Eng v172 n4470 Sept 28 1951 p 414–5. Comparator having good speed of response, consists essentially of hol-

low double piston which is air tight sliding fit inside cylinder of ½ in. bore; calculation of force exerted on surface under measurement; example of use of comparator for fine measurement.

Maximum Sensitivity in Pneumatic Gauging, N. R. WYNN, N. STOLOW. Letters in J Sci Instrum, v32 n4 p 55 Apr 1955. The first author points out with reference to the paper by the second that the condition for max. sensitivity when a null-point method is used in pneumatic gaging is obtained when $H_{eff} = \frac{1}{2}H$. The second author argues, however, that this is correct for one application of the gauging method but not for the practical operation of his apparatus.

Application of Pneumatic Gauging to High Precision Linear Measurement, J. C. EVANS, I. G. MORGAN. J Sci Instrum v33 n10 Oct 1956 p 388–90. Pneumatic system employed in precise measurement of variation in thickness, in each of three principal directions, of nearly perfect cube recently used at National Physical Laboratory; theoretical basis of method, and details of experimental arrangements; advantages of pneumatic gaging techniques for linear measurement.

Schlag- und Fluchtungsmessung mit Luftmessgeräten (Twist and alinement measurement with air measuring instruments), O. NIEBERDING. Zeit für Maschinenbau und Fertigung v90 n3 p 181–3 1957 13 figs 1 ref. Cites 5 advantages of pneumatic measuring apparatus for twist and alignment measurement. Discusses deviation from perpendicularity to axis of the end faces of bores and shafts, alignment of coaxial holes, and alignment of parallel bores.

Pneumatische Geräte Zum Messen von Achsabständen (Pneumatic Instruments for Measurement of Eccentricities), O. NIEBERDING. Werkstatttechnik und Maschinenbau v47 n11 1957.

Pneumatic Gauging Technique in Its Application to Dimensional Measurement, J. C. EVANS. Inst Prod Engrs J v36 n2 Feb 1957 p 110–20, 140; see also Inspection Engr v21 n3–4 May–June 1957 p 50–54, July–Aug p 79–86. Work described was carried out as part of research program at National Physical Laboratory dealing only with type of gaging in which displacement or change of size is determined by measuring change of pressure which it is made to produce; theoretical and practical considerations; calibration and performance; applications.

Eigenschaften pneumatischer Feinmessgeräte (Properties of pneumatic precision measuring instruments), O. NIEBERDING. Industrie-Anzeiger n20 Mar 8 1957 3p 11 figs. The problem of establishing finest dimensional differences with the necessary reliability is better solved with pneumatic measuring equipment than with usual and known means. The article discusses the manner of operation of fine pneumatic measuring equipment, air pressure requirements, contactless measurement, influence of surface roughness sensitivity against dirty surfaces, advantages of the pneumatic caliper, advantages of the jet in yielding numerical values, distance transmission of measurement values, measuring units yielding average values, pneumatic means for amplification, damping.

Dynamic Air Gaging Reduces Cycle Time in Precision Measurement, A. H. JOYCE, K. E. RUGG. Gen Motors Eng J v5 n4 Oct–Nov–Dec 1958 p 29–32. In study of dynamic gaging characteristics, analog computer was used to simulate dynamic air gaging; mathematical relationship between pressure, time, restrictor size, jet size, circuit volume, and distance established; diagrams of electronic circuitry and air gaging circuit; example.

Kennzeichnende Eigenschaften pneumatischer Messgeräte (Characteristic Properties of Pneumatic Measuring Equip-

ment), R. CARL. Four FoKoMa Oct 1959 p B81 München. In the scope of the investigations of measuring equipment and controls organized by Prof. Eisele this report is a compendium of the extensive theoretical and practical results. Contents: Introduction and systematik; the feeler; transducer and indicator; experimental investigations, conclusions, bibliography.

Bauarten und Eigenschaften pneumatischer Messgeräte (Types and Properties of Pneumatic Measuring Equipment), O. NIEBERDING. Four FoKoMa Oct 1959 München, p B77; Maschinenmarkt v66 n19 Mar 4 1960 4 p 10 figs. The author characterizes the types and properties of pneumatic measuring equipment, elaborates the common characteristics, and characterizes the individual peculiarities in their advantages and disadvantages.

Electrification of a Pneumatic Micrometer with a Liquid Manometer, B. D. KOSTROV, S. P. IUDIN. Meas Techns 1958 n5 Feb 1960 p 509. Translated from Izmer Tekh n5 Sept–Oct 1958 p 10. The authors have electrified a manometric pneumatic micrometer which used a 1.5% solution of sodium bicarbonate. Owing to the minute currents used and a polarity of connection in which the reducing agent, hydrogen, is produced on the small surfaces of conductors, the harmful electrolytic action was eliminated.

Pneumatic Gauges for In-Pile Measurements, J. PEFHANY. Nuclear Eng (GB) v6 p 77–9 Feb 1961. A description is given for the development of a pneumatic gauge for in-pile measurements of very small movements. Work done suggests that accurate results can be expected at temperatures in excess of 400 °C.

Pressure Stabilizers for Pneumatic Instruments Used in Linear Measurements, A. P. KUROCHKIN, F. V. TSIDULKO. Meas Techns 1961 n8 Feb 1962 p 604–7 3 figs. Translated from Izmer Tekh n8 p 4–7 Aug 1961. The special work carried out by the Interchangeability Bureau in establishing the relation between the operating pressure error, and hence, the error of measurement, has made it possible to specify the requirements for various measuring systems with respect to pressure stabilizer accuracy. Knowing the actual accuracy characteristics of stabilizers, it has been made possible to specify their ranges.

Pneumatic Self-Balancing Systems, A. P. KUROCHKIN, I. YU. OKUN'. Meas Techns 1963 n1 Aug 1963 p 14–5 1 fig 3 refs. Translated from Izmer Tekh n1 p 10–1 Jan 1963. Describes development of a bridge schematic, namely a self-adjusting balanced pneumatic bridge, which was successfully utilized in an automatic machine for selecting balls by the differences in the ball bearing races.

Errors in Pneumatic Linear-Measurement Systems, A. P. KUROCHKIN, E. L. NOSKIN, F. V. TSIDULKO. Meas Techns 1963 n2 Aug 1963 p 108–11. Translated from Izmer Tekh n2 p 14–6 Feb 1963. The error of a pneumatic measuring system produced by the instability of the operating pressure H is one of the components of the system's total error. The degree and nature of the effect produced by this error on the readings of the system depends on the type of the latter, its parameters, design, etc. The error is conveniently represented as a ratio of the absolute error to the corresponding measurement range expressed in linear or pressure units, provided the measuring range does not exceed the linear portion of the characteristic.

Les Capteurs Pneumatiques (Pneumatic Pickups), C. RENET. Automatisme v8 n9 Sept 1963 p 305–10. Basic structure of measuring instruments using pneumatic servomechanisms is reviewed; operation of various types of pressure-sensitive elements and pneumatic pickups is

described; relative merits and shortcomings are compared.

Precision of Pneumatic Instruments for Linear Measurements, A. YA. ROSTOVYKH. Meas Techns 1963 n5 Nov 1963 p 376–9 2 figs 4 refs. Translated from Izmer Tekh n5 p 10–2 May 1963. Analyzes and evaluates the factors which affect the precision of measurements made by the "solex" instrument based on a pneumatic method for measuring dimensions, and examines the problem of eliminating the causes which lower this precision.

Principles of Pneumatic Gauging, J. C. EVANS, I. G. MORGAN. NPL Notes on App Sci n34 1964 32 figs 19 refs. Discusses scope of pneumatic method, range of linear measurement, pneumatic sensitivity, overall magnification, basis for design, practical considerations, and pneumatic equipment developed at NPL.

5.3. Dials and Pointers

See also Subsection 3.6.4

A Set of Proposed Standard Numerals for the Scales of Measuring Instruments, A. P. TROTTER. Inst Elec Engrs J Feb 1 1916. Col. A. Strange's designs and proposed changes in interests of simplicity.

Pointers of Low Inertia for Measuring Instruments, R. MIELICH. Zeit fur techn Phys v17 n1 1936 p 27–31. It is shown experimentally that glass is superior to aluminum as a material for constructing low-inertia pointers for measuring instruments. This is mainly because glass can be drawn down into the form of tubes with extremely thin walls, and a suitable method of performing this operation is described. Rigidity in the pointers can be maintained by combining together tubes of different thicknesses; at the same time, low moments of inertia are achieved.

Designing Instrument Dials for Quick, Accurate Reading, W. F. GRETHER. Machine Design v20 n6 June 1948 p 150–2 208–9. Review of psychological findings which underlie first steps toward design of aircraft or other instruments for maximum ease and accuracy in reading. Based on paper before Soc. Automotive Engrs.

Machine Dials and Scales, W. R. GARNER, J. W. GEBHARD. Machine Design v21 n8 Aug 1949 p 98–105. Design of dials to insure quick, accurate reading; dial uses can be classed into three groups; check, directional, and quantitative readings; factors affecting reading precision and speed of reading as related to dial numbering and markings, kind of pointer, dial grouping, etc.; other design data. Bibliography.

Indicators and Controls, A. CHAPANIS. Machine Design v27 n4 Apr 1955 p 212–4. Designing for maximum readability and efficiency. From "Some Applications of Experimental Psychology to Machine Design" in Office of Naval Research, Research Reviews. June 1954.

Tensator Spring as Force Transmission System in Instrumentation, C. PERNETTA. Machy (London) v91 n2344 Oct 18 1957 p 927–31. Results of preliminary survey of possible applications of Tensator constant force spring as force/transmission element in field of instrumentation; dial gage incorporating Tensator springs; use of spring for avoiding hysteresis effects; Tensator employed in conjunction with metal band; suggested design for indicating reading gage and caliper gage.

On a Light-Pointer Arrangement for Null Instruments, H. HAAS. Optik v15 n2–3 p 135–7 Feb–Mar 1958 in German. The use of a porro-prism permits the light beam reflected from a mirror to be split into two beams which deflect in opposite directions for a mirror rotation. Thus the null position is shown as the only position for which there is a single beam.

Design of Visual Indicators, J. SPENCER. Eng Matls & Design v4 n9–10 Sept 1961 p 572–6, Oct p 672–5. Sept: Design characteristics of indicator dials and scales for general industrial purposes requiring accuracy of plus or minus 1% of maximum scale values; examples of good and poor design. Oct: Design of qualitative and representative indicators.

Quality and Quantity of Information, K. F. H. MURRELL. Soc Instrum Technol Trans v15 n2 June 1963 p 96–9. Progress review of instrumental displays and design of their use in Great Britain; it is concluded, from instruments still being manufactured, that not enough thought is yet being given to suitability of instrument to needs of operator.

Mechanische Schwingungen erschuetterter Messwerke in Spannbandlagerung. (Mechanical vibrations of tautsuspension instrument movements subjected to shock). F. WEIDENHAMMER. Frequenz v17 n8 Aug 1963 p 302–11. Motional equations for low-amplitude vibrations about finite, electrically established deflection of pointer; 6 degrees of freedom are considered; equations show that compliance with certain decoupling condition generally yields maximum possible mechanical stabilization of movement; otherwise, pointer extremity will perform amplified forced vibrations in plane of indication; such vibrations are approximately calculated for almost-satisfied decouping condition.

Recommendations for Design of Scales and Indexes. Brit Standards Instn—Brit Stand 1449 pt 1 1964 44 p. Recommendations in this part are intended to be generally applicable to quantitative instruments of bold presentation and designed for rapid reading, intended to be read to resolution of about 1 to 2% of scale range and are particularly concerned with relating scale dimensions to maximum reading distance; they are only applicable to single scale instruments having dials with full circle, part circle or straight scales as defined.

5.4. Optical Features

Optische Hilfsmittel an Messgeräten (Optical Aids to Measuring Apparatus), W. BLOCK. Betrieb v4 n9 Feb 11 1922 p 285–9 6 figs 2 refs. The object is not to form experiments regarding optical methods of measurement but to form about their convenient application a few considerations regarding optical auxiliaries to measuring equipment of each kind and to completely exploit and increase their measuring accuracy.

Quelques Points Particuliers de Métrologie (The Setting of Microscope Cross Wires), A. PÉRARD. Rev Opt v2 Dec 1923 p 506–11.

On the Limit of Accuracy in Optical Measurement. A. A. MICHELSON. J Opt Soc Am and Rev Sci Instrum v8 Feb 1924 p 321–8. The limits of accuracy obtainable in observations with the telescope, microscope, interferometer, and spectroscope are discussed.

Optical Measurement in the Workshop (Optische Messverfahren in der Werkstatt), C. von HOFE. Praktischer

Maschine-Konstrukteur v58 Mar 10, June 16, July 14, and Aug 11 1925 p 187–89, 382–84, 446–48, and 507–11 14 figs. Discusses methods of optical measuring, especially those used in optical shops, covering spectrometers, measuring thickness and radii. Bibliography.

Principles and Advantages of Optical Methods for Measuring Machine Parts, H. F. KURTZ. Mech Eng v47 Mid-Nov 1925 p 987–92 16 figs; Machy v63 Dec 3 1925 p 894 for abstract. Outlines four classes of optical instruments namely, interference apparatus, imaging systems, optical scale reading, and optical levers; and describes measuring instruments already designed for machine-measuring purposes.

Measurement of Fiber Diameters by Diffraction Method, H. J. McNICHOLAS, H. J. CURTIS. Rev Sci Instrum v2 n5 May 1931 p 263–86 6 figs. New construction of Young's instrument (eriometer); critical study of accuracy and adaptability of instrument in averaging of wide range of diameters as distributed in group of fibers; sources of error and limitations of method.

A Mirror Comparator for Production Inspection, O. P. VAN STEEWEN. Am Mach v75 Sept 10 1931 p 417–8 4 figs. Unit works with combined optical and mechanical magnification.

Quantitative Thermo-electric Magnifier for Optical Pointers, J. H. JEFFREE. London, Edinburgh and Dublin Phil Mag and J Sci v14 Sept 1932 p 366–72. Simple device for magnifying deflections of optical pointers, giving large magnification which is independent of fluctuations in illumination intensity.

Neue Erfahrungen mit dem Ultra-Optimeter (Recent experience with ultra-optimeters), C. BUETTNER. Werkstatttechnik und Werksleiter v29 n4 Feb 15 1935 p 65–6. Usefulness in measurements of high precision ultra-optimeter made by C. Zeiss, in Jena.

Durchmessermessgeraet fuer lange Bohrungen (Diameter measuring equipment for long bores), Werkzeugmaschine v40 n16 Aug 31 1936 p 394. Detailed description of equipment using optical methods of observation.

Ueber eine einfache Anordnung zur parallaxefreien Ablesung von Zeigermessageraeten (New type of mirror arrangement free of parallax error in reading of scale indicating instruments), H. BUMAN, G. RITZOW. Zeit fuer Techn Phys v19 n4 1938 p 97–8.

Method of Dimensional Gaging with Photoelectric Cells, C. TUTTLE, W. BORNEMANN. Instrum v12 n2 Feb 1939 p 67–70. Notes on procedure and equipment; photoelectric photometry applied to gaging; optical magnification in photoelectric gage; accuracy of method.

Some Applications of Optics to Engineering, M. H. TAYLOR. Inst Production Engrs J v20 n11 Nov 1941 p 439–65 (discussion) 466–70. Types of measurement to which optics can be usefully applied; notes on optical measurement to which optics can be usefully applied; notes on optical measurement of lengths, angles, and irregular contours; screw thread projection; measurement of some irregular shapes which cannot be projected by conventional means.

Uber die optischen Grundlagen der technischen Feinmessgeraete (Optical principles of technical precision measuring apparatus), K. RAENTSCH. Werkstatt und Betrieb v74 n11 12 Nov 1941 p 295–9, Dec p 315–22. Nature of light; law of reflection and refraction; survey of physiological optics; various optical instruments described; single lens microscope and telescope; protection devices; multi-lens microscope and telescope; photographs and diagrams.

A Long Optical Path in a Restricted Space, H. R. DRATZ, J. E. MACK. J Opt Soc Am v32 p 457–64, Aug 1942. An instrument is described for attaining a long optical path by repeated traversal between a concave spherical mirror and a totally reflecting prism. Its properties are outlined and compared with those of other devices for similar purposes. The number of traversals is in principle unlimited but the angular spread of the final beam is less than that of the first traversal. The final image, which is almost free of aberration, is as large and almost as bright as the source. The optics of the instrument is considered in detail.

The Measurement of Small Linear Motions by Optical Methods, R. W. G. HUNT. J Sci Instrum v23 p 119–21 June 1946. Two optical methods for measuring small linear motions have been used, and some results obtained thereby are reproduced. The first makes use of two microscope objectives and depends on lenticular magnification for high sensitivity; the second uses a concave mirror and two prism systems, high sensitivity being obtained by means of prismatic magnification.

Engineering Optics, K. J. HABELL, A. COS. Sir Isaac Pittman & Sons, London, 1948 411 p. illus diagrs charts tables, 35s. Critical survey of most important optical methods and instruments applicable to engineering practice; properties of ideal optical systems and actual systems discussed; light and illumination, microscopes, telescopes, optical projection and profile microscopes considered. Eng Soc Library, N.Y.

Die Optik in der Feinmesstechnik, K. RAENTSCH. Carl Hanser Verlag, Munich, Germany, 1949A 317 p illus diagrs charts tables. Book describes measuring instruments and their optical principles; fundamentals of technical optics discussed; various instruments for fine measurements considered. Bibliography. Eng Soc Library, N.Y.

Optical Tools for Shop Precision, C. EMERSON. Am Mach v93 n25 Dec 15 1949 p 91–8. Optical flats and their applications; optical projection discussed including lighting and lenses, screens and charts, staging and surface projection; shop microscopes and microscope attachments; collimation, optical systems for boring and grinding machines, and small optical tools described.

An Interference Micrometer for Diameter measurement of textile filaments in moisture-controlled atmospheres, P. DENTON. J. Sci Instrum v29 Feb 1952 p 55–7. An instrument is described for determining minute dimensional changes on a specimen enclosed in atmospheres of different but pre-determined moisture condition. Localized Fizeau fringes, formed by reflection from a pair of aluminized glass plates that correspond to the fixed and movable jaws of a normal micrometer, are used as sensitive fiducial indicators for the appropriate setting of a micrometer head. One edge of the movable plate is laid in contact with the specimen and the other rests on a lever, the longer arm of which lies in contact with the micrometer head. This is adjusted until the fringe formation, which is viewed through the eyepiece of a Fizeau interferometer, indicates parallelism of the aluminized surfaces in a direction set by the line joining the ends of the lever; specimen thickness is then derived from the lever reduction ratio. Air of standard moisture condition moves past the specimen in a glass cell which is fitted with a flat roof to transmit the light. The instrument applies a small known force on the specimen and is especially applicable to measurements on compressible bodies. Data on the variation in diameter of cellulose filament with moisture condition are presented to illustrate the performance of the instrument.

A New Instrument for Measuring the Thickness of Glass Tube Walls, K. BERNOLÀK. Exper Tech der Phys v1 n2 1953 p 91–2 in German. A simple optical device is

described whereby the direct measurement of the thickness of glass tube walls may be made to an accuracy of 0.01 mm; the latter depends on the regularity of the tube thickness.

Ultrasonic Microscope, S. Y. SOKOLOV. Radio & Television News (Radio-Electronic Eng) v49 n2 Feb 1953 p 8–9. How obtaining of very short ultrasonic waves of order of wavelength of visible light, has led to development of microscope with which it is possible to view object in magnified scale, image is seen directly on cathode ray tube screen; calculations show that magnification approaches order of tens of thousands of times; design and operating details of various versions. Translated from Russian journal, Progress in Phys Sci v40 Jan 1950.

Design of Graticules and Reference Marks, and Some Factors in Operation of Scientific Instruments, R. T. LESLIE, L. D. ARMSTRONG. Austral J App Sci v6 n2 June 1955 p 167–82. Experimental study of factors affecting accuracy of combinations of graticules with reference marks, effects of line thickness, separation of fixed line pairs, angle between crossed transverse lines, width of light gap between central and outer elements, illumination, ambient temperature and other factors.

A Large Optical Slit Mechanism Employing Spring Movements, R. V. JONES. J Sci Instrum v33 n5 May 1956 p 169–73. A spring layout is described for producing symmetrical movement in an optical slit 10 cm long, and capable of operating at any width between 5 and 1000μ. Such factors as the parallelism and separation of the jaws are made independent of gravity by suitable arrangement of spring strength and disposition of centres of gravity of the moving members. The jaw edges are optically worked to confine width variations along the slit to about $\pm 0.15\mu$ r.m.s., and the jaws can be set parallel by eye and hand to within about 0.3μ variation in the 10 cm length.

Measurement of Small Displacements of a Plane Surface with a Semi-Virtual Slit Modulator, P. BARRET. J Phys Radium v17 n6 June 1956 p 29 S in French. This method is suitable for measuring the displacement of a polished or plated surface. A metal plate, such as a razor blade, is mounted parallel to and about 0.01 mm away from the surface. Observation of the slit at grazing incidence shows a real and a virtual (reflected) edge. Variations in the magnitude of this "sem-virtual slit" are used to modulate a beam of light falling on a photocell for recording static or dynamic displacements of the surface.

Optical Probe for Accurately Measuring Displacements of Reflecting Surface, K. W. T. ELLIOTT, D. C. WILSON. J Sci Instrum v34 n9 Sept 1957 p 349–52. Displacement of plane reflecting surface along its normal can be accurately measured by probe without making mechanical contact with it; successive settings of probe relative to fixed surface indicate that standard deviation of single setting of probe is about $0.4\mu\,(1.6\times10^{-5}$ in.) when probe is used with calibrated line standard, displacements may be measured with standard deviation of $0.7\mu\,(2.8\times10^{-5}$ in.).

Precision Measurements on the Z-Axis of a Microscope, D. HEUGHEBAERT, J. HEUGHEBAERT. "Particle Photography" Conf, Montreal, 1958 in French. A considerable increase in the accuracy of measurements in the vertical plane is obtained if the relative distance between the objective and the eyepiece is made variable, the distance between the objective and the plate remaining unchanged. A device based on this principle is described, its use and the attainable accuracy are illustrated for a number of cases.

Considerations Regarding Possible Use of Some Optical Elements, N. BARANY. Periodica Polytechnica—Elec Eng v3 n3 1959 p 183–96. Review of known adjusting devices for optical and precision instruments with examples

of unduly neglected control mechanisms; mechanical constructions in military instruments adaptable to civilian uses.

A Recording Scanning Micrometer, V. R. REGEL', V. G. GOVORKOV. Pribory i Tekh Eksper (USSR) 1959 n4 p 133–6 July–Aug in Russian. This displacement micrometer is based on the photoelectric measurement of a luminous flux which passes through a system of two rasters moving with respect to each other. A laboratory model of the instrument permitted the measurement of displacements of up to 10 mm with an accuracy of 0.1μ. [English translation in: Instrum Exper Tech (USA) n4 p 654–7 July–Aug 1959; publ. June 1960.]

Berührungloses Messen grösserer Aussen-und Innendurchmesser (Contactless Measurements of Large External and Internal Diameters), K. RÄNTSCH, E. LEPPER. 4 FoKoMa Munich Oct 6–7 1959. Contactless measurement is an acute problem of the progressive finishing technique to the metrologist. This problem is solved electrically, pneumatically, and optically. The explanations of this paper are concerned only with optical contactless measurements, especially for external and internal diameters. Next the demands placed on new equipment are set forth for large measurements. An especially remarkable such measuring equipment is the flawless, contactless, indication response of the cylinder surface. For this the field of surface indication is especially treated. Optical indicators of known and of newer kinds are systematically arranged and closely elucidated. Two principal groups of indication responses are thus developed. These chief groups are further classified. Thereby the application possibilities of the single indicators may be recognized. From this knowledge conclusions are derived for practical application in metrology. The already obtained experimental information presents a prospect of future flawless measuring methods.

An Image-Splitting Microscope for Accurate Measurement, J. DYSON. Nature (London) v184 Nov 14 1959 p 1561. Dsecribes how, by fitting in the eyepiece a suitable image splitting device, the two images may be sheared across each other until edge-to-edge contact is obtained. By reversing the shear until edge-to-edge contact is again obtained. the diameter of the object may be measured. The technique is illustrated by application to blood corpuscles.

Adjusting Your Point of View, J. R. SULLY. Eng Matls & Design v3 n1 Jan 1960 p 13. Description and diagram of optical instrument developed to eliminate distortion often found when viewing small-scale models with naked eye; instrument can be used for models of various scales by adjusting distance between reflectors or prisms.

Precise Measurement of Small Objects, J. DYSON. AIE Eng (formerly AEI Eng Rev) v1 n1 Jan 1961 p 13–17; Machy (London) v92 n2520 Mar 1 1961 p 503–8; Quality Engr v25 n2 Mar–Apr 1961 p 41–5. Optical principle of and apparatus associated with new method based on application to microscope of "image splitting principle"; method enables measurements to be made with precision about 10 times better than resolving power of microscope allows, and is particularly suitable for rapid and precise measurements of repetitive nature, such as are required in inspection department.

Device for Adjusting Universal and Measuring Microscopes, N. K. KRASNOPEROV. Meas Techns 1961 n1 Sept 1961 p 21–2 2 figs 1 ref. Translated from Izmer Tekh 1961 n1 p 15–6 Jan 1961. A device was made for eliminating the displacement of the optical axis of a type UIM–21 and BMI microscope tube with respect to the axis of rotation of the supporting column.

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Development and Application of Fiber Optics Techniques to Precision Measuring Devices, Transducers and Automatic Transducers and Automatic Control Systems, E. D. GRIM. Electronic Components Conference-Proc 1962 p 137–40. Application of techniques using fine filament of glass of circular cross section and high index of refraction surrounded by thin jacket of lower index glass as basic element in design of transducers, distance and angle measuring devices, automatic position control systems, card and tape readers, light operated relays, function generators, and other similar devices.

Quality and Quantity of Information, K. F. H. MURRELL. Soc Instrum Technol Trans v15 n2 June 1963 p 96–9. Progress review of instrumental displays and design of their use in Great Britain; it is concluded, from instruments still being manufactured, that not enough thought is yet being given to suitability of instrument to needs of operator.

Optimum Operating Conditions for Scanning Devices in Photoelectric Recording, M. G. MIKHAILOVA. Meas Techns 1963 n1 Aug 1963 p 22–5 4 figs 6 refs. Translated from Izmer Tekh n1 p 16–8 Jan 1963. Scanning phototransducers are widely used in systems requiring precise focusing on a graduation. Scanned phototransducers with a small scanning amplitude can be used under the same conditions as similar transducers based on the measurement of the duration of adjacent pulses, since the parameters of the former do not depend in a zero measuring method on the amplitude of vibrations or the width of the graduation image.

Modern Optics in Machine Tool Technique. Firm of Dr. Johannes Heidenhain, Traunreut. Mar 1964 46 p 36 figs. Discusses advantages of optical measuring methods, fundamental terms in metrology, and principles of measuring system employing transverse step vernier chart. Presents a survey of standard instruments.

5.5. Pivots

Instruments Pivoting, C. E. FOSTER. Wld Power v14 Aug 1930 p 116–9 6 figs. To grasp nature of problems which face manufacturer of electrical instruments, it is necessary to study conditions under which pivoting system works; each modification or extension of existing standard specifications is in direction of greater sensitivity, smaller forces, and higher accuracy.

Important Points on Pivot Bearing Design, P. H. WHITE. Machy (N.Y.) v37 n6 Feb 1931 p 450 1 fig. Application and care of pivot and center bearing; construction details.

New Method of Pivoting on Instruments, A. J. LUSH. Instrum v4 n2 Feb 21 1931 p 106–8 4 figs. Position of pivots within their jeweled bearings is of vital importance; any other position taken up by movement than that in which it was calibrated will very obviously affect constancy of calibration.

Die Drehzapfen-Aufstellung (Pivot Mounting), K. LUEDEMANN. Zeit fuer InstrumKde v51 n9 Sept 1931 p 449–63 10 figs. Historical review; test results on measurement of small-size pivots; avoidance of centralizing error was so complete that remaining error could be disregarded; results of various measurements given in tables. Bibliography.

Friction of Pivots and Journals. Machy (London) v39 n995 Oct 29 1931 p 142–4 7 figs. Mathematical investigation of conditions obtaining in flat, conical, truncated conical, hemispherical and Schiele pivots and journals.

Static and Clinging Friction of Pivot Bearings, M. C. HUNTER. Proc Inst Mech Engrs London v151 n3 1944 p 274–84; Abstract in Eng v157 p 117–20, Feb 11 and p 138–40, Feb. 18, 1944. Describes special apparatus used in the investigation carried out to determine the static friction of various combinations of metals, including stainless steel and duralumin, under several conditions of dry and viscous lubrication. The paper gives data showing the rapid growth of the coefficient of friction during the first 24 hr at rest, and the subsequent increases over a period of 5 days. A series of long-term tests of 30, 60, and 90

days, on a selected number of specimens, provides a direct comparison from which the relative merits of the various combinations of materials is drawn. Evidence is provided suggesting advantages to be derived from the use of graphite as a preventive of clinging friction.

Apparatus for Measuring Static Frictional Torques of Instrument Jewels, W. H. PEARSE. J Sci Instrum v25 n10 Oct 1948 p 344–6. Device which can be used to obtain measure of surface quality of synthetic sapphire "V" jewels and hence enable their performance as jewel bearings for precision indicating instruments to be expressed quantitatively; pivoted element rests on jewel to be examined and is deflected by air jet, flow of which is gradually reduced and element allowed to return to position of equilibrium; results of tests given.

Physical Basis of Mechanical Factors of Merit in Pivoted Measuring Instruments, L. MERZ. Archiv tech Messen Issue n16 (Ref. J011–2) T3–T4 Jan 1950 in German. The Keinath mechanical factor of merit, given by $F_m=10$ (torque for 90° deflection)/(weight of moving system)$^{1.5}$, is discussed. The view that this factor of merit is empirical is concluded to be unjustified, and that the index 1.5 has a real physical basis.

Design and Manufacture of Jewels and Pivots for Instruments and Meters, G. F. TAGG, E. A. HOWELL. Soc Instrum Technol Trans. v3 n3 Sept 1951 p 124–33. Pivots and jewels employed in indicating instruments and meters are subject to considerable stress in normal usage, during transport, etc.; theoretical considerations necessary in design of bearings to give satisfactory performance under static and impact conditions; design nomograms for determining whether safe operating conditions prevail.

Gas Bearings in Precision Instruments, G. B. SPEEN. Electromechanical Components & Systems Design v8 n4 Apr 1964 p 40–3. Use of gas bearings in instruments, such as gyroscopes, accelerometers, gimbal bearings of inertial platforms, space simulators, and test tables, is discussed, along with methods of avoiding their improper application.

5.6. Slides, Stands, and Tables

Micrometer Leveling Table, J. H. DOWELL. J Sci Instrum v9 July 1932 p 234–6. Levelling table designed to give precise adjustment in three directions. Particularly valuable for interferometers. The construction is robust and its geometrical design ensures that wear is taken up automatically.

Standard Dimensions of Ball-Bearing Slide Races and Derived Kinematic Constraints, A. F. C. POLLARD. J Sci Instrum v11 n6 June 1934 p 173–83. Construction and dimensions for ball-bearing slide races suitable for slides with single degree of freedom as well as for certain bearings of spherical contacting elements peculiar to kine-

matic design, are discussed; table of dimensions for use of designers, in inches and millimetres included.

Precision 60° V-Block, A. N. APPLEBY. Machy (London) v66 n1706 June 21 1945 p 675. Author presents several additional uses for V-block applications; providing block is made with 60° included angle and distance from apex formed by angular sides to base of block is known, precision measurements can be obtained by aid of height gage, clock indicator or any two point measuring instrument; exemplary application is defined.

Ball Bearing Slides, C. JOBST. ASME Advance Paper n47 A–42 for meeting Dec 1–5 1947 6 p 2 supp sheets. Examples of progress made in reducing friction in sliding movements of machinery to minimum with addition of preloading of slide mechanism so that higher operating speeds, greater precision of product and longer life at lower cost are possible; preloading produces high stability in slide because operating loads merely modify total load, either increasing or decreasing it, in contrast with conventional slides in which live load changes from no load to full load.

Ständer mit Tisch für Messgeräte (Stand with Table for Measuring Instruments). DIN 2223 Oct 1949 1 p, available from ASA. Gives post diameters and lengths of support arms for various ranges.

Surface Plates, Sizes, Dimensions, and Requirements. DIN 876 June 1950 2 p, German Standard available from ASA. Cast iron surface plates, design and bearing area requirements.

The Sliding Surface, G. I. FINCH. Proc Phys Soc London B v63 p 465–83 July also ibid A v63 Aug 1950 p 785–803. The 34th Guthrie Lecture delivered to the Physical Society. A review of the existing state of knowledge of what actually takes place when one solid surface slides over another, with or without intervening lubricant, a critical survey of past and current ideas, and an account of the author's own work and that of his school on the subject: Particular attention is paid to the role of the oxide layer on the surfaces and to the lubricant as a carrier of oxidant to the high temperature regions of solid-to-solid contact.

Nine Types of Ball Slides for Linear Motion. Prod Eng v21 n9 Sept 1950 p 128–9. Diagrams show construction details of antifriction devices used for precision, straight line motion.

Three-dimensional Surface-table. Machy (London) v78 n2000 Mar 15 1951 p 438–9. Surface table developed by Fairey Aviation Co., Ltd. of Hayes Middlesex, permits measurement in three dimensions; guide rails attached to two adjacent edges of table serve as means of supporting vertical members; great accuracy of table noted; details of equipment and its use.

Get More From Your Surface Plates, J. HYLER. Iron Age v173 n5 Feb 4 1954 p 156–8. Requirements of cast iron and granite surface plates employed for inspection and checking operations; selection and use of surface plate; their value for gaging, checking, and especially for layout work on small lots of parts where tooling is not economically practical.

Wear of Cast Iron Machine Tool Slides, Shears and Guideways, H. T. ANGUS, D. MARLES, M. H. HILLMAN. Brit Cast Iron Res Assn J Res and Development v6 n3 Dec 1955 p 72–82, 4 plates, 3-page chart, Appendix 83–135. Survey of slides of 30 machine tools, still in operation at time of examination; severity of wear indicated by gradings good, fair, poor and very bad; influence of microstructure and phosphorus content on wear particularly considered; case history of each examination, including operating details, analysis, hardness, etc.

The Influence of Elastic Deformation Upon the Motion of a Ball Rolling Between Two Surfaces, K. L. JOHNSON. Proc Inst Mech Engrs (GB) v173 n34 1959 p 795–810. When a ball rolls between two surfaces, in general, a tangential contact force and a relative angular velocity of spin are present at each point of contact. Both these actions give rise to tangential frictional tractions transmitted across the contact surface which are shown to result in a velocity of creep of the ball in a direction perpendicular to the nominal rolling path. The magnitude of the creep velocity depends critically upon the magnitudes of the tangential force and the velocity of spin. If these actions are small there is negligible slip between the contacting surfaces and the creep motion is predominantly a function of the elastic properties of the materials. At larger spin velocities slip extends over a greater proportion of the contact area and the creep is influenced by the frictional properties of the surfaces. Creep measurements were made over a wide range of conditions of rolling. The results are reduced to non-dimensional form, in terms of two parameters expressing the effect of tangential forces and spin respectively. The resistance to rolling was measured and is shown to control the axis about which the ball rolls. The detailed mechanism of the rolling process is discussed.

Cantilever Indicator Stand for Precision Inspection, D. C. K. PEARCE, F. R. TOLMON. Machy (London) v95 n2452 Nov 11 1959 p 1002–4. New stand developed by National Physical Laboratory is very much simpler than previous designs and therefore less expensive to manufacture; very fine adjustment can be obtained by bending vertical column through medium of cantilever and fine screw; data showing sensitivity of adjustment provided by indicator stand; specially devised steel band clamp for holding indicator.

Anti-Distortion Mountings for Instruments and Apparatus, R. V. JONES. J Sci Instrum (GB) v38 n10 Oct 1961 p 408–9. Some principles for the mounting of instrument platforms are discussed. For many optical and mechanical instruments, the working platform may best be protected from external mechanical distortion by supporting or suspending the platform by members, usually three, whose stiffness is much less than that of the platform. At the same time, these members can be stiff enough to give a fairly rigid location. Some possible arrangements are outlined.

The Design of Air Bearings and their Application to Measuring Instruments and Machine Tools, H. L. WUNSCH, NPL. Int J Mach Tool Design and Res v1 n3 Nov 1961 p 198–212 14 figs 6 refs. Contents: Introduction; general principles; design data for flat air bearings operating under steady load conditions; same under alternating load conditions; application of pressurized air bearings for machine tool slideways, automatic lead screw measuring bench, pneumatic roundness measuring instrument, etc.

Method for Slideway Error-Compensation on Measuring Instruments and Machine Tools, C. HOFFROGGE. Microtecnic v15 n6 Dec 1961 p 247–50. Slideway errors may be compensated with respect to guided element by using simple lever system arranged between that element and slideways, system of levers being controlled by means of compensation guidebar or rail; this makes it possible to reduce angular errors of graduated scale carrying table of longitudinal comparator 4.50 m in length from 3.5 to 0.3 sec of arc.

Amelioration des Surfaces Planes de Glissement et Particulierement des Glissieres de Machines Outils par Differents Procedes. et Notamment, par Trempe Haute Frequence et par Sulfinusation (Improvement of plane sliding surfaces, and of machine tool slides in particular, by various processes, especially by HF hardening and by Sulfinuz

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process), Y. DE VILLEMEUR. Rev Universelle des Mines v18 n1 Jan 1962 p 102–9. Selection of materials for slides and their hardening treatment considered.

Raschet napravlyayuschikh kacheniya iiprichiny vykhoda ikh iz stroya, Z. M. LEVINA. Stanki i Instrum n6 June 1962 p 8–12; see also English translation in Machines & Tooling v33 n6 1962 p 10–15. Anti-friction slideway calculations and causes of failure; as result of experiments and analysis of influence of manufacturing errors on magnitude of pressure, engineering calculation method has been derived based on contact stresses; calculations make it possible to determine optimum slideway dimensions and materials; roller slideways can bear considerably greater loads than ball bearing slideways, their load bearing capacity being approximately 10 times greater.

How to Stop "Stick-Slip" on Ways, H. E. TIFFANY. Am Mach/Metalworking Mfg v107 n4 Feb 18 1963 p 102–3. Difficulty of detecting and preventing stop-start motion of table as it slides along machine ways is noted; why table sticks and slips as it slides along ways; special lubricants can help to make it easier to start table; how to select right lubricant.

A Rotator to Study the Dimensions of Non-Circular Filaments, J. D. COLLINS. J Sci Instrum GB v40 n4 Apr 1963 p 198–9. An instrument is described which enables a fiber or filament to be rotated under a micro-scope so that the fiber profile diameter at any angle may be measured. In particular, for elliptically shaped fibers such as wool, the major and minor axes and the angles at which they occur may be observed. The instrument uses a dial gage, which measures in 0.0005 in. intervals up to 1 in., and this enables accurate longitudinal movements of the fiber to be made. By the use of an adjustable stop accurate movements may be made along the whole length of fibers up to six inches long. Cross-sectional area variations and ellipticity along the whole fiber length can thus be measured. Further, the mechanism enables the fibers to be extended by a known amount so that dimensional changes may be studied. The instrument was designed to be used with a projection microscope specially made for wool fiber diameter measurements.

Universal Measuring Block, R. D. PURVIS. Machy (Lond) n103 n2662 Nov 20 1963 p 1154–7. Equipment described, meeting requirements of accuracy and also those of full utilization of instrument, consists basically of block of close grained cast iron which has accurately machined central vees and locating pads on base, sides and ends; these pads allow block to be set in any of 5 positions while maintaining squareness, parallelism and symmetry with central vees to high degree of accuracy; applications indicated; equipment was found to be extremely useful for toolroom and experimental machine shop applications.

5.7. Springs and Suspensions

Reed Gages Guarantee Close Tolerance Under Shop Conditions, C. F. DREYER. Factory and Indus Mgmt v80 n4 Oct 1930 p 722–4 10 figs. Improvement in indicator gage which will permit its use in control of product tolerances defined in ten-thousandths of inch; limitations of fixed gages and of usual forms of indicators; construction of fixed gages and of improved indicator gage; advantages shown in number of successful applications.

Flexure Pivots to Replace Knife Edges and Ball Bearings, F. S. EASTMAN. Univ Wash Eng Experiment Station— Bul n86 Nov 1935 47 p. Derivation of equations for simple flexure pivot without fixed center of rotation, flexure pivots with fixed centers of rotation, self-compensating flexure pivot; miscellaneous uses for flexure-pivot. Equations.

Instrument Springs, J. W. ROCKEFELLER, JR. Wire and Wire Prod v11 Nov 1936 p 631–9. Considerations important in design and manufacture discussed, together with relative merits of extension under axial load, mechanical hysteresis, creep under load, temperature effect on modulus of elasticity; Elinvar and related nickel-chromium steels, and approved methods of manufacture. Bibliography.

Measuring Elastic Drift, R. W. CARSON. ASTM Preprint n107 meeting June 28–July 2 1937 10 p. Recording electronic micrometer, sensitive to deviations as small as millionth of inch, developed to measure deflections of spring members of precision instruments without disturbing load deflection; test strip specimens and actual elastic elements used in instruments. Bibliography.

Ueber die elastische Nachwirkung (Theory of Elastic After-action), SCHOLETZER. Zeit fuer InstrumKde v57 n9 Sept 1937 p 371–78. Theory of elastic after-action of instrument spring; mathematical and graphical analysis.

Utilizing Flat Spring in Accurate Mechanisms, A. M. WAHL. Machine Design v11 n11 Nov 1939 p 40–2. Indicative of versatility of flat springs are some unusual applications to two recently designed extensometers; both utilize flat strips of spring steel to serve dual purpose of guides to obtain straight line motion and as means of exerting definite pressure on contact points.

Federgelenke im Messgeraetebau (Spring Suspensions in Measuring Instruments), H. STABE. VDI Zeit v83 n45 Nov 11 1939 p 1189–96. Most important of numerous suspension systems discussed and illustrated; necessity for elimination of frictional defects pointed out.

Instrument Springs Control Performance, P. MacGAHAN. Elec Mfg v34 n4 Oct 1944 p 99–102, 174, 176. Compared to springs in other mechanisms or even in watches, springs used in instruments may be very weak; their strength is measured in "mili-metergrams" of force required to produce certain angular deflection; measuring strength of springs; proper mounting of springs.

Bandaufhaengung fuer den beweglichen Teil bei Messgeraeten (Suspensions for moving parts of measuring instruments), J. BUBERT. Archiv fuer Tech Messen n152 Oct 1947 p T29 2 p. Considerations concerning bearing friction; fiber suspensions in electric and other measuring devices; simple and fixed suspensions.

Aufhaengebaender (Suspensions), J. BUBERT. Archiv fuer Tech Messen n152 Oct 1947 p T30 (4 p). Suspension fiber materials; applicability in galvanometers and like devices, of phosphor bronze, silver, gold and copper as well as silk or quartz fibers and steel wires; torsional and other characteristics of fibers as related to cross sectional shape.

Theory of Symmetrical Crossed Flexure Pivots, W. H. WITTRICK. Austral J Sci Res Ser A v1 n2 June 1948 p 121–34 1 supp plate. Use of pivots in scientific instruments in place of knife edge bearings; general theory of symmetrical crossed flexure pivots under any combination of vertical and horizontal loads is given; theory used to derive set of curves presenting all information necessary for design of such pivots.

Parallel and rectilinear spring movements, R. V. JONES. J Sci Instrum v28 Feb 1951 p 38–41. Discusses the design

of instrument movement in which the moving member is held by two equal and parallel leaf springs; the member can be moved parallel to itself by pushing it normally to the springs. In a constructed specimen the parallelism was maintained to within ±3.5 sec of arc over 6 mm of travel by a simple method of balancing the springs. Arrangements are described for combining two or more spring systems to develop a rectilinear movement. Performances are quoted for three constructions, the best of which held a straight line within about ±0.25μ over 5 mm of travel, and ±1μ over 10 mm. In some applications spring movements are superior to kinematic slides.

Suspension Strip, P. CHRISTOPH. Arch für Tech Messen Issue n182 (Ref J013-5) Mar 1951 p T34 in German. Suspensions for comparatively heavy weights (e.g. gyros, torsion balances, torsional pendulums for clocks) are considered. Formulae are given for: (1) torsion moment for given dimensions of suspension, suspended weight, torsion angle, and constants of suspension material; (2) width/thickness ratio of suspension to give minimum torsion moment for given cross-sectional area; (3) ratio of torsion moments of round wire and rectangular suspension of optimum width/thickness ratio, of same cross-sectional area and material; (4) time of swing as function of weight and amplitude.

Instrument Springs and Spring Instruments, J. W. ROCKEFELLER, JR. Wire and Wire Prod v26 n9 Sept 1951 p 764-5, 802-7. Properties required in springs to make them suitable for precision instruments; principle of spring as measurement of force; attitude of Weights and Measures departments toward tolerances; Elinvar wire; instrument spring; improvement in scale springs; three charts showing errors in otherwise perfect 3-revolution circular dial in scale, and effects of these errors.

Design Characteristics of Cross-Spring Pivots, L. W. NICKOLS, H. L. WUNSCH. Eng v172 n4472 Oct 12 1951 p 473-6; Engr v192 n4994 Oct 12 1951 p 458-61; Machy (London) v 79 n2030 Oct 11 1951 p 645-51. Investigation to provide information of use to designers wishing to incorporate cross spring pivots in their instruments; sizes were kept within range usually employed for this purpose; work relates to type of cross spring pivot most commonly used, in which cross strips intersect at 90° at midpoint of their functional lengths to 90° symmetrical cross spring pivot; illustrations, graphs.

Alignment by Suspension on Elastic Strip, J. E. C. PLAINEVAUX. Note in Nuovo Cimento v10 Oct 1953 p 1451-60 in French. After a brief review of systems used for the near rectilinear alignment of a suspended part on elastic strips, a method is described for calculating these suspensions where the strips operate in flexure along the whole of their length. The method takes account of the large deformation of the strip and enables the parasitic movement perpendicular to the principal movement to be determined.

A New Method for the Measurement of Small Changes in Length, D. KUHLMANN-WILSDORF. Z Angew Phys v6 n 4 1954 p 171-4 in German. The instrument described consists of a horizontal roller which is divided into two parts of different radii and which is supported by two vertical bands. The upper band is fastened at one end to the part of smaller radius and the lower band to the other part. The other ends of the bands are fastened to the two points between which the changes in length are to be measured. The rotation of the roller is measured by means of a mirror attached to the roller. Details of suitable properties and materials for the bands, the types of measurement and of the practical application, range of use and sensitivity of the instrument are given.

Flexure Devices, P. J. GEARY. Brit Sci Instrum Res Assn 1954 44 p. Literature survey and bibliography. Discusses means of: supporting movable members, control influencing scale shape, indicating recording, and influencing sensitivity.

Angle-Spring Hinges, R. V. JONES. J Sci Instrum v32 n9 Sept 1955 p 336-8. Features of hinges whose design is based on each of twisting L-section cantilever beam about its corner edge; simplest form is easier to make and is more compact than cross strip hinge; limitations of angle spring are described and various designs of simply compensated hinges indicated; such hinges can be useful components in instrument design, being free from friction and backlash.

Application of Spring Strips to Instrument Design. Notes Appl. Sci NPL n15 1956 25 p 22 figs 4 refs. This booklet provides designers with information about some of the various applications for providing pivoting and parallel motion, conversion of linear to angular motion. The uses of buckling and twisting strips are described, and indicating mechanisms based on them. Miscellaneous uses include support of counterweights, protection of precision scales, biasing springs, and locking a carriage to a slide. Methods of attachment of spring strips are also described.

Zur Berechnung von Torsionsbaendern und Torsionsspponnbaendern im Feingeraetebau, (Calculation of torsion suspension bars and prestressed torsion bars in precision apparatus), S. HILDEBRAND. Dresden. Tech Hochschule-Wiss Zeit v6 n4 1956-7 p 749-56. Calculation for rectangular cross sections according to L. Bubert-A. Foeppl formulas, and C. Weber method; comparison of these methods.

Some Parasitic Deflections in Parallel Spring Movements, R. V. JONES, I. R. YOUNG. J Sci Instrum v33 n1 Jan 1956 p 11-15. Some parasitic departures from parallel and rectilinear movement in simple and compound assemblies are analyzed. The following factors are considered: accuracy of construction, geometrical proportion, spring variations, spring distortion, platform bending, clamp distortion, and gravity effects. It is shown that the "ideal" height at which to drive a parallel spring element is at half the spring height, and it is concluded that while spring tolerances are surprisingly "easy" care must be taken with the platforms and clamps if the highest performances are to be achieved. In compound movements, the possibility of "slaving" the intermediate platform, suggested by Plainevaux has been tested in practice with good results.

Fundamental Behavior of Sensitive Springs, R. TOMASCHEK. J Sci Instrum v33 n2 Feb 1956 p 78-81. It is shown that by extending a flat spiral spring by a force acting at one of its ends perpendicular or at an angle to its original winding plane, shapes of a special form, called serpent springs, can be obtained. Though capable of supporting relatively heavy loads, these springs respond under certain conditions to small changes in the loads by considerable lengthening and twisting. The conditions for obtaining such springs of high sensitivity and their fundamental behavior are described.

Pitching Movement of an Elementary Suspension on Elastic Strips, J. E. PLAINEVAUX. Nuovo Cimento ser10 v4 n5 Nov 1956 p 1133-41 in French. A horizontal plate mounted on two identical vertical elastic strips, rigidly fixed to its ends and clamped vertically at their lower extremities, tilts whenever it is moved laterally, through a small angle of the second order in the horizontal displacement, unless the loading of the plate is symmetrical. If such pitching is to be reduced to a minimum, there is an optimum position for the line of action of the horizontal displacing force, which is approximately midway between the plate and the fixed ends of the strips. But the application of the force in the plane of the plate may be

preferable, for this makes the system less sensitive to vibrations and involves only a third-order error in the orientation of the plate.

Elastic Aftereffect in Bronze Suspensions of Electrical Measuring Instruments, A. A. TIMOFEEVA. Meas Techns 1958 n3 May–June 1958 p 342–6 6 figs. Translated from Izmer Tekh n3 Nov 1959 p 73. Investigation establishing certain regularities in behavior of suspensions, which provide possibility of determining stresses arising in them and expected deviation from their return to zero, with error permissible in preliminary instrument calculations.

Statics and Dynamics of a Helical Spring, R. GEBALLE. Am J Phys v26 n5 May 1958 p 287–90. The theory of the extension and twisting of a helical spring was given in a recent paper by Krebs and Weidlich. This theory is reviewed and its applicability as an experiment in advanced mechanics is described. From measurements of extension and twisting under static load, and also from simple observation of the coupled oscillations of these degrees of freedom, it is possible to calculate Poisson's ratio and the shear modulus. The two independent procedures give consistent results. The experiment provides an excellent demonstration of the geometry and elastic deformation of a helix, its static equilibrium and its coupled oscillations.

Improved Magnetic Suspension System, C. G. McILWRAITH, J. B. BREAZEALE, E. N. DACUS. Rev Sci Instrum v29 n11 Nov 1958 p 1029–33. Magnetic suspension apparatus which supports ferromagnetic object free from contact with its surroundings and which is capable of maintaining this support for any attitude or orientation in space of apparatus as whole; applications as frictionless bearing and as force balance in various instruments, such as accelerometer, analog double integrator, differential pressure detector, long period pendulum, and fluid density instruments.

Torsion Devices, P. J. GEARY. J Electronics and Control v5 n5 Nov 1958 p 483–96. Elastic connections are being used increasingly in measuring instruments for suspending or guiding moving parts which have to travel back and forth through limited distances or angles; two types of torsion devices are described; torsion suspensions and torsion hinges; suitable types of material indicated and problems in mechanical construction discussed.

Dynamik der Spannbandlagerung (Dynamics of strap suspension systems), E. SAMAL. Archiv fuer Tech Messen n277 Feb 1959 p 31–4. Analysis showing advantages of such system for protection of measuring instruments against shock damage during transportation as well as other undesirable effects of shock and vibration during operation.

A Gauge for the Precision Measurement of the Thickness of Germanium and Silicon Wafers, D. BAKER. Proc Inst Elec Engrs Paper 2891E [Int Conv on Transistors and Associated Semiconductor Devices], publ. May 1959 3 p. Some of the difficulties associated with the precision measurement of the thickness of thin germanium and silicon wafers, together with several possible methods of measurement, are briefly discussed. A gauge which employs the optical-lever principle is described in which frictional restraint of the moving parts is reduced to that of a knife edge alone, thus ensuring good repeatability of reading with probe pressures of less than 3 g. The gauge covers the range 0.270 micron with an overall accuracy of ±0.5 micron.

Taut-Band Suspensions for 250-Degree Instruments, V. S. THOMANDER, R. C. MACINDOE. AIEE Trans v 79 pt 1 (Communication and Electronics) n44 Sept 1959 p 379–83 (discussion) 383–4. New design of instrument

suspension containing moving element suspended by two metal bands under tension which replace conventional spiral springs, jewels, and pivot bearings, design is free from bearing friction, thus eliminating major causes of trouble experienced particularly with electrical measuring instruments. Paper 59–159.

Torsion Devices, P. J. GEARY. Brit Sci Instrum Res Assn Survey of Instrument Parts n3 1960 142 p. Review of available information on design, construction and functioning of torsion devices as working parts of measuring instruments; torsion suspensions; suspension ligaments; bifilar and trifilar suspensions; coiled torsion suspensions; torsion hinges; torsional magnifying devices, 207 refs.

Magnetic Suspension for Low Temperature Studies, A. D. SHVETS, V. B. KASHIRIN. Instrum & Exper Techn (English translation of Pribory i Tekhnika Experimenta) n6 Nov–Dec 1961 p 1180–2; Cryogenics v2 n5 Sept 1962 p 276–8. Arrangement for connecting apparatus for studies both at normal and at low temperatures, to ferromagnetic part of suspension; portion at helium temperatures is electromagnet coil, control and ferromagnetic core to which vessel with liquid helium is fixed; whole system is brought into rotation by external rotating magnetic field; such apparatus has been used for measuring moment of inertia of rotating liquid helium; circuit and apparatus diagrams.

Taut-Band Suspension Instruments, G. STOLAR, C. B. STEGNER. Instrum & Control Systems v35 n2 Feb 1962 p 134–5. Advantages obtained in using taut band suspension, instead of pivot type suspensions, including elimination of friction in movement; suspensions developed by Weston Instruments Div. Daystrom, Inc. especially for a-c and d-c indicating instruments.

Instruments without Pivots. Eng v193 n5005 Mar 23 1962 p 388. Dispensing entirely with jewels, pivots and control springs, instruments are being manufactured by Crompton Parkinson Ltd, in which movement is suspended on ribbon of heat treated beryllium cooper held taut by tension springs mounted on bushes fitted to supporting brackets on movement frame; ribbon may be only 0.005 in. wide by 0.0005 in. thick, with latter held to within 0.00001 in.; suspension is for ammeters, voltmeters, frequency and speed indicators, etc.

Why Taut-Band Suspension, J. MEILI. ISA J v9 n4 Apr 1962 p 44–7. Advantages of taut-band suspension, use of which has been made economically feasible by modern manufacturing techniques; eventually, taut-band suspension will replace pivot-and-jewel movements in electric instruments.

Some Uses of Elasticity in Instrument Design, R. V. JONES. J Sci Instrum (GB) v39 n5 p 193–203 May 1962. The paper presents the text of a discourse delivered at the 1962 Exhibition of The Institute of Physics and The Physical Society, which reviews anti-distortion instrument mountings, elastic movements for rotation and translation, movement magnifying and reducing devices, elastic averaging schemes, simple harmonic force and constant force systems, elastic energy stores, and a slow relaxation device for transmitting rapid displacements only.

Accuracy of Parallelogram Spring Suspensions, A. S. VALEDINSKII. Meas Techn 1962 n4 Sept 1962 p 284–5 3 figs 1 ref. Translated from Izmer Tekh n4 p 13–4 Apr 1962. Determines the error in displacement in the direction of the indicator tip movement which is placed at an angle β.

Construction and Performance of Various Flexure Hinges, D. M. MARSH. J Sci Instrum v39 n10 Oct 1962 p 493–7. Simple and yet precise clamp for strip hinges which facilitates construction of flexure hinges of fairly

general application; merits of single strip hinge, which becomes especially simple to construct by method proposed; it is shown that for limited rotations it is often superior in performance to cross strip hinge.

Considerations in the Application of Flexural Pivots. H. TROEGER. Automatic Control v17 n4 Nov 1962 p 41. Sensitivity, accuracy and repeatability are limited primarily by pivot friction and backlash where pivoted members are used to transfer or algebraically operate upon forces or displacements. Since many instruments, controls, and measuring devices employ pivoted members the reduction of pivot friction and backlash is consequential to the reduction of their contributed error.

Spannband- and Spitzenlagerung (Strap and point suspension), S. GOETZE. Assn Suisse des Electriciens Bul v53 n25 Dec 29 1962 p 1268–73. Relative merits of two types of suspensions for measuring instruments are discussed; taking into account accuracy, robustness and other characteristics of intruments involved.

Guides with Flat Springs for Forward Displacements, YA. M. TSEITLIN. Meas Techns 1963 n9 Feb 1964 p 732–6 2 figs 11 refs. Translated from Izmer Tekh n9 p 11–5 Sept 1963. Deals with widely-known spring guides of the parallelogram type for forward displacements, and certain characteristics to be considered in design to prevent overloading and premature failures.

Addendum to Section 5

5.2.2. Electrical Amplification

The Ultra-Micrometer; an Application of the Thermionic Valve to the Measurement of very small Distances, R. WHIDDINGTON. Phil Mag 6ser v40 n289 Nov 1920 p634–9 2 figs; v46 n274 Oct 1923 p607–8, with A. HARE, co-author; v49 n289 Jan 1925 p113–21 3 figs with F. A. LONG, co-author. If a circuit consisting of a parallel plate condenser and inductance be maintained in oscillation by means of a thermionic valve, a small change in the distance apart of the plates produces a change in the frequency of oscillations which can be accurately determined by methods described. It is shown that changes as small as one two-hundred millionth of an inch can be easily detected.

Sensitive Valve Method for the Measurement of Capacity; Applications, J. J. DOWLING. Roy Soc Dublin. Proc v16 Dec 1920 p175–84, Mar 1921 p185–8; Eng v112 Sept 9 1921 p395; Phil Mag v46 July 1923 p 81–100, Nature v111 June 2 1923 p 742–3. Describes arrangement of the apparatus and its application as an ultramicrometer for measuring minute movements, inasmuch as the capacity of a condenser varies with the separation of the plates.

Electrical Apparatus for Measuring Small Motions, H. A. THOMAS. Engr v135 Feb 9 1923 p138–40; J Sci Instrum v1 1924 p22–6 7 figs. Apparatus consists of a high-frequency oscillator and an inductance coil arranged in close proximity to the metallic body whose motion is to

be measured. It is applicable to the analyzing of the transient conditions existing in all types of engineering structures when subjected to live loads. The principle has been applied successfully to the operation and maintenance of a standard pendulum, without any contacts being required to operate the mechanism for inserting energy into the stroke.

The "Ultramicrometer," a New Instrument for Measuring very small Displacement or Motion, and Its Various Applications, J. OBATA. World Eng Congress, Tokyo, 1929 v5 p79–84 12 figs refs. Distributed by Kogakkai, Marunouchi, Tokyo, 1931. The detailed construction together with various applications were published previously, elsewhere. The present paper contains the results of further applications, namely: The recording of earth movements; direct recording of accelerations; an electrical indicator for high speed internal combustion engines; precise recording of sounds, pressure variations, and various mechanical vibrations.

Capacitive Displacement Transducers, A. V. FEDOTOV. Meas Techns n7 Feb 1965 p 571–5 2 figs. Translated from Izmer Tekh n7 p 15–6 July 1964. The necessity of extending the range of capacitive displacement transducers has led to the theoretical and experimental investigation of certain systems of these transducers. A capacitive transducer with a range of 200μ and a scale factor of 1μ was produced. It is stable in operation and insensitive to external interference.

3.5. Measuring Machines and Bench Micrometers

Thickness Gauge with an Antenna Transducer for Non-conducting Materials, B. M. SHLYAPOSHNIKOV, E. M. KON'KOVA. Meas Techns n7 Feb 1965 p 578–81 1 fig 3 refs. Translated from Izmer Tekh n7 p 18–20 July 1964. A device has been designed and built for measuring the thickness of glass plastics and similar nonconducting materials by means of a metal backing. It is provided

with direct reading in units of length and can be used at any distance from the edge of the tested sample, without destroying it and without first determining its physico-chemical properties. Extensive testing has shown that the design is satisfactory and it is convenient to use. Its electrical circuit is simple, and the number of control devices is small.

Section 6. Angle Measurement

CONTENTS

6.1. Angle Measurements, General

The Telescope-Mirror-Scale Method, Adjustments and Tests, S. W. HOLMAN. John Wiley & Sons, N.Y. (reprinted from The Technology Quarterly), Sept 1898 39 p 11 figs 3 refs. This presentation is designed for putting the method of measuring small angles into direct service. It discusses the several sources of error. It describes the various adjustments and tests in the sequence in which they should ordinarily be made and gives a numerical measure of the closeness with which each must be carried out to secure a specified precision in the result. Some remarks on the selection of instruments are appended.

Solid Angles, L. WEBER. Zeit für InstrumKde v28 May 1908 p 129–36. Describes at length two new methods of measuring solid angles. In the first method, which is adapted to measuring areas on the surface of a sphere, use is made of the pantograph to obtain (1) the projection of a given area on some fixed plane and (2) the projection of the central section parallel to this plane. From a comparison of these two the area on the sphere can be determined. In the latter part of the paper a modified form of Moritz apparatus is described.

Setting Angles for Milling Angular Cutters and Taper Reamers, W. A. KNIGHT. Machy v15 Nov 1908 p 161–8. Mathematical development of subject with numerous tables. Bibliography.

The Measurement of Angles and the Rectilinear Scale of Constant Sensibility (La Mesure des Angles et L'échelle Rectiligne de Sensibilité Constante), M. DUGIT. Techn Mod v12 n9 Sept 1920 p 353–61 14 figs. Advantages and disadvantages of rectilinear scale as compared with circular scale. Construction of spiral protractors.

The Measurement of Angles in Radians (Le Mesure des Angles en Radians), J. MAITRE. Génie Civ v78 n2003 Jan 1 1921 p 10–2 1 fig. Utilization of radians for measuring angles by means of straight lines.

Winkelmessung (Angle Measurement), F. GÖPEL Chapter 3 of Handbuch der Physik, Verlag Julius Springer, Berlin v2 1926 p 91–111 20 figs refs. Discusses the division of the circle, and instruments and set-ups for angle measurement.

Determination of Angles by the Use of Microscopic Areas, A. ARNULF. CR Acad Sci v189 July 22 1929 p 152–3.

The object of the device is to determine to an accuracy of 1' the direction of the normal to a polished surface of small radius of curvature (e.g., 0.001 mm²). A luminous point situated laterally is by means of an unsilvered plate of glass placed at an angle of 45° in the optical axis of a microscope, reflected through the object glass on to the polished surface under examination, and thence back to the eye. The variations in the resultant illumination reaching the eye according as the tangent plane to the surface at the point of incidence of the pencil of light is, or is not, accurately perpendicular to the optical axis of the microscope, enable the direction of the normal to be accurately determined.

Accuracy in Angle Gaging, J. A. POTTER. Am Mach v72 June 26 1930 p 1024–5 8 figs. Procedure for proper measurement of angles, simple, double and compound.

Testing Safety Razor Blades, R. W. WOODWARD. Iron Age v131 June 22 1933 p 981–3 22 figs. Measurement of cutting angle, testing edge with photoelectric cell, Woodward sharpness tester.

Winkelverwandler und Winkeluhren (Angle Converters and Meters), H. MAURER. Zeit für InstrumKde v55 Nov 1935 p 448–56 2 figs 4 refs. Disadvantages of various systems of angular measurement, e.g., in terms of radians, degrees, minutes, seconds, etc., are briefly referred to, the application of such systems in military and naval science being, inter alia, referred to. The advantages of a system in which 2π radians is divided into 6000 units are pointed out. The term "set" (derived from sechs and tausend) is suggested for the new unit. Devices for interconversion of the various scales are described and their use exemplified.

Simple High-Sensitivity Method for Optical Measurement of Very Small Angles, A. PERRIER. Helvetica Physica Acta v9 n5 1936 p 332–4 in French. Details are given of a method of measuring small angles in which the movement of a real image of a fixed object, formed by a concave mirror attached to the moving system, is measured with a micrometer eyepiece.

Messen von Winkeln mit Messcheiben und Lehrdornen (measurement of angles with disks and plug gages). Werkstatt und Betrieb v70 n¾ Feb 1937 p 33. Outline of practice for measurements of angles by aid of disks and cylindrical calipers; practical examples given.

Alignment Projectors and the Precision Measurement of Angles, C. DÉVÉ. L'Optique (Rev Opt Theor Instrum) v20 1941 p 115–48. Discusses the limitations of telescopes for the measurement of small angles, then proceeds to analyse the advantages, and estimate the precision, of alignment projectors. Two types of work are discussed, the measurement of angles subtended by distant objects and the use of goniometric work in laboratories and workshops. Details are given of the instrument suited to each type of work and the various methods of use and applications are considered. These include the manufacture of precision prisms, measurement of small angles between two reflecting faces, the variation of the refractive index of the atmosphere, etc.

Measuring and Inspection Instruments. Eng v156 n4053 Sept 17 1943 p 227. Brief illustrated description of three instruments demonstrated by E. H. Jones (Machine Tools), Ltd, London, namely, Sigma taper measuring machine manufactured by Sigma Iustrument Co; Brisdon inspection table made by F. Brauer; and universal sine table made by Papworth, Ltd.

Projection Angle "Dekkor." Eng v157 n4093 June 23 1944 p 487–8. Illustrated description of improved precision optical instrument for checking angular relationship between plane surfaces, manufactured by Adam Hilger, Ltd; scales are visible on screen on to which they are projected by optical system.

Notes on the Use of Circular Dividing Apparatus for Angular and Linear Measurement, G. P. BARNARD, NPL, His Majesty's Stationery Office July 1945 81 p 55 figs. Contents: Introduction; main apparatus required; dividing heads; universal measuring block; accessory apparatus; introduction to measurement; preparation for gauge inspection; measurement of selected examples. Appendixes, note on location of center of small circular arc; note on pitch radius measurements; rotation involving translation, sources of error; intersection dimensions and gauging triangles; principle of minimum rotation; propagation of accidental error.

Calibration of a Set of Master Wedges, D. H. RANK. J Opt Soc Am v36 Feb 1946 p 116–9.

Calibration of a Set of Master Wedges, D. H. RANK. J Opt Soc Am v36 n2 Feb 1946 p 116–9 2 figs. Discusses two methods: (1) telescope and scale and (2) multiple beam method. The latter permits determinations to better than 0.25''. Describes experimental procedures and discusses quality of surfaces, measurement of index of refraction, errors, and comparison of wedges with the Twyman Interferometer.

Standards of Length and Angle for Precision Engineering. H. BARRELL, NPL. Trans. Instrum and Meas Conf, Stockholm, 1947 p 182–90 7 figs. Discusses practical standards of length, measurement of longer distances, practical standards of angle.

Precision Method of Checking 'Compound Angles, J. AHEARN. Machy (NY) v53 n5 Jan 1947 p 178–81. Method involves use of angle block for supporting work piece on sine plate which is elevated to bring compound angle face into horizontal position; steel ball is placed in pocket formed by faces of included angle of angle block and supporting end plate; largest size ball will give most accurate measurements.

A New Theodolite Goniometer. I. R. RAO, and S. V. S. RAO, J Sci Industr Res v6 Dec 1947 p 485–7. The general features, adjustment and method of use, of a universal type of goniometer for measurement of the angles between crystal surfaces is described. The instrument consists of a 6 in diameter horizontal and 5 in diameter vertical scale, both divided in half degrees, together with

verniers and magnifiers enabling readings to one minute; a crystal-holder attached to the centre of the horizontal telescope, with total light from the crystal surface. The telescope has a combination objective so that it can also be used as a low power microscope. A photograph of the assembled instrument is given.

Applications of the Hilger Angle Dekkor, B. P. HARROLD Machy (London) v72 n1848, 1850 Mar 25 and Apr 8 1948 p 391–7, 458–60 27 figs. An instrument intended for measuring and comparing angles. The standard instrument gives readings through an eyepiece to 1' and by estimation to 6''. The large instrument reads directly to 30'' and by estimation to 3''. Comprises a telescope, base, and telescope arm. Numerous accessories and their applications are described.

Alignment Testing, K. J. HUME, Eng. Inspection v13 n4 Winter 1949 p 163–73. Methods in accurate establishment and checking of large dimensions and measurement of deviations from straight line or plane; use of instruments and autocollimators; applicability to testing of machine tools, jigs and fixtures.

Electro-optical Measurement of Angles by a Photometric Method, H. BENDER. Optik v8 n5 1951 p 206–23 in German. A detailed description of the apparatus necessary for surveying operations using i.r. lignt for its greater penetrating properties. The light is detected by a photocell, and the visual alignment of a telescope is replaced by an adjustment similar to a photometric setting. An accuracy of 4'' of arc is claimed under favourable conditions.

Grundlagn der Technischen Winkelmessungen (Fundamentals of angular measurement in industry), K. RAENTSCH, Carl Hanser Verlag, Munich, Germany, 1952. 110 p illus, diagrs, tables, graphs. Publication deals with most useful methods, procedures, and fields of application; describes and discusses German and foreign instruments for both direct and indirect measurement and layout of angles in machine shop work. Eng Soc Library, N.Y.

A New Mirror Multiplier, B. M. LEVIN. Zh Tekh Fiz v22 n1 1952 p 105–10 in Russian. A method is described permitting of raising and varying the sensitivity of autocollimation readings and photo-recording arrangements; this is accomplished through the corresponding selection of angles with the known multiplier having two mirrors.

On the Elimination of Some Errors of Angular Measurement, E. TERRANA. Atti dell' Accademia Nazionale dei Lincei Randiconti della Classe di Scienze Fisiche, Matematiche e Naturali. v12 Mar 1952 p 290–3 in Italian.

Messgeraete fuer 90° Stahlwinkel (Measuring instruments for 90° tool angles), G. BERNDT, K. SCHMIDT. Dresden—Tech Hochschule—Wiss Zeit v3 n3 1953–54 p 397–406. Angle measuring apparatus with precision indicator; determination of angle error.

Construction and Use of Angle Dekkor, B. P. HARROLD. Machy (London) v82 n2104, 2105 Mar 13 1953 p 481–6, Mar 20 p 547–9. New type redesigned by Hilger & Watts for 5, 15, and 30 min of arc, in addition to five original prisms, modified set of angle gages, consisting of gage blocks for 5, 15, and 30 min of arc, in addition to five original prisms, is included; checking of tools and production equipment; setting up precision optical instrument casting; use of Angle Dekkor in fitting shop; testing motions of optical projector workstage.

Reflection Goniometer for Microscope, B. RANKIN. Rev Sci Instrum v24 n5 May 1954 p 496–8. Instrument which measures angles accurately and rapidly under microscope; use of mathematical model to display principles involved; it is shown that accuracy is achieved with "optical lever arm" which moves when eyepiece rotates, being comparable to 25-cm mechanical arm attached to outside of eye-

piece; rapid measurements are possible by reading relative positions of "optical arm" on illuminated scale.

The Calibration of Circular Scales and Precision Polygons, A. H. COOK. Brit J App Phys v5 Oct 1954 p 367–71. The theory of two methods of calibration is discussed and expressions are obtained for the values and standard deviations of the corrections to the nominal values of the angles. Ways of setting out the computations are also given.

Instrument for Direct Measurement of Angles in Field of View of Naked Eye, A. H. BOERDIJK. Rev Sci Instrum v26 n4 Apr 1955 p 382–3. Instrument which contains illuminated scale of which virtual image is formed at infinity by means of spherical mirror and glass plate; image of scale is superimposed on normal field of view of naked eye, enabling direct measurement of angles in that field; applicability to measurement of apparent angles between remote objects such as stars and clouds, halo phenomena, or of apparent angular velocities.

Use of Polarized Light for Measurement of Small Angular Displacements, A. J. BARTLEY. J Sci Instrum v33 n1 Jan 1956 p 20–2. Method of measuring displacements of order of 1 min of arc; features of test system built to determine sensitivity of method; suitability of system for dynamic measurements; recommendations regarding possible future developments; applicability to measurements on shaft which is subject to torque.

Mirror Micrometers, N. BÁRANY. Periodica polytech Elec Eng v2 n3 1958 p 205–27. Some of the known micrometers for measuring small angles and short distances are described above. An attempt was made to replace the 200 years old Boscovich rotating pair of wedges by a mirror micrometer. In the new instrument a mirror micrometer is used as a penta mirror, thus associating the penta mirror with the mode of drive on one hand, the deformation of the mirror mounting owing to changes of temperature on the other. As regards the mode of drive, a gear mechanism can only be applied on a laboratory scale, as it does not give a satisfactory accuracy in the transmission of angles. Therefore, one has to apply other modes of drive. Temperature influences can be felt by the mirror mounting, generally used for penta mirrors too. It is therefore essential to provide for heat insulation, and to resort to the most careful methods of manufacture.

Photoelectric Angular Error Sensors, R. A. NIDEY, D. S. STACEY. Rev Sci Instrum v27 n4 Apr 1958 p 216–8. A technique is described for the accurate measurement of angular errors using photoelectric detectors. Utilizing two types of robust, compact cartridges, a wide range of characteristic curves may be synthesized. Examples of various systems are shown, including one for high-accuracy servo. The latter has coverage of 360 degrees, a null accuracy of one minute and is in current use in Aerobee Rockets.

The Phasolver System for High-Precision Rotational Measurement, E. BURGESS. Data Instrum Div of Telecomputing Corp Mar 1959 29 p 12 figs. A system for digitizing azimuth and elevation shaft positions to a precision to 1 part in 2×10^5.

Use of Radial Gratings in a Small Inclinometer, A. LEWIS, I. R. YOUNG. J Sci Instrum v36 n4 Apr 1959 p 153–7. Some of the factors involved in the choice of gratings for use in the digital measurement of angles are discussed. This problem is accentuated in the case of the instrument described by its small size and the decision, therefore, to use two complete circles for the gratings, instead of the less critical method using one circle and adjustable grating cursors. The tolerances which have to be achieved for satisfactory performance are considered and the instrument itself, a pendulous inclinom-

eter intended to measure the pitch angle of wind tunnel models, is described.

Micrometer Adjustment of Mirrors and Prisms, N. BÁRANY. Periodica Polytech Elec Eng v4 n1 1960 p1–16. The paper gives the geometrical conditions to be satisfied by a rotating mirror or prism in an angle-measuring instrument. In particular the optimum point of rotation is determined. Such mirrors or prisms are commonly rotated by a micrometer screw and cam. The shape of the cam for typical cases is derived and the effect of the shape of the cam-follower considered. A typical mechanical design is described in some detail.

A Method to Detect the Direction of Normal of a Small Flat Surface and Its Practical Application to Measurement of the Profile of Vickers Diamond Pyramid, K. YAMAMOTO. Report of the Central Inspection Institute of Weights and Measures, Japan, v8 n4 rept 20 1960 in Japanese. The direction of a normal of small flat surface, for example the surfaces of Vickers diamond pyramids, cannot be determined accurately by autocollimation, for diffraction effect is produced by the apparent minuteness of the diameter of the collimator lens. Therefore a new apparatus is invented. The apparatus is composed of an ordinary microscope to which a half reflecting mirror and cross hairs graticule are attached. When the graticule is illuminated, its primary image is formed at a point of some distance apart from the object point of the microscope. And when a mirror is so placed that its normal is parallel to the optical axis of the microscope at the middle point between the object point and the primary image point of the cross hairs, the image of the cross hairs is visible through the microscope. The mirror is tilted by a small angle, then the images of the cross hairs are displaced in the view field of the microscope, the displacement is proportional to the tilting angle of the mirror. The performance of the apparatus is studied by introducing the parameters of m (magnification of the objective) and n (magnification between the cross hairs and their primary image). And the following results are obtained: 1) The sensitivity of the measurement Δ can be calculated by the following equation,

$$\Delta = \frac{f(m+1)(m-n)\theta}{n(m+1)} \ (\text{mm})$$

where f: focal distance of the objective (mm)
θ: tilting angle of the mirror (rad)

2) The lower limit of the diameter of a measurable flat surface can be calculated by the following equation,

$$2r = \frac{f(m+1)(m-n)}{m^2(n+1)} \tan \ u \ (\text{mm})$$

where $\sin n$: numerical aperture of the objective

3) An apparatus for inspecting angular accuracy of Vickers diamond pyramid is designed and satisfactory results are obtained.

Checking Squares of Over 500 mm by Simple Devices. V. I. NIKOLAEV. Meas Techns 1959 n6 June 1960 p 412 2 figs. Translated from Izmer Tekh n6 June 1959 p 17. Describes surface plate set-up for checking squares of over 500 mm.

Remote Measurements of Large Displacement Angles, A. D. BARINBERG. Meas Techns 1959 n12 Sept 1960 p 938–9 1 fig 1 ref. Translated from Izmer Tekh n12 Dec 1959 p 12. Proposes a new type of transducer intended for remote measurement of large angular displacements; is based on the use of a transformer whose secondary winding has a smoothly variable transformation ratio.

Measurement of Angle in Engineering, J. C. EVANS, C. O. TAYLERSON. Notes on App Sci n26. NPL. Her

Majesty's Stationery Office 1961. Contents: Systems of units, reference and working standards for use in engineering, auxiliary instruments, calibration of angle standards, engineers' angle measuring machines and instruments, measurement of displacement through measurement of angle, references, appendixes.

Sensitive Method for Measuring Small Rotations of Distant Object, R. J. KING, S. P. MIDDLETON, I. M. G. THOMPSON. J Sci Instrum v38 n5 May 1961 p 207–8. Application of polarimetric system to measurements of relative orientation of 2 units separated by large distance; sensitivity of 0.1 min of arc is easily obtainable, with separation of 2000 ft.

Suggested Arrangement of Mirrors to Form Multiple Reference Angles, J. B. SAUNDERS. J Opt Soc Am v51 n8 Aug 1961 p 859–62. Reference angle to be used as standard for calibrating circular scales with autocollimator or interferometer; angle forms, by successive or multiple reflections, multiplicity of equal optical angles having common vertices.

Analog-to-Digital System for Recording Angular Rotation, S. SHENFELD, H. R. MANKE, E. F. SODERBERG. Automatic Control v15 n4 Oct 1961 p 40–4. Direct-reading data-reduction system, developed at US Navy Underwater Sound Laboratory, provides high order of accuracy in bearing readout at appreciable saving in data-reduction time over that of former systems using analog or photographic recording; system, intended for use in limited types of data-recording applications, permits recording of angular rotation with accuracy of 0.01°.

New Angle-Measuring Table with an Induction Transducer, E. M. GOLOUL'NIKOV, M. I. KOCHENOV, A. YA. PELIKA, V. S. CHAMAN. Meas Techns 1961 n4 Nov 1961 p 270–4 5 figs 1 ref. Translated from Izmer Tekh n4 p 9–13 Apr 1961. Discusses induction methods and describes design of an instrument. This article deals with the qualitative analysis of the degree to which various errors affect the accuracy of the induction angle-measuring device. The value of the accumulated errors in the shaft rotation angles did not exceed 5.3″. These values characterize the systematic errors of an angle-measuring table made without a cam compensator. Random errors in a single measurement of an angle did not exceed 2″. A dividing head with geared rings 180 mm in diameter has been developed and constructed. The measurement errors of this head do not exceed 5″. The rotation angles of this head in the range of 1″ are measured by means of a wedge and screw device graduated in 5″ intervals.

Untersuchung eines Winkelmessgerätes (Investigation of an Angle Measuring Apparatus), R. NOCH. Werkstattstechnik v52 n5 1962 p 249–53.

Instrument Measures Dynamic Accuracies of Gears to 0.05 Second of Arc. Machy (NY) July 1962 p 134. Electro optical instrument used for checking the drift rates of gyros employed in inertial guidance systems.

Raising the Efficiency of Testing Straightness by the Microleveling Method, L. L. MEDYANTSEVA, V. V. GOR-BACHEVA. Meas Techns 1962 n8 Feb 1963 p 646–8 2 figs. Translated from Izmer Tekh n8 Aug 1962 p 22. Recommends a method of measuring linearity by means of a moving microlevel.

Harmonic Drive, a Factor in the Gear Industry. Part I, Principles and Applications, D. L. MANSFIELD. Part II, Harmonic Drive Compared with Gearing, R. L. BEN-FORD. AGMA 109.12 Oct 1962 23 p 31 illus 7 refs. Harmonic drive is not a form of gearing but can be used with supplementary gearing or as a substitute for gearing. It could become a basic laboratory reference for angular position accuracy, allowing rapid calibrations and measurements in place of current mechanical-optical instrumentations.

Application of Precise Angular Measurement in Metrology, A. W. YOUNG. ISA Proc Preprint 2.2.62 for meeting Oct 15–8 1962 6 p. Progress review of methods and instruments for angular measurement.

Voprosy teorii vozdushnykh induktivnykh datchikov ugla s pechatnymi obmotkami (Air inductive angle pickups with printed windings), L. N. SAFONOV. Avtomatika i Telemekhanika v23 n10 Oct 1962 p 1334–42; English translation in Automation & Remote Control v23 n10 Oct 1962 p 1255–62. Theory of inductosyn is presented; formulas for output voltage in terms of angle of rotation and basic parameters of pickup are derived; recommendations are given concerning choice of basic parameters of pickups and power supply.

Use of Solar Radio Emission for Measurement of Radar Angle Errors, J. T. KENNEDY, J. W. ROSSON. Bell System Tech J v41 n6 Nov 1962 p 1799–1812. Method of calibrating angle indicators of radar tracking antenna to true direction of radio line of sight; sun used as primary direction reference; technique accounts for displacement of "radio center" of sun.

The Testing of Cylindrical Squares, J. C. MOODY. SCR–612 Feb 1963 14 p 10 figs. Publ by Sandia Corp., Albuquerque, N. Mex. Describes the equipment required and the procedure used to test the straightness and perpendicularity of the reference lines and the parallelism of the straight lines formed by joining the end stations. Presented at the 18th Annual Meeting of the Standards and Metrology Division, American Ordnance Association.

Measurement of Internal Angles in "Dovetail" Type Prisms, V. YA. ÉIDINOV. Meas Techns 1962 n 11 June 1963 p 914 1 fig. Translated from Izmer Tekh n11 p 18 Nov 1962. Describes method using accurate measuring rolls.

Optical Methods of Measuring Angle, A. W. YOUNG. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 614–8. Published by ASME. State of art of optics in angular measurement is reviewed together with typical solutions and their limitations.

Measurement of Angle in Engineering, J. C. EVANS, C. O. TAYLERSON, Great Britain. Nat Phys Laboratory—Notes on Applied Science n 26 1964 32 p. Review is presented of developments and current practice in angle measurement, including units of measurement, standards, auxiliary instruments, and calibration of angle standards; angle measuring machines and instruments are reviewed, including rotary tables, dividing heads, precision levels, "Talyvel" electronic level, sine-bars, clinometers, Watts circular division testers, Baty "Sinometer", and bevel protractors.

A Simulated OAO Fine Optic Error Sensor, M. I. BAKER. Tech Paper n6 presented to Radio Stand Lab NBS Apr 7 1964 14 p 8 figs. The fine optic sensor is an angle transducer designed to provide the time pointing error signal to the Orbiting Astronomical Observatory control system. Calibration is limited to the readily available goniometric standards in the 0.1 to 0.01 arc second region. The author suggests that a device similar to this might provide a secondary standard which, because of its simplicity of construction and operation, would actually be a "readily available" standard.

6.2. Alinement, Straightness, and Autocollimators

Optical Testing of Linearity, G. LIPPMANN. CR Acad Sci v134 Jan 6 1902 p 17–8. A movable carrier is guided by the sliding base or scale whose rectilinearity is to be tested. A lens is carried in this way to various points, and by it is viewed another coaxial lens fixed in position. The parallelism of the carrier in all positions indicates the rectilinearity required.

Straightness Test for Beds of Machines, Edges, etc., AT-WELL. Eng v100 July 23 1915 p 92. A straight edge or bar is supported on the bed by two gage blocks differing in height 0.01 in, mounted at the same distance from either end of the bed. Other gages differing by small steps are slipped into this space and their spacing is noted. Operation is repeated with bar turned over and thickness variations in bar are also determined.

Das Autokollimationsablesefernrohr (Autocollimation Telescope), G. GELHOFF. Zeit für tech Phys v3 n6 1922 p 225–8. Detailed description of the design of the instrument.

A New Autocollimator, F. E. WRIGHT. J Opt Soc Am v9 Aug 1924 p 187–8 1 fig. Experience has shown that in autocollimation more accurate settings can be made if the two fields are not superimposed but, as in the range finder of the coincident, self-contained type they are placed side by side in contact. In the autocollimator described this factor has been taken into account.

The Determination of the Parallelism of the Measuring Surfaces of Measuring Tools, G. BERNDT. Instrum v1 June 1928 p 263–70 12 figs. Description of various types of devices and instruments with two plane surfaces facing each other for measuring length such as vernier calipers, amplifying gages, dial gages, measuring machines, and micrometers; methods of determining parallelism of measuring surfaces; advantages and disadvantages of different types for different purposes. Contains a detailed description of the application of the auto-collimating telescope to determination of parallelism and the measurement of angles.

Ein Optischer Flucht- und Fuehrungspruefer (Optical equipment for measurements of proper alignment of guides). Maschinenbau v13 n9–10 May 1934 p 265–6. Detailed description of equipment developed by Zeiss, Jena.

Visierorrichtung fuer das Ausrichten von Lagern (Sighting equipment for alignment of bearings), W. FRANK-ZENBURG. Werkstattstechnik und Werksleiter v32 n20 Oct 15 1938 p 451–3. Details of equipment.

Alignment projectors and the precision measurement of angles, C. DÉVÉ. L'Optique (Rev Opt Théor Instrum) v20 1941 p 115–48. See 6.1 for abstract.

A Multi-Purpose Collimator, R. J. BRACEY. Proc Phys Soc London v55 May 1943 p 182–8. The collimator consists of an achromatic object glass with a graticule placed in its focal plane, the graticule having divisions 1/10 and 1/100 of the equiv. focal length of the object glass. Additional features are (1) that about ¾ along the tube from the object glass a half-silvered prism is fitted, with an additional eyepiece mounted at rt.a. The introduction of this prism causes the focal plane of the object glass to be displaced, and (2) in this new focal plane is placed a removable cell containing a stainless-steel mirror with a circular pinhole at its centre. This provides an artificial star, but its main function is to turn the collimator into a spherometer, when supplementary lenses are mounted in front of the collimator, thus bringing the parallel beam to a focus. Details are given of the method of using such a collimator for measuring (1) radii of curvature of lens surfaces, (2) the equivalent focal length of a positive lens,

(3) the back focal length of pos. or neg. lenses, (4) certain prism angles ($\pi/4$ and $\pi/6$), for interferometric tests of plates for parallelism.

Precision Measurement. Automobile Engr v34 n449 May 1944 p 208–10; Machy (London) v64 n1651 June 1 1944 p 608–12. Precision optical instrument developed by Adam Hilger Ltd has primary function of checking angular relationship of plane surfaces; three models described.

A Method for Precision Alignments, A. C. S. VAN HEEL. J Opt Soc Am v36 Apr 1946 p 242–3. In aligning three points, one point being midway between two end points separated by 30 to 50 m, an attempt was made to use the diffraction max. and min. on the outside of the geometrical shadow of a straight edge. A precision of the order of 0.1 mm was thus obtained. A second attempt substituted a double slit for the straight edge and in this case a precision of the order of 0.01 mm was obtained. The suggestion is made that the method could be used for the determination of the deviations of machine parts, lathe beds, etc.

Precision of Telescope Pointing for Outdoor Targets, F. E. WASHER, H. B. WILLIAMS. J Res NBS v36 May 1946 p 479–88 4 figs 3 refs; J Opt Soc Am v36 n7 July 1946 p 400–11 22 refs. The probable error of a single pointing (PE_s) is measured for a single telescope with a variety of targets. This investigation shows that, although some change in PE_s with distance does occur, the distribution of PE_s as a function of distance can usually be neglected and a value of 0.62 second assigned as a practical average. The values of PE_s for an indoor target usually show a small variation from one experienced observer to another, and from right to left eye of the same observer. There is also a measurable systematic difference in pointing between the right eye and the left eye of the same observer. In outdoor pointing, a long-period error or drift is usually superposed upon the short-period errors.

Appareillages transportables pour l'étude des très petits Deplacements angulaires d'Ouvrages d'Art (Portable apparatus for study of very small angular displacements for structures, machinery framework, etc.), P. FLEURY, E. PERRIN. Tech Mod v39 n11–12 June 1–15 1947 p 185–8. Regulation and application of recording apparatus with concave mirrors and of indicating apparatus with plane mirror and autocollimatic lens; measurements can be made with accuracy of some arc seconds.

Effect of Magnification on the Precision of Indoor Telescope Pointing, F. E. WASHER. J Res NBS v39 Aug 1947 p 163–71 4 figs 13 refs RP 1820. Derives formula for the relation between the probable error of a single pointing and magnification under specified conditions.

Collimators and Autocollimators for Workshop Control, J. G. VOGL. Tekn Tidskr v77 Sept 6 1947 p 655–8 in Swedish. Describes various applications and special adaptations.

Influence of the Atmosphere upon the Precision of Telescope Pointing, F. E. WASHER, L. W. SCOTT. J Res NBS v39 Oct 1947 p 297–302 3 figs 3 refs. The probable error of a single pointing (PE_s) was measured under conditions such that the effect of the air column intervening between observer and target was introduced or eliminated at will. The substantial reduction in PE_s for the air-column-eliminated method as compared with the air-column-present method showed that precision in outdoor pointing is definitely limited by the air column. Some approximate computations were made to show that the value of PE_s cannot be appreciably reduced by increasing the magnification of the telescope above 20.

Auto-Collimator and Its Applications. Machy (London) v71 n1830 Nov 20 1947 p 568–70. Features of microptic

(E. R. Watts & Son) auto-collimator designed to measure small angular deflections to fraction of second of arc; set up procedure; applications in engineering and scientific work, particularly in measurement of parallelism, squareness, and alignment.

The Auto-Collimating Telescope; Principle, Design, Application, C. B. KEANE. Inspection Gage Sub-Office, U.S. Army Ordnance 10 p.

Optical Testing of Straight Slideways, J. TERRIEN, T. MOREAU. Microtecnic v2 n1 Feb 1948 p 13–20. Comparison of several methods of measuring vertical deviations of straight slideways of precision comparator bed; use of autocollimator furnishing tilt angles of carriage resting on slideways, Koesters double prism, duplicate image instrument, and optical straightness tester made by Société Jobin and Yvon.

Measure-Scope System of Instrumentation for Precise Physical Measurement. American Instrument Co. Bul 216 Apr 1948 15 p 27 figs. Embodies an autocollimating telescope as sensing element. Basically an angle measuring device to within 1 arc second. Discusses measurement of parallelism, comparison of angles, measurement of straightness of large flat surfaces, hole direction, true level, etc. Detailed description of Tuckerman autocollimator.

Reviewing Auto-Collimator Practice, H. ROCKWELL. Mach April 17 and 24 1948. Principles are outlined with descriptions of practical applications.

Autokollimations-Spiegelablesung (Autocollimation Telescope), H. FREISE. Archiv fuer Techn Messen n155 June 1948 p T75 2p. Sensitive autocollimating telescope for measuring small angles; telescope is combined with mirror galvanometer for physical and chemical research; illustrations.

Mirror Readings by Autocollimation, H. FREISE. Archiv fuer tech Messen Issue 155 (Ref. J1112–1) T75 June 1948 in German. Description of an autocollimating telescope arranged to read angular displacements of mirrors.

Optical Alignment. Aircraft Prod v10 n117 July 1948 p 241–2. Details of two new instruments developed by Hilger & Watts, Ltd.; these are alignment telescope and auto-collimator; alignments or deviation from alignment are measurable in angular terms with auto-collimator, and in linear terms with alignment telescope.

Some Practical Applications of Precision Alignment Method, A. C. S. VAN HEEL. App Sci Res vB1 n4 1949 p 306–24. Alignment method makes use of single slit, double slit, and cross wire with eyepiece; by making pointings on transition colors in interferences pattern, precision attained is of order of 0.1 sec. of arc or 0.01 mm in transverse deviation for distances of from 3 to 60 m; use of method in construction of large steel bridge and in measuring deflection of reinforced concrete beam.

An Optical Device Facilitating Accurate Alinement, R. H. BROCKMANN. J Sci Instrum Phys Ind v26 July 1949 p 231–3. A device combining the angle-measuring properties of an auto-collimating telescope with that of lateral displacement indication is described. Both the measurements may be made at the same time; the method is essentially a development of the process for centering lenses prior to "edging."

Auto-Collimator for Precision Inspection. Tool & Die J v15 n7 Oct 1949 p 80. Watts Microptic Autocollimator, designed to measure slight angular deflections to fraction of second of arc; two applications illustrated.

Light Rays Can Be Tools, A. P. FULTZ. Tool & Die J v15 n7 Oct 1949 p 64, 66, 68, 70–1. Description of auto-

collimator; inspection setup for checking parallelism of end faces of flanged tube and for measuring angular relationship between two bearing surfaces and ends of tubes; operation of combined autocollimator and aligning telescope used to align three bearings over four foot spread described.

High Precision Measurements with Simple Equipment, A. C. S. VAN HEEL. J Opt Soc Am v40 n12 Dec 1950 p 809–16. Method of obtaining precise alignment using single slit, double slit, and cross wires placed respectively at points to be aligned; precision of at least 0.17 in. attained when use is made of pointings on transition colors in interference pattern; applications for measuring sag of loaded bar, flatness of surface, position of bridge members during construction and alignment of ships' propeller shafts.

Interferometric Alignment Set, P. W. HARRISON. Machy (London) v84 n2164 May 7 1954 p 976–9, 984; Engr v197 n5128 May 7 1954 p 670–1. Investigation by National Physical Laboratory in connection with new precision alignment method developed several years ago by A. C. S. Van Heel: Principle of optical method employed; tests conducted for examining variable factors likely to influence performance; design details of alignment set constructed by NPL; performance checkers, with regard to accuracy of repetition and of alignment; possible applications.

Accurate Alignment Over Long Distance, P. W. HARRISON. Eng v177 n4608 May 12 1954 p 654–5. Investigation carried out by National Physical Laboratory of precision method suitable for use by engineers, surveyors, and others, originally described by A. C. S. van Heel (see Engineering Index 1949 p. 694); interferometry ensures 0.0005 in. over 18 ft; optical and mechanical design; performance and applications. Communication from Nat Physical Laboratory.

Principles and Applications of Alignment Telescopes, A. METZ. Instrum & Automat v27 n10 Oct 1954 p 1634–5. Special telescopic instruments useful for leveling benches and bedplates, for testing perpendicularity of machine tool guides, or aligning bearings, etc.; method of using alignment telescope in testing guideway of machine tool or lathe bed.

Alignment Testing, K. S. HUME. Engis Equipment Co. 1955 8 p.

Line of Sight Replaces Squares, Levels, Straight Edges in Holding Tolerances on Large Work Pieces at Moore Dry Dock, C. J. ALCIATI. Western Metals v13 n2 Feb 1955 p 78–9. Details of measuring instruments employed in production of welded workholding fixture for milling machines; how optical tools are used in measurements for checking alignment.

Toepassingsmogelijkheden van een precisie-aligneermethode, J. G. DOEKES, W. DE BRUIN. Ingenieur v67 n10 Mar 11 1955 p 043–6. Precision alignment method developed by A. C. S. van Heel permits three points to be put in straight line with accuracy of order of 0.2 sec of arc for distances up to 50 meters or more; explanation of principle, description of applications of method, especially of aligning of machine tools; method is compared with water level and autocollimation methods.

Telescope Cuts Inspection Time, J. SEDORIC. Am Mach v99 n6 Mar 14 1955 p 122–3. Large diesel and pump bores, machine tool ways, and big surface plate checked with $32\times$ magnification Leitz alignment telescope focusable with rack and pinion adjustment between 40 in. and 164 ft; instrument has micrometer attachment reading to 0.001 in. for measurements in vertical and horizontal planes; illustrated examples.

Optical Tooling—New Equipment and Techniques Broaden Use, W. L. EGY. Tool Engr v34 n4 Apr 1955 p 86–91. Use of optical tooling for making precise measurements for automotive, machining and lofting work; alignment telescopes employed to form basic reference line, and jig transits or optical transit squares to set up planes perpendicular to base line; accessory tools, such as micrometers, for still greater accuracy, measurements made in all three-dimensional planes by adding precision levels to two-dimension system.

Optical Tooling. Aircraft Prod v17 n8 Aug 1955 p 304–10. One great advantage claimed for optical methods to check alignment of engineering assemblies is that greater accuracy can be achieved over larger distances, more easily and quickly; details of techniques now used and developments in individual items.

Auto-Collimator Quickly Measures Small Angular Differences, J. C. MOODY. Am Mach v99 n20 Sept 26 1955 p 124–5. Industrial use of autocollimator or autocollimating telescope; rotational lag of synchro system was determined in 30 min by comparing displacement of polygonal surfaces; observational error amounted to only plus or minus 10 sec of arc.

Optical Trueing of Lathes Saves Time, E. B. BROWN. Tool Engr v35 n5 Nov 1955 p 75–8. Alignment telescope, being combined sighting telescope and autocollimator, determines alignment of ways of lathe to accuracy of plus or minus 2 sec of arc and measures lack of straightness to 0.001 in. or finer; checking operations.

How to Use Optical Tooling, Methods, E. B. BROWN. Tool Engr v36 n2 Feb 1956 p 93–8. Optical methods applied in construction of large jig, for example, can obviate need for angle plates, master squares, etc; fundamental principle of optical tooling is that ray of light is accepted definition of straight line; alignment telescopes, procedure for establishing jig fittings along basic reference line by using tooling bar; simplicity and accuracy of optical tooling methods for locating and positioning over long distances and large areas.

Aligning Large Machines with Optical Tooling, H. H. POETT. Tool Engr v36 n3 Mar 1956 p 100–3. Use of alignment telescope for setting beds of spar mills, planers and skin mills; setting columns or points at exact right angles; setting given points exactly opposite point and perpendicular to line; other applications of optical equipment.

Optical Tooling, A. R. PAOLI. Western Machy & Steel Wld v47 n4, 5, 6 Apr 1956 p 106–8, May p 84–6, June p 83–5. Apr: Definition of optical tooling and its application for aligning generator bearings and shafts, checking surface plates and tooling bars for straightness, etc. May: Basic and accessory tools of optical tooling, and step-by-step procedure for installation of large planer. June: Versatile alignment telescope; its functions and attachments; how it is used in installing turbine generator.

Telescope-mirror Alignment Method, H. SCHULTZ. Power v100 n12 Dec 1956 p 117–9. Optical device for detecting bearing misalignment within thousandths of inch in hot machines that are running and under full load; comparison of this "hot" alignment method with cold alignment; results obtained with hot alignment as applied to large turbine generator units; use of Keuffel & Esser "tilting dumpy" level.

Projection System Developed for Optical Instrument Inspection and Calibration, E. J. BARNET. Automotive Indus v116 n11 June 1 1957 p 64–8. Method evolved at Convair Div. of General Dynamics Corp. permits greatly enlarged image of focal plane of instrument being adjusted to be projected upon screen; projection system depends upon powerful light source projected through very accurate and leveled collimator; basic setup for alignment; procedure and instructions; tilt level, optical micrometer, and alignment telescope calibration.

Optical Tooling: Short Cut of Accurate Alignment, W. CZYGAN. Iron Age v180 n18 Oct 31 1957 p 63–5. Numerous applications of optical tooling which is widely used to align and level long machinery beds; locating airframe parts in large jigs and fixtures, alignment of bearings, spindles, drive assemblies, etc., and closer control of angular and linear tolerances with optical tooling; use of alignment telescope, optical square, jig transit, optical level, and precision targets or scales described.

Making Precision Measurements with Optical Tools, J. C. MOODY, J. M. BUNCH. Tool Engr v40 n2 Feb 1958 p 83–91. How autocollimation and geometry can be applied in shop and laboratory; principle of autocollimator; optical square tested by means of two mirrors and autocollimator; checking 12-sided optical polygon; setup for testing Dowell prism; checking straightedge; example of calibrating $10°$ index stations of aerial plotting camera; setup for testing parallelism of pads.

How to Recalibrate Optical Tooling Devices, R. LE GRAND. Am Mach v102 n3 Feb 10 1958 p 108–12. Compact test stand for recalibration of jig transits, alignment telescopes, precision levels and optical squares developed by Keuffel & Esser Co., Hoboken, NJ; method saves time and produces accurate results; optical tooling devices are used to check alignment, levelness and squareness of components of aircraft jigs and machinery.

Optical Tooling and Its Uses in Industrial Plants, J. I. HANOLD, H. R. OSMICK. ASME—Paper n58-MPE-2 for meeting Apr 14–15 1958 11 p. Development and principles of instruments and accessories designed and built around optical lines of sight and industrial applications of optical tooling; benefits derived from application of optical tools to alignment of production equipment are better alignment, reduced alignment costs, improved operation and reduced maintenance.

Optics Gain as Aircraft Tooling Aid, J. D. WOMACK. Western Metalworking v16 n9 Sept 1958 p 55–7. Description of sight level, transit, alignment telescope, and optical square used in optical measurement, alignment and positioning; optical tooling operations made possible by these devices; alignment of jigs in aircraft production line; other examples.

The Adjustment of the Orientation of a Plane Surface by an Auto-Collimation Method, H. JURICIC. Rev Opt v38 n4 p 202–4 Apr 1959 in French. In setting up specimens for the measurement of reflection coefficient with a monochromator as a light source, it may be difficult to determine the normal by the standard auto-collimation technique. A modified method is described which does not require the reflected beam to be found within the monochromator. An auxiliary optical system is used, with a $45°$ semi-reflecting mirror to produce a second beam. Practical details are given.

The Measurement of Angles, K. W. BRITTAN, K. J. HABELL. NPL, Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 141–7 3 figs 3 refs. A brief survey of existing methods. The high accuracy attainable with interference comparators is discussed. Reports progress aimed at achieving comparable accuracy in absolute measurements with an automatic (continuously recording) goniometer.

Circular Diffraction Gratings as Alignment Devices, J. DYSON. Optics and Metrology, P. MOLLET. Pergamon Press 1960 p 169–71 1 fig. Methods for measuring straightness using diffraction gratings of which the rulings are

concentric circles. Cross-hairs can be set on an interference pattern with great accuracies over a considerable range of distances. Accuracy of setting approach 1 μ over distances up to 6 m.

Alignment in Autocollimation, A. C. S. VAN HEEL. Optics in Metrology, P. MOLLET. Pergamon Press 1960 p 420–5 2 figs 7 refs. Apparatus for alinement of points at distances up to 100 meters. Front lens of collimator is provided with a ring system giving a diffraction pattern consisting of rings and allowing very precise settings. Overall precision is about 0.4 sec.

Optical Lineup Shortcut to Tooling Precision, L. E. BATCHELOR. Am Mach/Metalworking Mfg v104 n4 Feb 22 1960 p 97–9. Optical tooling programs developed by aircraft industry are readily adaptable throughout metalworking industry; examples of saving achieved by Allison Div. of GM in checking gear boxes and aligning gun drill; how four basic optical checking instruments are employed.

Modern Alignment Devices, A. C. S. VAN HEEL. Progr in Optics v1 1961 p 289–329 26 refs. Review of work mainly by the author and his co-workers on non-image-forming alignment systems, in which a straight line is produced as the axis of a diffraction pattern in space.

A Two-Channel, Recording Autocollimator, L. R. BAKER. Opt Instrum Conf London 1961 p 212–20. A visual path enables this instrument to be used as a conventional auto-collimator for setting-up purposes, whilst an electronic system operated in parallel with it records simultaneously angular movements of the plane mirror about two axes at right angles. For convenience of operation the instrument is provided with three ranges of full scale deflection which are, 0±2½ minutes of arc, 0±20 seconds and 0±2 seconds of arc. The instrument employs a light source modulated at 400 c/s and a S.I.R.A. position-sensitive photocell. An open loop system was required initially, and so there is provision for displacing the light beam by a known amount for the calibration of gain and linearity of the complete instrument. The loop may be closed if required by the addition of a simple a.c. servo system.

An Alignment Telescope of Which the Direction of the Pointing Axis Is Defined by the Normal to a Fixed Surface, K. HILDEBRAND. Optik (Germany) v18 n10–11 p 547–8 1961 in German. The target is fixed at the real principal plane of the objective; it, together with its image in a fixed plane mirror, defines the direction of the pointing axis as perpendicular to the mirror. The telescope is focussed by moving the objective and target together.

Testing the Straightness of Lines and the Flatness of Surfaces, A. C. S. VAN HEEL, J. D. DE VEER. Opt Instrum Conf London 1961 p 383–405. By making use of conventional optical parts, alignment and the flatness of surface can be tested to within a few tenths of a second of arc by making use of spherical aberration and diffraction. The range in some cases is several hundreds of metres, and the brightness of the diffraction pattern is high enough for observation in daylight. Only flat and spherical surfaces are needed. The most simple form to test alignment is a sphere with a cap of the same material of very good homogeneity. A concave spherical mirror and a flat mirror were used in combination, in order to obviate the stringent requirement of homogeneity of the glass. Though the sphere with cap can be used also to test the flatness of surfaces, other means are more efficient. In the first place one spherical mirror with one minute light source (of white light) suffices to test the flatness up to distances of, say, 20 meters with a precision below one second of arc. By combining a concave and a convex spherical mirror, precision can be lowered to a few tenths of a second of arc, while the observation distance

is enlarged. The working of the mirrors is based on the forming of (colourless) "rainbow," a fact that is perhaps not well known. The diffraction pattern associated with these rainbows (Airy's fringes) makes it possible to attain the mentioned precision. Much time was given to testing the straightness of the line produced by the apparatus by independent means, a difficult process seldom applied by other workers.

Optische precisiemetingen op civiel en werktuigkundig gebied in de praktijk, S. H. LIEM. Ingenieur v73 n8 Feb 24 1961 p 033–42. Optical precision measurements in civil and mechanical engineering; precision alignment methods developed by Van Heel, which permit three points to be put in straight line with accuracy better than 0.2 second of arc, appear to be practical, accurate and simple; optical instrument for measurements on experimental runways at Schiphol airport described.

High-Precision Pointing, A. MARÉCHAL. J Opt Soc Am v51 n4 Apr 1961 p 396–8. Two methods permitting high-precision pointing (image location) have recently been developed by members of the staff of the Institut d'Optique. The method of Simon for high precision in longitudinal positioning is based on the use of two identical grids, longitudinally separated, one forward and one back of the object point. The position is determined by observing the equality of contrast of the out-of-focus images of the grids. The method of Arnulf and Duppuy for lateral pointing is based on the formation of a system of interference fringes by light from a double slit illuminated by light from a single slit. By placing the entrance pupil of a telescope on a dark fringe, the image of the slits, though very dim, reveals and amplifies any irregularities in the edges of the slits even though the irregularities are very small. If the two slits are separated only by a fine line, the lateral position of this line can be located with high precision.

Optical Alignment Devices Based on a Two Mirror System, J. DYSON. Optica Acta (Int) v8 n3 July 1961 p 217–31. The requirements to be satisfied by an optical alignment system are indicated, and a two-mirror system is described. The elementary form of this is restricted in its field of application, but it can be converted into a very sensitive interferometer for toolroom or laboratory use. Its errors and coherence conditions are examined. Modifications of the simple system suitable for more practical conditions are described, and their errors are investigated. It is shown that very high accuracies can be obtained without excessive demands on the optical workmanship. The effects of atmospheric irregularities are indicated, and test results are described briefly.

Suggested Arrangement of Mirrors to Form Multiple Reference Angles, J. B. SAUNDERS. J Opt Soc Am v51 n8 Aug 1961 p 859–62. A reference angle is described that forms, by successive or multiple reflections, a multiplicity of equal optical angles having common vertices. This angle may be used as a standard for calibrating circular scales either with an autocollimator or an interferometer. The angle can be adjusted in an interferometer to a very high accuracy. If the faces of the mirrors are 6 in. long, an error of 0.1 fringe corresponds to an error in the angle of 0.02 sec of arc.

Photelectric Angle Sensor, Electromechanical Components & Syst Design v5 n11 Nov 1961 p 12–8. Principles of Refractosyn system, manufactured by H. H. Controls, Burlington, Mass., using two photocells to sense balance of energy refracted through glass prism, as angle of incidence of light beam to face of prism deviates from critical angle; system can be used with various instruments and measures angles down to 0.05 sec. of arc, drifts less than 1 sec. in 10 days.

An Alignment Interferometer for Precision Straightness-Measurements and Control Even of Rapidly Moving Car-

riages, G. W. STROKE. J Opt Soc Am v51 n12 Dec 1961 p 1340–1. A new, easily adjusted and very stable interferometer, defining a semistatic fringe field by reflection on two mirrors, has permitted a simple solution to the problem of rapid and accurate alignment of moving carriages, of fixed reference beams, and of carriage-ways in the interferometric domain. Precisions in the 0.1 sec-of-arc range are easily obtained in visual work in rotations up to minutes of arc, without the usual limitations of slow fringe counting and of loss of fringe-contrast at large path differences in particular. In fact, the fringe-constant is independent of the distance from the reference-support to the moving mirrors in this interferometer, and permits measurements and alignments over traverses and distances of many feet if required. Precisions in the 0.01 sec-of-arc range and better can be obtained with the help of electronic location of interference fringes. Experiments with carriages moving at rates up to 1 ft/sec and over distances of the order of 1½ ft have demonstrated the versatility of the alignment interferometer in various applications, in particular in the alignment of ways on a velocity-of-light apparatus and on ruling engines.

Accurate Alignment. Aircraft Prod v24 n2 Feb 1962 p 38–40. Optical instrument based upon circular diffraction grating made by Cooke, Troughton and Simms, Ltd., comprises sighting head and target unit, which contains diffraction grating itself in adjustable mount; accuracy of 0.0001 in. (0.00025 mm) can be achieved in definition of straight line over distance of 20 ft (6096 mm); characteristics of grating; establishing alignment and vertical alignment.

Optical Properties of Conic Surfaces. I. Reflecting Cone, S. FUJIWARA. J Opt Soc Am v52 n3 p 287–92 Mar 1962. The optical properties of a reflecting cone, which have acquired fresh importance in connection with alignment measurements, are treated on the basis of Huygen's principle. Approximate expressions for the intensity distributions in diffraction images of an axial point source and an off-axis one are derived by the stationary phase method. The results of the calculation are found to be in good agreement with the photographs of images made by an actual reflecting cone.

New Optical Methods of Precision Alignment (Straight Lines and Flat Surfaces), A. C. S. VAN HEEL. Soc Instrum Technol Trans v14 n4 Dec 1962 p 270. Growing need for precision in civil and mechanical engineering and in shipbuilding, when putting 3 points on a straight line; review of methods useful in practice; novel instrument described enables observer to determine deviations from perfect plane with precision; instrument is applicable for distances from 1 or 2 up to more than 100 m, observations being made in daylight; by slight modification, distances from decimeter to about 10 m can be served.

Applications of Setting Heavy Equipment, H. R. OSMICK. ASTME Creative Mfg Seminars Tech Paper SP63–108 1963 10 p. In 180° rotation method developed by du Pont for setting and aligning heavy equipment, optical telescope and target is attached to shaft; readings are taken at 0 and 180° and averaged to establish reference sight line or plane; application of this method for installation of machine tools, multiple roll machines and 3 component in-line drives (motor, magnetic coupling and gear box) is discussed.

Use of Optical Tooling in Installation of Capital Equipment, W. M. SMITH. ASTME Creative Mfg Seminars Tech Paper SP63–122 Feb 1963 6 p. Methods of procedures employed by R. J. Reynolds Tobacco Co for performing alignment requirements; examples of optical alignment of printing presses, large drying drum and sole plates.

Optische Fluchtungspruefung, R. SCHULZE. Archiv fuer Tech Messen n325, 327 Feb 1963 p 37–40, Apr p 89–92 20

refs. Optical alignment measurements; basic principles of alignment measurements are reviewed and description given of some instruments used.

Point Target Autocollimator, J. E. TAYLOR. Rev Sci Instrum (USA) v34 n2 Feb 1963 p 188. A simple, high sensitivity autocollimation system uses the tip of an optical transmitting glass fibre as a self-illuminated target. Practical details are given of a system having 3 seconds of arc resolution. Greater resolutions can be obtained with more elaborate reading methods.

Alignment and Measurement Techniques Using Electronic Levels, J. M. MILLER. ASTME Creative Mfg Seminars Tech Paper SP63–96 Feb 1963 9 p. Attempts made by Grumman Aircraft Engineering Corp. to apply electronic level to dynamic measurement situations, aiming to decrease effort and cost in performing periodic checks on machine tools; types of electronic level transducers employed for bearing race alignment and checking surface tables and other pieces of machine tool equipment; results of dynamic measurements described are significant, but inconclusive.

Economics of Establishing Optical Tooling Group in Small to Medium Sized Manufacturing Firm, A. W. YOUNG. ASTME Creative Mfg Seminars Tech Paper SP63–100 Feb 1963 6 p. Optical tooling requirements; examples of aligning drying rolls in paper company with micro-alignment telescope and target, and of using autocollimator on large boring mill in machine shop for solving bearing problems; other applications and costs of instruments discussed.

Raising the Efficiency of Testing Straightness by the Microleveling Method, L. L. MEDYANTSEVA, V. V. GORBACHEVA. Meas Techns 1962 n8 Feb 1963 p 646–8 2 figs. Translated from Izmer Tekh n8 p 22–3 Aug 1962. Describes and recommends method of measuring linearity by means of a moving microlevel for use in factory testing.

Optics in Manufacturing, P. KISSAM. ASTME Creative Mfg Seminars Tech Paper SP63–103 Feb 1963 26 p. Why and how optical tooling is capable of developing high accuracy it attains; reasons for this high accuracy are analyzed; how elements that create this accuracy are embodied in some of standard types of optical tooling equipment; applications are not discussed; in addition to materially reducing costs both in down-time on work and in making measurements themselves, optical tooling often can be used to meet rigid tolerances that cannot be successfully handled by other means.

Testing Straightness of 40-inch Ways to ±3 Microinches, E. G. LOEWEN, B. L. BARLOW. ASTME Creative Mfg Seminars Tech Paper SP63–92 Feb 1963 10 p. Design of new precision ruling engine at Bausch & Lomb called for pair of machine ways 4 ft. long, which had to be straight within 20 μin. over 40-in. segment of length; measuring system capable of detecting surface displacements of 2 μin. or less was required; Davidson Optronics Model D–665 Automatic Autocollimator was selected for inspection; lapping of ways; direct recorder of surface profile; results given; advantages of surface inspection technique described over conventional methods.

A Novel Prism for Total Reflection, A. N. DE JONG. Optica Acta (Int) v10 n2 Apr 1963 p 115–9. For purposes of autocollimation alignment a reflection prism was developed with certain advantages over the triple mirror (corner-cube). Not only is the parallelism of the incident and emergent rays (travelling in opposite directions) independent of the orientation of the prism, but it is also possible to conserve the state of polarization much better. This makes the prism useful for the determination of the optical thickness of thin layers in vacuo by Savart's plates in autocollimation. Some advantages and disadvantages are discussed.

A New Method for the Experimental Investigation of the Position of the Line of Sight for an Optical Telescope System, K. KAROVIČ, J. BOLF, L. KUBÁČEK. Optik (Germany) v20 n5 May 1963 p 259–74 in German. A method for determining the sighting precision of a theodolite is given.

Rapid Testing of Maximum Straightness Ways, E. G. LOEWEN. Stand and Metrology Div, AOA, May 16 1963. Evaluation of direct optical and indirect straightness measurement methods.

Concerning Several Basic Relationships in Telescope Observation, H. KOEHLER. Reprint from Zeiss-Werkzeitschrift v17. Discuss basic function, magnification, brightness of image, and telescope efficiency. Seven literature references.

Angular Alignment Mechanism, J. P. GOLDSBOROUGH. Rev Sci Instrum (USA) v34 n7 July 1963 p 806. A device is described for making small variation in the angular alignment of optical components to an accuracy of about 0.01''. Its operation depends on elastic deformation, and two orthogonal axes of rotation are provided. A suggested use is for adjusting the mirrors in a Fabry-Perot type laser.

Engineering Applications of Rodolite, R. J. TILLEN. Prod Engr v42 n8 Aug 1963 p 462–78, 491. Tests of reflection and mercury Rodolite, featuring equipment that is based on optical properties of circular diffraction gratings which consist of series of equally spaced concentric rings; principles of instrument to define straight optical line; use of reflection Rodolite to measure errors in rotation; use of mercury Rodolite to measure crosswind (roll) in vertical guideways; yaw and pitch measurements using device as autocollimator.

An Alignment Interferometer, J. B. SAUNDERS. J Res NBS v67C n4 Dec 1963 p307–9 7 figs. Describes a diverging-beam type of alignment interferometer that permits the use of large apertures, provides ruggedness, high sensitivity, and is relatively compact. Since this interferometer is fully compensated, white light can be used. The narrowness of the zero order fringe, relative to separation of fringes, in such a well compensated system permits settings to better than one twentieth of a fringe width. This corresponds to a lateral displacement of the light source of less than 1.5 mm at a distance of one mile for a one-inch aperture instrument and to less than 0.15 mm for a 10-inch aperture instrument. Its performance, because of its high sensitivity, is severely affected by the homogeneity of the atmosphere or medium through which the light passes. However, this effect is also greatly reduced by the proximity of any two interfering rays of light.

Autocollimator with Photoelectric Display, G. A. LENKOVA, A. I. LOKHMATOV, V. I. SOSNOVSKII. Meas Techns 1963 n8 Feb 1964 p 656–7 2 figs 4 refs. Translated from Izmer Tekh n8 p 20–1 Aug 1963. Measurements are recorded by a photoelectric method based on the properties of a double rectifier photocell, which obviates use of a vibrator.

Electrical Read-Out from Optical Alignment Devices, J. DYSON, P. J. W. NOBLE. J Sci Instruments v41 n5 May 1964 p 311–6. Three methods are described of obtaining, from 2 types of alignment devices, electric output which represents, in sense and magnitude, error of alignment; output can be used to operate recording or indicating meter for convenience, or if measuring head is in inaccessible position; in some cases it can also be used as input signal to servomechanism which corrects error; applications include alignment of large turbogenerator bearings, and installation and periodic checking of machine tools.

Align Machinery by Optical Measurement, E. H. KOENIG. Plant Eng v18 n5 May 1964 p 140–3. Optical alignment method is described that makes direct precision measurements rapidly and consistently; optical metrological and alignment equipment sets up 3-dimensional pattern for making accurate measurements of point within its view; electronic autocollimator is featured that has sensing unit, power amplifier, and indicator; sensing unit reads amount of tilt of reflective surface mounted perpendicular to its axis.

New Techniques for Very Accurate Measurement, E. H. KOENIG. Civ Eng (N.Y.) v34, n8 Aug 1964 p 41–3. It is shown how newly developed equipment and techniques with conventional instruments give new order of accuracy to measurements and how optical metrology and alignment aid in setting machines and equipment straight, flat, plumb, square and dimensionally correct; "square" may be established by pair of jig transits, one of which has precision-mounted mirror on its axle to reflect line of sight back on itself.

Alignment Interferometer, R. R. BALDWIN, L. G. WHITTEN. ASME n64–WA/PROD–5 presented at Winter Annual Meeting Nov 29–Dec 4 1964 4p 10 figs. The development of an interferometer for the measurement of straightness is described. With this instrument, deviations from straightness can be measured directly without resorting to trigonometric conversion techniques. Various modes of operation can be used to isolate errors due to pitch, roll, or yaw. This characteristic greatly simplifies error analysis and correction. A deviation from a straight line of less than 0.000010 in. can be detected at a distance of two yards. Calibration is performed with routine procedures and equipment.

6.3. Angle Gage Blocks and Polygons

A Machine Shop Square that is a Square, J. E. SWEET. Am Mach v31 June 18 1908 p 929–30. Illustrated description of a square in the form of a right 60-degree triangle having broad surfaces. Discusses advantages and uses, and methods of originating angles.

Table for Spacing Holes in Circles, F. W. SEIDENSTICKER. Am Mach v31 Dec 17 1908 p 889–90. A useful table for dividing circles into parts up to 500. Table gives the number of sides (3 to 250) of polygons, $\frac{1}{2}$ of angle subtended by side, and sine of that angle. (See also Am Mach v31 May 14 1908 p 767.)

Johansson Angle Blocks and Other Precision Instruments. Am Mach v51 Oct 2 1919 p 669–70 5 figs. Details and illustrations of some special precision instruments manufactured in Sweden to supplement blocks marketed by C. E. Johnsson, Inc., New York City.

Die Genauigkeit von 90° Stahlwinkeln (The Accuracy of 90° Steel Angles), G. BERNDT. Zeit für Feinmech und Präzision v35 n23 Dec 1927 p 279–83, 295–9. Detailed discussion of angle measurements, including: Testing angles by the light-slit method; indicating angle testers; measuring angles with the telescope and level; measuring angles with 2 auto-collimating telescopes; interior angles; effect of unevenness of the angle-leg on accuracy of measurement; tolerances, measurement of 90° angles; optical angle measurements; measurement results on 24 steel angles.

Apparatus for Measuring Solid Angles, A. AUBERTIN. Rev d'Opt v15 Aug 1936 p 263–71. The principle of the apparatus and a description of its construction, and its method of use are given. A solid angle w is measured in terms of an arc rotating on a divided circle. The apparatus can also be used as a planimeter.

Gauge, N. TRBOJEVICH. U.S. Patent 2,134,062 Oct 25 1938. Describes invention in the formation and selection of 15 blocks to form a set and the method of stacking the blocks to obtain any desired angle from zero to 90 degrees in degrees, minutes, and seconds.

A System of Combination Angle Gauges and a New Type of Dividing Head, G. A. TOMLINSON. NPL S.S. 190 Feb 1940. Describes a set of 12 angle gauges which can be combined to form any angle required to the nearest 1.5 seconds. Certain uses of the gauges are given, in particular their application to a new type of dividing head of high precision and great simplicity. See also British Patent n559748.

New Gage System, G. W. BIRDSALL. Steel v114 n2 Jan 10 1944 p 74–5. By using gage blocks, produced by Webber Gage Co., Cleveland, any angle from zero to 103° may be measured at 1-sec intervals with accuracy of $\frac{1}{4}$ sec.

Standards of Length and Angle for Precision Engineering. H. BARRELL. Trans Instrum and Meas Conf, Stockholm, 1947. Includes description of combination angle gages.

Testing Circular Division with Precision Polygons, C. O. TAYLERSON. Machy (London) v71 n1821 Sept 18 1947 p 327–30, 333. Polygon method for determining accuracy of readings of optical rotary dividing table incorporating graduated glass scale; method utilizes micrometric autocollimator for reading; calibrating polygon using two autocollimators; use of several polygons in combination; Tomlinson small angle tester used for calibration of microscope graticules.

Testing Angular Divisions, C. O. TAYLERSON. Aircraft Prod v9 n109 Nov 1947 p 430–2. Procedure described has been evolved by Metrology Div of NPL, and makes use of polygonal blocks of hardened steel, with polished faces, as reference standards.

Testing Circular Division with Precision Polygons, C. O. TAYLERSON. Eng v166 n4304 July 23 1948 p 73–5. Polygon method described was devised in Metrology Div of NPL; polygons themselves can be accurately calibrated by comparatively simple means and require only one optical micrometer reading at each point of comparison with table readings; photographs and line drawings.

How to Generate a Standard Square. Mach Oct 9 1948. A rectangular block having faces square and parallel within 0.0001 in. in a length of 20 in.

Production of Combination Angle Gauges, C. H. KNOYLE. Engr v190 n4936 Sept 1 1950 p 237–8; Machy (London) v77 n1975 Aug 31 1950 p 275–9. Methods successfully employed in producing and in generating sizes of gages to high order of accuracy from first principles; machining and heat treatment of blanks; preparing 27° and 9° gages; preliminary adjustment; production of gages in minutes and seconds; diagrammatic drawings. Communicated by Nat Phys Laboratory.

Assembled Polygon for Calibration of Angle Blocks, C. E. HAVEN, A. G. STRANG. J Res NBS v50 n1 Jan 1953 (RP2387) p 45–50; abstract in Machy (London) v83 n2138 Nov 6 1953 p 915–6. Method described for constructing

and calibrating assembled, multiple sided, angular standard of exceptional accuracy, although designed as master for 30 or 45° angle blocks of series made in United States, polygon is equally suitable for test or calibration of circular dividing equipment.

Precise Angular Standard Made From Gage-Blocks. Machy (N.Y.) v59 n12 Aug 1953 p 200–1. Exceptionally accurate polygon with 24 sides constructed by National Bureau of Standards to serve as basic standard of angular measurement; polygon permits comparison of "unknown" angle with consecutive angular intervals until total of such intervals equals integral number of perfect angles; design and operational details of instrument given.

Calibration of Circular Scales and Precision Polygons, A. H. COOK. Brit J App Phys v5 n10 Oct 1954 p 367–71. Although there is extensive literature about linear scales, calibration of circular scales and polygons has had but slight consideration; yet, some of computations are very much simpler for circular than for linear scales; theory of two methods of calibration; expressions obtained for values and standard deviations of corrections to nominal values of angles.

La Mesure Précise à l'Atelier des pièces ou Calibres à Faces non Parallèles (Accurate machine shop measurement of pieces with nonparallel faces), H. GUILLAUME. Pratique des Indus Mechaniques v42 n1 Jan 1956 p 13–6. General method of measuring conic surfaces; design and operation of "Micyl" checking blocks.

Angular Positioning Accuracy of $\frac{1}{10}$th Second. Tooling & Prod v24 n3 June 1958 p 51. New dividing head developed by AA Gage Co. indexes to accuracy beyond measuring capacity of best current scientific procedures; head incorporated two mating master plates, each with 360 precision ground serrations; parallelism and flatness of meshed plates is fast check on spacing accuracy.

Optical Polygons; Ultimate for Setting up, Checking Angles. Tooling & Prod v25 n9 Dec 1959 p 58–60. Entirely new polygon concept offered by Webber Optical Polygons which are calibrated to extreme accuracy of 0.2 sec of arc; used with small telescopes (autocollimators) that beam line image to one of polygon's reflecting surfaces, they are economical, abrasion resistant, and built to last for years of hard shop use; tools are especially helpful for calibration of "space age" instruments and guidance systems.

Reproduction and Transmission of the Value of an Angle in Reference Measurements, G. I. STRAKUN, L. I. SMIRNOVA, E. E. SHAROVA. Meas Techns 1960 n10 July 1961 p 832–5 2 figs 5 refs. Translated from Izmer Tekh n10 p 13–5 Oct 1960. The reference angle measuring method, which is basic to the whole measuring system, consists in determining the angles of polyhedral prisms by calibrating them with two independent autocollimators. These instruments are placed in such a manner that the optical axes of their objectives are perpendicular to the reflecting surfaces of the prism, and the angle between the collimators is equal to the nominal value of the central angle between the perpendiculars to the sides of the prism. The above method is one of the simplest and most accurate ways of reproducing and transmitting discrete values of an angle.

6.4. Calibration of Graduated Circles, Dividing Heads, and Protractors

See also subsection 10.2.5

An Account of the Equatorial Instrument, G. SHUCK-BURGH. Phil Trans Roy Soc London 1793 p 93. Two microscope method of calibration by making simple comparisons, plotting and noting deviations from the cosine law.

Untersuchungen der Theilungen der Kreises (Investigations of the Division of Circles), F. W. BESSEL. Königsberg Beobachtungen v7 1822 p IV. One of the early and much-used methods.

Description of the Armaugh Mural Circle and Examination of Its Divisions, T. R. ROBINSON. Monthly Notices Roy Astron Soc v3 1835 p 111–3. Four microscope methods with one pair of diametrically opposite microscopes fixed, the other movable; no details given as to computational method.

Über ein auf der Dorpater Sternwarte befindliches—Durchgangsinstrument—Repsold (Regarding the Repsold Transit Instrument at the Dorpater Observatory), W. STRUVE. Astron Nachr v15 n344 and 345 1838. Bessel's method of calibration (as used by Bessel on Cary's Circle).

Erste Leistungen eines auf der Königsberger Sternwarte befindlichen Repsoldschen Meridiankreises (First performances of a Repsold's meridian circle situated at the Königsberger observatory), F. W. BESSEL. Astron Nachr v21 n481 1844 p 482.

Spherical Astronomy, F. BRUNNOW. Translated from 2d German Ed 1865 Section VII p 389. Theory of astronomical instruments, includes topic of errors of circles.

Untersuchungen über die Theilungs-fehler beim Meridiankreise (Determination of circle errors by use of four fixed microscopes and two movable ones), F. KAISER. Ann der Sternwarte in Leiden v2 1870 p 50.

Eine neue Methode Kreisteilungen zu Untersuchen (A New Method of Investigating Circle Divisions), G. QUINCKE. Carl's Reportorium für Exper-Phys v9 1873 p 413. Mirror method for astronomical circles.

Determination of the Errors of Graduation of the 12-Inch Troughton and Simm's Theodolite, R. WOODWARD. Report of Chief of Engineers, U.S. Army for 1876 part III p 64. Periodic error of circle observed with two microscopes; application of method of Chauvenet.

Untersuchung von Kreisteilungen mit zwei und vier Mikroskopen (Investigation of Circle Divisions with Two and Four Microscopes), O. SCHREIBER. Zeit für InstrumKde v6 1886 p 1–5 47–55 and 93–104. Schreiber used the Wanschaff circle tester; he developed one of the thorough tests. For description of the Wanschaff instrument, see Brun's article in Astronomische Nachrichten 130, 1892.

On the Determinations of Errors of Graduation Without Cumulative Error and the Application of the Method to the Scales of the Cape Heliometer, D. GILL. Monthly Notices Roy Astron Soc v49 1888–9 p 105–18. It is stated that the general condition for freedom from cumulative error for circles is that there shall be as many microscopes (or the equivalent for as many microscopes) as the number of spaces into which the circle is to be subdivided.

Untersuchung einer Wanschaffschen Teilung (Investigation of a Wanschaff Graduation), H. BRUNS. Astron Nachr v130 n3098 1892. Contains description of Heyde circle tester.

Untersuchung über die Bestimmung der Theilungsfehler am Nonius und an der Kreistheilung (Investigation Regarding the Determination of the Division Error of a Vernier and a Circle Division), CAVILLE. Zeit für Vermessungswesen v22 1893 p 385.

A Simple Method of Determining the Eccentricity of a Graduated Circle with One Vernier, F. L. O. WADSWORTH. Am J Sci v47 ser 3 n281 May 1894 p 373–6 3 figs. The method applies a telescope and mirror.

Division Errors of the Repsold Meridian Circle, R. H. TUCKER. Publications of the Astron Soc of the Pacific v7 1895 p 330–9. Two circle method used with 2 microscopes on each circle; simple calibration, duplicate results considered only as checks; 29,000 readings.

Flexure and Division-Correction of the Circles of the Meridian Instrument at Albany, L. BOSS. Astron J n382, 383, 401. Total work on 4320 graduations with 350 hours observing by two people and nearly as much more computing.

The Normal Equations That Arise in the Usual Schemes of Observation for Division Errors and Their Solutions, P. H. COWELL. Monthly Notices Roy Astron Soc v61 1901 p 527. Various schemes for calibrating circle, considered as a scale, with different number of microscopes; mathematical.

On the Determination of the Division Errors of a Graduated Circle. HOUGH, Monthly Notices Roy Astron Soc v64 1904 p 461–88.

Methode Nouvelle et Rapide pour la Determination des Erreurs de Division d'un Cercle Meridien (Division Errors of Meridian Circle), LOEWY. CR Acad Sci v143 Oct 15, 29, Nov 12 Dec 3 1906 p 529–35, 621–7, 719–26, 857–63; Ann de l'Observatoire de Paris (Mem), v27 1910 p a1. Announcement and preliminary description of a new method of rigorously determining the errors of each division on instrumental circles of high precision. Details and formulas of reduction are given in later papers.

Die Ausgleichsrechnung nach der Methode der kleinsten Quadrate (The Compensation Calculation According to the Method of Least Squares), F. R. HELMERT. Publ. by Teubner, Leipzig (2d ed 1907 chapter 7 p 435–63). Describes methods of calibrating circles.

Sur la Methode de M. Loewy pour l'Etude des Cercles Divises (Loewy's Method of Determining Circle Errors), GONNESSIAT, G. FAYET. CR Acad Sci v145 July 16 1907 p 157–65. The authors have applied Loewy's method and find it practical, rapid, and accurate.

Testing the Dividing Head of the Cincinnati Milling Machine. Machy (N.Y.) v14 Jan 1908 p 315–7. Shows a sample inspection sheet and illustrates a variety of tests.

Dividing Engine, G. T. McCAW. Monthly Notices Roy Astron Soc v69 Jan 1909 p 226–8. Details of testing of a 55 cm circle ruled on a new dividing engine made by E. R. Watts & Son, So. London. The range of errors is from $+1\overset{.}{''}8$ to $-1\overset{.}{''}7$.

Sur la Determination des Erreurs des Traits d'un Cercle Divise (On the Determination of Errors of Lines of a Divided Circle), G. FAYET. Ann de l'Observatoire de Paris (Mem) v27 1910 p A$_2$ 1. Method of Bruns.

Geodäsie (Geodesy), H. HOHENNER. Publ by Teubner, Leipzig 1910. On p 42–5 is a discussion of the errors of graduated circles.

Bemerkungen über die Untersuchung von Kreisteilungen (Remarks Regarding the Investigation of Circle Divisions), H. BRUNS. Ber über die Verh der Koniglich Sachsischen Ges der Wissenschafter zu Leipzig (Mathematisch-Physische Klasse) v64 1912 p 62–107. "Rosette" method using Heyde circle tester.

Bestimmung des Regelmässigen und des Mittleren Zufalligen Durchmesser-Teilungsfehlers bei Kreisen von Theodoliten und Universalinstrumenten (Determination of the Regular and of the Mean Accidental Diameter-Division Errors in Circles of Theodolites and Universal Instruments), H. J. HEUVELINK. Zeit für Vermessungswesen v42 1913 p 441–52. Describes test of an assembled theodolite using collimators.

Untersuchung eines automatisch geteilten Kreises (Investigation of an Automatically Divided Circle), J. SPANNUTH. Doctorate Dissertation, Univ. of Leipzig. Publ by Friedr. Vieweg & Sohn. Braunschweig, 1913. Test by "Rosette" method using testing machine made by Heyde; this machine shown by photograph on p 6.

Untersuchung zweier Teilkreise der Fa. Heyde und Hildebrand auf dem Wanschaffschen Teilungsprüfer (Investigation of two graduated circles on the Wanschaff graduation tester), G. FÖRSTER. Zeit für InstrumKde v33 Jan and Feb 1913 p 10–9 and 39–51; Veroff des Geodatischen Inst Berlin 1917. A considerable amount of theory is involved in comparing two machines (a) by Heyde, (b) by Hildebrand, the error of a single measurement and also the mean error, a number being worked out in each case. Calibration tables and curves are given, the greatest error found anywhere on either machine being 1.5 seconds of arc.

Calibration of Repsold Meridian Circle, P. HARZER, H. KOBOLD, O. TETENS. Zeit für InstrumKde v34 Jan 1914 p 20–3. Notes of tests made on the calibration of the divisions on the limb of a Repsold meridian circle. A summary is given showing the variations at various positions.

Movable Divided Circles, A. VERSCHOFFEL. CR Acad Sci v163 Oct 23 1916 p 421–7. Attention is drawn to the possibility of considerably reducing the probable error of observations made with a divided circle by arranging for it to be movable on its axis, so that readings on a given object may be made on different divisions.

Description et Emploi des Appareils de Mesure et d'Observation (Description and Use of Apparatus of Measurement and Observation), H. BOUASSE. Publ by Libraire Delagrave, Paris, 1917. Method of graduating and calibrating circles on p 184 and 203. On p 199 is given basic idea of a method employed in NBS testing.

Prüfung von Kreisteilung (Testing of Circle Divisions). A. AREGGER. Schweizerischen Zeit für Vermessungswesen und Kulturtechnik, 1921. Method developed by Aregger, geometer of the military-geographical institute of Argentina. Test of assembled instrument using collimators.

The Circular Dividing Engine of Edward Troughton, 1793, D. BAXANDALL. Trans Opt Soc London v25 1923–4 p 135–9. Very interesting history of circular dividing engines.

Handbuch der Vermessungskunde (Handbook of Surveying), W. JORDAN. Publ by J. B. Metzlersche Verlagsbuchhandlung Stuttgart v3 7th ed 1923 p 49–56. Section

entitled, "Kreisteilungsfehler", refers to various methods of test.

The Adjustment and Testing of Transit Theodolites, Levels and Surveying Cameras at the Laboratory of the Dominion Lands Surveys. Canada, Topographical Surveys Branch Bul 48 1923. Test of a complete instrument using collimators; errors given in tabular form; eccentricity determined as described by Chauvenet, same as Hosmer. (This method of determining eccentricity used at National Bureau of Standards.)

Divided Circles, E. O. HENRICI, G. W. WATTS. Article in Glazebrook's Dictionary of App Phys IV p 53 (Pub by Macmillan London 1923).

Winkelmessung (Angle Measurement), F. GÖPEL. Being chapter III of Vol 1 of Handbuch der Physik. Edited by H. Geiger and K. Schell and published by Julius Springer, Berlin 1926. Method of graduation; types of graduation error; calibration of circles by methods of Schreiber, Bruns, Heuvelink and Zeiss. Illustrations: Reichenbach arrangement (schematic drawing), Heyde 500 mm dividing engine, Zeiss circle tester.

Prüfung der Teilung eines Wildeschen Universaltheodolite (Testing the Graduation of a Wild Universal Theodolite). F. ACKERL. Österreichischen Zeit für Vermessungswesen v25 n6 1926. Tests made in Vienna of the circle as mounted in the theodolite, sighting telescopes on church spires.

Calibration of a Divided Scale, L. V. JUDSON. NBS Cir n329 1927. The method described here has been applied to circle graduations at the Bureau of Standards.

Untersuchung eines Breithauptschen Kreises nach der Methode von Heuvelink und Bermerkungen zu dieser Untersuchungsmethode (Investigation of a Breithaupt Circle According to the Method of Heuvelink and Remarks on This Method), L. FRITZ, W. UHINK. Zeit für InstrumKde v48 n2 Feb 1928 p 53–68 4 figs 17 refs. The method of Heuvelink is applied to a triangulation theodolite having a 235 mm diameter divided circle. The method here given deviates in two minor respects from that of Heuvelink. It corresponds to the Bruns method with four microscopes. If there is the possibility of setting up more than two collimators the Rosette method may also be used. However, this is not treated further.

Preisliste V: Teilmaschinen und Hilfsinstrumente (Price List V: Dividing Machines and Auxiliary Instruments), G. HEYDE. 1929 ed p 33 and 34 illustrates and describes circle tester of similar construction to that made for Dr. Bruns. Univ Observatory of Leipzig. On p 30 and 31 of 1911 ed are illustrated and described a variation of this.

Prism Refractometry and Certain Goniometrical Requirements for Precision. L. W. TILTON. J Res NBS v2 n5 May 1929 p 909–30. Includes description of techniques in using graduated circles to attain an accuracy of measurement to a fraction of a second.

Geodesy, G. L. HOSMER. Publ. by Wiley, New York, 2d ed 1930. Errors of circles, p 84–8.

Apparatus for Testing Graduations on Circles, Soc Genevoise d'Instrum Phys. Pamphlet n425. Illustrates and describes the apparatus at the National Bureau of Standards.

Determining the Graduation Corrections of the Horizontal Circles of Theodolites from the Filed Results of Primary Triangulation, J. L. RANNIE. Can Surveyor v3 n7 Jan 1930. Field measurements with assembled instruments (16 positions of circle).

Bausch & Lomb Optical Bevel Protractor. Am Mach v72 Mar 20 1930 p 507. For precise work where the usual protractor would not be sufficiently accurate, this optical bevel protractor can be used. The device has an accurately machined base on which the main body is hinged, and can be swiveled by turning the thumb screw at the lower front. The level vial may be positioned accurately. The dial is graduated to one-sixth of a degree, and every degree line is designated by a number. The graduations are observed through the eyepiece, which so magnifies the spaces between the graduations that a vernier can be read with ease to within one minute of arc. The instrument has been found useful for checking dovetail surfaces of machine tool slides.

Beurteilung von Kreisteilungen aus Exzentrizitatmessungen (Evaluation of Circle Divisions from Eccentricity Measurements), W. UHINK. Zeit für Vermessungswesen v61 1932 p 177.

Untersuchung eines Teilkreises nach zwei Methoden und Aufklärung der dabei aufgetretenen Widersprüche (Investigation of a Graduated Circle by two Methods and Clarification of the Encountered Inconsistencies), F. MÜHLIG. Zeit für InstrumKde v53 Nov 1933 p 477–85 3 figs 5 tables.

Der Einfluss einer besouderen Anordnung der Kreisstände auf die Bestimmung der Kreisteilungsfehler (The Influence of a Special Arrangement of the Circle Positions on the Determination of Division Errors), F. HAUER. Zeit für InstrumKde v56 Aug 1936 p 309–21. Heuvelink's formulae for the general case for the determination of errors of fractions of a circle are first derived. These can be simplified to find the amplitude and phase constant of the errors of the partial circles if the necessary regular subdivision of the circular distances of the half circumference of the circle is carried out. These considerations are investigated. Two practical examples are taken in which the instruments have the degrees divided into sixths and twelfths. The exact and approximate methods give almost identical results. The relations are generalized in a table for fractions of 5′, 10′, 20′ and 30′. Conclusions are drawn regarding this method of operations.

Notes on Testing of Workshop Dividing Head, F. H. ROLT, C. O. TAYLERSON. Machy (London) v51 n1311 Nov 25 1937 p 229–31. Objects of tests were to ascertain general degree of accuracy of angular spacing obtainable with commercial dividing head, and to investigate possible sources of error, by adopting modern methods of grinding gears and worm threads; it should be possible to considerably reduce errors.

Calibration of Circular Scales From Eccentricity Measurements, W. KRUG. Zeit für InstrumKde v58 Oct 1938 p 412–6. Comparison of results obtained using Uhink's method of eccentricity measurements with those given by Forster's method shows that the eccentricity method gives in practice curves which are sufficiently accurate to determine considerable errors in circular division.

Art of Original Circular Dividing (1650–1859), E. W. TAYLOR. Eng v156 n4052, 4053, Sept 10 1943 p 204, Sept 17 p 235. Author traces developments made, pointing out urgent need that was felt, particularly through Eighteenth Century, for unprovement in accuracy of astronomical instruments. From Empire Survey Rev July 1943.

Equipment for Producing Divided Circles at the Zeiss Plant. CIOS Rep. XXIX—59 (H.M. Stationery Office; U.S. Dept Comm.) 1946 5 p. Describes the dividing machines in use; the main worm is driven by a gear shaped like an hour-glass, so that contact is made with several teeth at once, thus reducing the effect of irregularities in pitch. Two lines are traced with each ruling, so that each line on the finished product consists of a pair, very close

together, thus eliminating some systematic errors. Photographic methods were in the development stage. The capacity is 300–400 circles per month, with an error rarely exceeding 1.5 seconds of arc.

Bevel Protractors (Mechanical & Optical). Brit Stand Inst-BS n1685 1951 10 p. Standard relates to three types of mechanical bevel protractors and to optical bevel protractor with internal circular scale graduated in divisions of 10 min of arc and read by means of optical magnifying system.

The Graduation of Precision Circles, B. L. PAGE, NBS. Surveying and Mapping v13 n2 Apr–June 1953 p 149–61 10 figs. Contents : The dividing engine ; the ruling points ; the circle blanks ; setting of the engine ; mounting the circle blank ; graduating the circle ; testing the circle.

Effects of Alignment Errors in Dividing Heads, C. T. BUTLER. Machy (London) v83 n2144 Dec 18 1953 p 1211–4. Two causes for errors arising when checking angular spacing of work mounted on mandrel between centers of dividing head ; analysis of errors resulting from lack of alignment of axes of rotation of dividing head and work ; expressions are derived for these errors and experimental confirmation of expressions is given.

Reading Rotary Table to 1 Second of Arc. Machy (N.Y.) v64 n5 Jan 1958 p 139–42. Ultra precision in jobs on jig borers and similar equipment requiring circular spacing or angular positioning is obtained by using optical rotary table ; made by Pratt & Whitney, it embodies Gurley UNISEC optical coincidence system and can be read to 1 sec of arc ; diagram shows optical train in table.

Theodolites. I–II, H. HOITZ. Arch tech Messen n285 (J1112–2) Oct p 213–6 ; n286 (J1112–3) Nov 1959 p 233–6 in German 14 refs. A descriptive survey covering design of telescopes, circle bearings, glass divided circles, methods of circle reading which automatically eliminate centering error, spirit levels and self-levelling devices.

Photoelectric Method for Recording Circle Readings of Meridian Instruments, A. A. EFIMOV, YU M. OTRYASHENKOV. Astron Zh v37 n1 1960 p 146–50 in Russian. English translation in : Soviet Astron AJ (New York) v4 n1 p 140–4 July-Aug 1960. A photoelectric technique for recording circle reading has been developed, and an experimental working model has been built. Tests of the arrangement have shown that this method can be used for automatic recording of limb readings to a precision of 0.1μ in linear units. Errors in the readings are largely independent of the quality of the calibration marks, which may be dark against a light background, or vice-versa.

A New Dividing Head, E. I. FINKEL'SHTEIN. Meas Techns 1959 n3 May 1960 p 164–6 2 figs. Translated from Izmer Tekh n3 Mar 1959 p 8. How accuracy of optical dividing heads with single-sided reading can be increased by introducing more sensitive reading device, such as optical micrometer and simultaneously raising accuracy of circular dial scale and improving its centering with respect to axis of rotation features of modernized optical dividing head which has less error of old-type instruments, yet preserves old construction changing only optical system.

Attachments for the Optical Divider head, M. M. MERGOL'D. Meas Techns 1959 n5 June 1960 p306–7 2 figs. Translated from Izmer Tekh n5 May 1959 p 4. Describes development of very simple adaptors permitting wide application of the divider head for this purpose, in conjunction with the ocular head, tube, objective, and stand of a small microscope-type instrument which is widely used in machine construction.

An Attachment for an Optical Dividing Head, F. P. VOLOSEVICH. Meas Techns 1959 n7 June 1960 p 499–503

7 figs 2 refs. Translated from Izmer Tekh n7 July 1959 p 6. Attachments consist of: (1) lugs for truing articles having center holes; (2) blocks for raising head and tail-stock; (3) special adjustable angle pieces for determination of taper; (4) special mounting for centering two instruments on a common axis; (5) special square fixed in slot of base plate; and (6) a dog having set screws.

New Method of Testing Divided Circles, C. KÜHNE. Rev Sci Instrum v31 n8 Aug 1960 p 882–5. The residual uncertainties of angular measurements due to the circle graduation testing methods presently used are touched upon. A new method is described, and its mathematics elucidated. Theoretically, the method permits one to obtain exactly equidistant angular intervals even if the master circles used have errors in their graduations. The method suggested enables division errors of diameters to be measured directly. Further, it is shown how the measurement procedure may be rendered automatic by suitable technical means which would permit determination of the totality of division errors for all graduated circles without prohibitive cost.

Messverfahren für die Teilungsfehler eines Theodolit-Horizontalkreises in seiner Gebrauchslage (Measuring Methods for the Division Errors of a Theodolite-Horizontal Circle in its Bearing), R. NOCH, PTB. Zeit für Instrum-Kde v 69 1961 p 33–9 5 figs 19 refs. A measuring equipment for the angular pitch errors of gears and dividing plates can also be used for direct high-precision measurement of the errors of the horizontal circular graduation in a theodolite. The errors of a theodolite WILD T3 were measured for every 6 degrees; the equation of its regular division errors is derived.

Ein photoelektrisches Gerät zum Bestimmen von Kreisteilungsfehlern (Photoelectric Apparatus for Determination of Circle Graduation Errors), E. M. FEKLISTOV. Zeit Vermess-Techn v5 1961 p 159; VEB Verlag für Bauwesen, Berlin.

Investigating Errors in Optical Dividing Heads, L. YA. GUSTYR'. Meas Techns 1960 n9 Apr 1961 p 739–41 3 figs 3 refs. Translated from Izmer Tekh n 9 p 10–2 Sept 1960. The reading errors of a Leitz optical dividing head were investigated by comparing the angles of a 18-sided prism by means of autocollimator with the angles of rotation of the head. The linearity of the working surface of the base was measured in two positions along the width of the base by a collimator method.

New Small-Angle Generator for Calibrating Rotary Tables to High Accuracy, L. W. NICKOLS. Machy (London) v100 n2589 June 27 1962 p 1456–8. Description of equipment developed at Nat Phys Laboratory, which is designed to meet requirement for better method of calibrating rotary tables at intervals of less than one degree of arc; effect of errors on accuracy of angular measurement; performance tests on apparatus.

High-Precision Circular Scales. Firm of Dr. Johannes Heidenhain, Traunreut. Oct 1963 16 p 14 figs. Describes advantages of circular scales manufactured by the patented Diadur process. Discusses assessing the accuracy of circular scales including line errors, eccentricity error, and diameter error.

High-Performance Indexing Fixtures, P. L. GARRETT. ASME n64–Mech–42 presented at Mechanisms Conference, Lafayette, Ind. Oct 19–21 1964 4p 4 figs. Indexing fixtures of the type treated are inherently more accurate than optical polygons but lack the resolution required for testing high-performance shaft position encoders such as those used on radio telescopes and tracking cameras. Double fixtures will increase the inherent error to one half second but will permit a wide choice of test points, the choice being controlled by a Diophantine equation. The properties of this equation show that the most frequently desired division of the circle, namely 2^n exactly equal parts, is impossible whereas certain other divisions are entirely practical.

6.5. Angle Measurement by Interferometry

Mesure des tres petits Angles de Rotation (Measurement of Very Small Angles), M. BRILLOUIN. CR Acad Sci v137 Nov 16 1903 p 786–7. Two nicols are set for extinction. Between them insert (1) a thick slab of spar, cut at 45° to its axis, (2) a half-wave plate placed at 45° to the section of the spar; (3) a second slab of spar identical and parallel to the first. The half-wave plate reduces these three to be equal optically to a slab of very small thickness. In parallel light a uniform color is obtained when the light has passed the analyser. A rotation of one spar 54″ on an axis perpendicular to a principal section corresponds to a wave length. Hence as 0.01 of the breadth of an interference band can be measured, we can use the apparatus to show a movement of ½ sec. of arc.

A New Contact Lever Using Achromatic Fringes, C. BARUS. Nat Acad Sci Proc v5 Feb 1919 p 39–43. The method of measuring small angles by the rectangular interferometer is here applied to delicate devices such as the contact lever or the spherometer.

Measurement of Small Surface Angles, N. BARAKAT. Letter in Nature (London) v163 Apr 16 1949 p 603. In using fringes of equal chromatic order to measure the angle of a wedge, it is necessary to rotate the specimen in order to locate the maximum angle. It is shown that the wedge-angle can be obtained directly by the superposition of fringes of equal chromatic order and Fizeau fringes. An angle of tan $\theta = 0.001$ was measured, with a suggested accuracy of 1% even in an unfavourable case.

Recording Interferometer for Precision Wavelength Determinations, W. R. SITTNER, E. R. PECK. J Opt Soc

Am v39 July 1949 p 544–6. A recording interferometer is described which permits the precise measurement of an angle by means of interferometric measurement of chord length. The present instrument, working in conjunction with a recording spectrometer, is applied to the problem of precise wavelength determinations. Preliminary results indicate that the average deviation of a single measurement is 0.044 A. The application of this interferometer to the measurement of linear or rotational motion is discussed.

Measurement of Angle by Interferometry, C. F. BRUCE, W. A. F. CUNINGHAME. Austral J. App Sci v1 Sept 1950 p 243–58. The method used has given a precision of the order of 0.1 sec of arc in angle measurement. The variation in flatness of the existing angle standards and the distortion of the surfaces that occurs in wringing have been immediately observable and measurable to a high precision. The method has shown that the angles of the gauges vary by 1 or 2 sec over their surfaces. The uncertainty in definition of angle is, therefore, of this order and will be still greater when gauges are wrung in combination. Work is proceeding on combinations of gauges in order to calibrate complete sets and to investigate the reliability of an angle made up of a combination of several gauges.

An Angle Comparator for Laboratory Use, H. LLOYD, A. T. F. SIMMONS, G. E. WINDER. Safety Mines Res Establ Res Rept n37 June 1950 12 p. The instrument is primarily for use in experimental researches on explosives for improving the accuracy and ease of measuring photographic film records of detonation speeds. The opti-

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cal principles and construction are described, and an analysis is given of its performance.

The Calibration of Standards of Angle by Interferometry, C. F. BRUCE, W. A. F. CUNINGHAME. Austral J App Sci v3 Sept 1952 p 210–8. The calibration by interferometry of complete sets of angle standards used in length metrology is described. A detailed account of the departures from flatness and the distortion that occurs in the use of these standards is given. The results confirm earlier conclusions that standards from 3 seconds to 9° are reliable only to several seconds of angle and should be increased in thickness. The standards of larger angle have greater rigidity, but departures from flatness of the surfaces can cause errors of several seconds if they are used in the normal way.

An Improved Angle Interferometer, R. E. SUGG. NBS Cir 581, Metrology of Gage Blocks Paper n6 Apr 1 1957. Discusses principle of angle interferometer, design and construction details, results and conclusions.

Use of Radial Gratings in a Small Inclinometer, A. LEWIS, I. R. YOUNG. J Sci Instrum v36 n4 Apr 1959 p 153–7. Some of the factors involved in the choice of gratings for use in the digital measurement of angles are discussed. This problem is accentuated in the case of the instrument described by its small size and the decision, therefore, to use two complete circles for the gratings, instead of less critical method using one circle and adjustable grating cursors. The tolerances which have to be achieved for satisfactory performance are considered and the instrument itself, a pendulous inclinometer intended to measure the pitch angle of wind tunnel models, is described.

Interferometric Method of Measuring Angles of Polyhedrons, L. N. LOGACHEVA. Meas Techns 1958 n1 Aug 1959 p 11–3 3 figs 2 refs. Translated from Izmer Tekh n1 Jan–Feb 1958 p 10. The interferometric method of measuring small angles (up to 2′) described allowed authors to measure the angles of polyhedrons with a precision of the order of 0.2″, using Koesters' interferometer. When the angular standard is wrung by one of its faces to the flat plate placed in the proper position on the table of the apparatus one can see in the field of vision two systems of interference fringes of different widths, one corresponding to the free working surface of the angular standard, and the other to the plate. Authors have calibrated two steel hexahedrons by this method, on a vertical Koesters' interferometer by using the yellow light of helium as light source.

Interferometric Measurement of Small Angular Displacements, P. HARIHARAN, D. SEN. Brit J App Phys v10 n10 Oct 1959 p 455–52. A modified three-beam interferometer is described. The instrument is extremely sensitive to angular displacements in a specified plane and is capable of a high degree of accuracy. In addition it is easy to handle and quite stable, since it is relatively insensitive to angular displacements in any other plane and is also completely unaffected by a linear translation of the detecting element.

Micrometer Adjustment of Mirrors and Prisms, N. BÁRÁNY. Periodica Polytech Elec Eng v4 n1 1960 p1–16. The paper gives the geometrical conditions to be satisfied by a rotating mirror or prism in an angle-measuring instrument. In particular the optimum point of rotation is determined. Such mirrors or prisms are commonly rotated by a micrometer screw and cam. The shape of the cam for typical cases is derived and the effect of the shape

of the cam-follower considered. A typical mechanical design is described in some detail.

Fringecount Gonimet Interferometer, R. A. WOODSON. Paper WC11, J Opt Soc Am v50 n11 Oct 12 1960 p 1128. A two-beam interferometer system to measure angular displacements. Fringes may be reversibly counted by a pair of photomultipliers and a counting circuit.

Interferometric Measurement of Small Angular Displacements. II. The Double-Passed Jamin Interferometer, P. HARIHARAN, D. SEN. Brit. J App Phys v12 n1 Jan 1961 p 20–4. When the rays emerging from a Jamin interferometer are reflected back through the instrument, fringes similar in appearance and behaviour to three-beam fringes are obtained. These fringes can be used to measure small angular displacements of one of the beam-dividing plates, with an accuracy of the order of 0.01 μ. A modified set-up is also described with which angular displacements of a comparatively light, auxiliary mirror can be measured with the same degree of accuracy.

An Alignment Interferometer for Precision Straightness-Measurements and Control Even of Rapidly Moving Carriages, G. W. STROKE. J Opt Soc Am v51 n12 Dec 1961 p 1340–1. A new, easily adjusted and very stable interferometer, defining a semistatic fringe field by reflection on two mirrors, has permitted a simple solution to the problem of rapid and accurate alignment of moving carriages, of fixed reference beams, and of carriage-ways in the interferometric domain. Precisions in the 0.1 sec-of-arc range are easily obtained in visual work in rotations up to minutes of arc without the usual limitations of slow fringe counting and of loss of fringe-contrast at large path differences in particular. In fact, the fringe-constant is independent of the distance from the reference-support to the moving mirrors in this interferometer, and permits measurements and alignments over traverses and distances of many feet if required. Precisions in the 0.01 sec-of-arc range and better fringes. Experiments with carriages moving at rates up to 1 ft/sec and over distances of the order of 1½ ft have demonstrated the versatility of the alignment interferometer in various applications in particular in the alignment of ways on a velocity-of-light apparatus and on ruling engines.

Extended-Range Gonimet Interferometer, R. A. WOODSON. Paper WD 17 J Opt Soc Am v52 n11 Nov 1962 p 1315. An extended range interferometer has been designed to measure very large angles to an accuracy of ±0.025 sec.

Neuentwicklungen bei Teilgeraeten (New developments in indexing attachments), L. MEYDING. Werkstatt und Betrieb v95 n12 Dec 1962 p 805–8. Indexing errors in optical instruments; description of attachments for more accurate calculation of angular positions of uniform graduations and for reduction of setup times.

Angular Measurements by Means of a Ronchi Ruling, J. R. MEYER-ARENDT, E. D. MINER. App Opt v2 n1 Jan 1963 p 77 1 fig 4 refs. Describes goniometer which combines a simple optical lever and a Ronchi ruling in which the shift of one fringe equals 10 seconds of arc for a grid having 133 lines/in.

An Interferometer for Precision Angle Measurements, J. ROHLIN. App Opt (USA) v2 n7 July 1963 p 762–3. In a Michelson interferometer with corner-cube reflectors, one corner-cube rotates about an axis 300 mm from the optical axis; the amount of rotation is deduced from the fringe displacement.

6.6. Sine Bars, Plates, and Fixtures

Use of the Sine Bar for Measuring Angles. Machy (N.Y.) v18 Jan 1912 p 376 4 figs. Includes description of sine bar having one end formed to a 30 degree angle for inserting in narrow openings.

The Sine Bar and How to Make it, A. H. SHIELD. Mech Wld Apr 16 1915. Diagrams and description.

Improved Type of Sine Bar, W. G. GROOCOCK. Am Mach v45 July 13, 1916 p 77, 342–3, 869–70. Slotted angle plate used for supporting sine bar. Discussion by G. A. REMACLE and W. McARDELL. See also Am. Mach. v44 May 11 1916 p 820.

A Sine Protractor, L. C. BLOMSTROM. Am Mach v45 Aug 24 1916 p 340 1 fig. Combination of sine bar and bevel protractor which is set by a micrometer caliper.

Sine Bar Applications, D. BAKER. Machy (N.Y.) v23 Oct 1916 p 120–4. Details of construction and methods of obtaining accurate angular work, with tables of constants for 5-inch sine bar.

A Sine Bar. Am Mach v45 Oct 12 1916 p 656. "Simplex" 5″ sine bar.

Adjustable Sine Bar, E. P. DAVIS. Machy (N.Y.) v23 May 1917 p 806. Buttons are adjustable in position to obviate precision boring of holes, but as buttons may be displaced in use it is desirable to test their position before using.

Checking Angles with Swedish Blocks, H. B. LEWIS. Am Mach v47 Aug 30 1917 p 353–5. Methods of checking angles by means of precision gage blocks, principally in conjunction with the sine bar.

Slocum Sine Bar and Indicating Square. Am Mach v47 Sept 27 1917 p 567. Sine bar fixture in which one button is fixed and acts as fulcrum. Square has indicator reading from 80° to 100°.

Universal Angle Plate for the Use of Toolmakers, R. BERNHARDSON. Am Mach v47 Oct 25 1917 p 736. Combined angle plate and sine bar. The angle plate consists of 11 parts, the body having all of its sides square, tilting table, hinge plate, 2 locking screws, 2 adjusting bars, hinge bar, sine bar, and 2 locating pins.

Uses of the Sine Bar, E. J. BRYANT. Am Mach v47 Nov 1 1917 p 749–51 17 figs. Describes its use in one of the large tool, gauge, and fixture shops. The sine bar fixture shown in Fig. 1 is a self-contained tool and does not have to be clamped to something else and measurement taken from still some other object.

Sine Bars of Improved Design, W. C. BETZ. Machy (N.Y.) v24 June 1918 p 933. Bar having notched ends for location of pins. See also Am Mach v50 Mar 13 1919 p 515–6.

Kar Sine Angle Plate. Am Mach v49 Nov 28 1918 p 1007–8. Consists of a movable plate swiveled on a stationary base with adjusting screw and clamp. Micrometer measurements are taken over either of two buttons at the side of the plate and the underside of an overhanging reference plate located below the main pivot.

Sine Bar and Attachment, PRESTO MACHINE WORKS. Am Mch v49 Dec 26 1918 p 1195. The sine bar is 4 in. long and the attachment is an accurately finished 4-in. cube. All faces of the cube are provided with a number of tapped holes for attaching work, clamps, etc. Five sides have accurate V-grooves for seating cylindrical work and one side has a T-slot quadrant for attaching the sine bar. The sine bar can be set to either the sine or the cosine of the angle, whichever is most convenient, and then by using the proper side of the fixture as a base the desired sine or cosine is placed in working position.

"Loway" Sine Bar. Am Mach v50 Mar 13 1919 p 515–6. The sine bar has two right-angled notches cut in the side and two rolls are inserted therein and held in place by small coil springs passing through the sides of the rolls and into the sine bar, the ends being held by small pins. This construction is used to prevent distortion. A similar bar is described in Machy (N.Y.) v24 June 1918 p 933.

Universal Sine Bar for the Toolmaker, J. B. GRAY. Machy (N.Y.) v25 Aug 1919 p 1159–62 8 figs. Describes method of making a sine bar to meet the special requirements of tool-room applications.

Tables for Use With the Sine Bar. Western Machy Wld v12 Nov 1921 p 433–7 3 figs. Also explains use and gives illustrations for its application.

The Use of the Sine Bar. Machy (London) v19 Feb 2 1922 p 529–31 6 figs. Gives some examples of wide range of angle work covered by it. Is more adaptable than the protractor.

Sine Bar Gage for Large Work, R. H. RAUSCH. Am Mach v61 60 July 10 1924. Sine bar fixtures replace numerous special gages.

Measurements of Cones in V-Blocks, N. P. SKINNER. Machy (London) v68 n1743 Mar 7 1946 p 310–2. Principle of method described is similar to that applied to comparator method of inspecting taper pins, machine tapers, etc.; method claimed not suitable for small quantities, but economical for small to medium batches of several items recurring at intervals; necessary equipment; formulas proofs; error possibilities.

Calculation of Pin Measurement for Right and Oblique Cones, C. D. WRIGHT. Tool Engr v16 n2 Mar 1946 p 51. By use of formulas given, solution is reduced to simple operation that can be done on calculating machine, with but single reference to tables; problem concerns determination of measuring pin location, when measuring right and oblique cones in relation to each other, as in gages and tools.

Sine Bars, Blocks, Plates, and Fixtures. Commercial Standard CS 141–47. Superintendent of Documents, Government Printing Office, Washington, D.C.

Accurate Method of Measuring Dovetails, L. F. WILHARM. Machy (N.Y.) v56 n4 Dec 1949 p 178–9. Method based on sine bar principle of measuring angles is described; details of tool used for measuring dovetail explained and illustrated.

Correction Charts for Sine Bars, C. T. BUTLER. Machy (London) v83 n2125 Aug 7 1953 p 254–6. Errors occurring in sine bars, employed for establishing and measuring angles to high degree of precision, can be readily analysed and simple corrections made for more important discrepancies; formulas and charts for corrections to be made.

Compound-Angle Setups Made Easy by Unique Three-Ball Sine Plate, J. R. HANSEN. Machy (NY) v63 n5 Jan 1957 p 160–1. Setup for machining or inspecting compound angles on jigs, fixtures, cutting tools, and work pieces simplified by employing novel, three ball sine plate assembly; example of using sine plate in inspection setup to check compound angle.

High Precision Compound Angle Sine Tables, Coventry Gauge and Tool Co. Ltd., Coventry, GB (1958) 6 p 3 figs. The outstanding feature of these tables is the substitution of a hemisphere riding in a hemispherical seating for the conventional hinged bearings at 90° to one another. Angles up to 45°, both simple and compound, can be set quickly and simply to an accuracy of 10 arc seconds.

Sine Bars and Sine Tables. Brit Stand Inst—BS n3064 1959 14 p. First section of standard provides for three types of sine bar made in inch sizes of 4 in., 5 in. and 10 in. and metric sizes of 100 mm, 200 mm and 250 mm; second section covers sine tables inclinable about single axis in sizes of 5 in. and 10 in. and metric sizes of 100 mm and 200 mm; designating sizes represent center distances between axes of rollers.

Dividing Head with a Sine Rule. A. B. FRANKEL. Meas Techns 1959 n9 Aug 1960 p 685 1 fig. Translated from Izmer Tekh n9 Sept 1959 p 21. A combination of a dividing head for measuring 5° intervals and a sine bar for measuring angles within the intervals.

Measurement of Small Angles, V. I. NIKOLAEV. Meas Techns 1959 n12 Sept 1960 p 940 1 fig. Translated from Izmer Tekh n12 Dec 1959 p 14. Describes a structional modification of a sine bar in order to measure angles smaller than 10′.

Kritische Untersuchung der Bestimmung der Verjüngung von Metrischen (und Morse) Kegeln mit dem Sinuslineal (Critical Investigation of the Determination of Taper of Metric and Morse Tapers with the Sine Bar), E. H. G. BERNDT. Microtecnic v15 1961 p 45–53. Mathematical investigation of errors in measurement using the sine bar.

A New Small-Angle Generator for Calibrating Rotary Tables to a High Accuracy, L. W. NICKOLS, Machy (London) v100 June 27 1962 p 1456. Instrument operates on the sine arm. A mirror on the sine arm permits viewing by an autocollimator. Repeats to 0.1 Sec. Angles can be set out to 0.5 Sec or better.

New Sine-Table Method of Measuring Angle of Male Tapers, L. GOLDES. Machy (London) v103 n2646 July 31 1963 p 242–52. Two standard methods, using plain and grooved type sine plates, are analyzed and their shortcomings shown; theory of new method; practical procedure illustrated by table for standard tapers and by graphs suitable for all tapers up to 45°, from which inherent reliability and simplicity may be assessed; sensitivity of method is determined, and comparison with that of plain sine table further establishes superiority over latter; it is very simple in operation and only standard equipment, of type in general use, is required.

Universal Sine Mounting Block, A. P. EMEL'YANOV. Meas Techns 1963 n3 Sept 1963 p 195–6 1 fig. Translated from Izmer Tekhn n3 p 12–3 Mar 1963. Describes a massive sine mounting block to avoid the cumbersome combined use of existing quadrilateral mounting blocks and sine bars.

6.7. Spirit Levels

Irregularities of Spirit Levels, DR. RIETH. Zeit für Vermessungen 1887 p 297. Abstracted in minutes Proc Inst Civ Eng v90 1887 p 459–60. Irregularities in level vials are shown to be due to excrescent formations insoluble in alcohol, formed on the side of the tube.

Level of Variable Sensibility, L. MACH. Zeit für InstrumKde v14 1894 p 175–6. The inner wall of the tube of a level is usually made slightly barrel-shaped by grinding, great patience and skill being required. In the level described, there is employed a cylindrical glass tube which can be curved to the extent desired, by means of pressure produced by a fine-pitch screw placed under the middle part.

A Level of Ye Olden Time, O. VON GELDERN. J Assn Eng Soc Dec 1897. Historical review of the earliest contrivances for this use, and a memoir published with the papers of the Royal Acad. of Paris, for the year 1704, by M. de La Hire, describing a level on the principle of fastening an iron rule at its center of gravity to an upright support canting on its base. Discussion.

Hydrostatic and Spirit Levels, R. P. KING. Am Mach v26 June 25 1903 p 902–3. On methods of testing levels and using them, determining the probable error, etc.

Precision Levels and Accurate Leveling. Am Mach v31 Apr 30 1908 p 669–72 and 696. Articles on setting boring-mill uprights with a novel method of level, and leveling planers properly for accurate work. Various contributors.

Spirit Levels, J. BONSDORFF. Zeit für InstrumKde v28 Nov 1908 p 344–6. Discusses the movement of the air bubble in spirit levels. Four levels tested, three very sensitive. Motion of the bubble is similar to that of a strongly damped pendulum. With the three very sensitive levels the motion was aperiodic, but with the fourth the motion was periodic and the period increased as the length of the bubble diminished. The equation for damped vibrations is discussed, and the various constants are determined for the particular levels dealt with.

The Testing of Spirit Levels. Machy (N.Y.) v18 Apr 1912 p 617–8 2 figs. Describes a device for testing spirit levels and its application.

Spirit Levels, E. O. HENRICI. Opt Soc Trans v20 Dec 1918 p 45–7. A description of the requirements which should be fulfilled by levels used for the most accurate work. Bibliography.

Millionth Comparator, Tilting Level Type. NPL, 1919 p 87–8.

Levels and Level Bubbles, S. G. STARLING. Trans Opt Soc v24 n5 1922–23 p 261–88. Density, surface tension, and viscosity of water, benzol, xylol, chloroform, alcohol, and ether with varying temperature and pressure, length of bubble and temperature; damping and length of bubble, damping and diameter of tube; calibration of levels; photographic method of calibration and investigation of the irregularities of the tube; bubble having constant shape.

Grinding and Testing Level Vials, G. N. SAEGMULLER. Am Mach v56 Mar 16 1922 p 405 1 fig. Grinding tubes to curves of long radii. Formula for curves to produce determined sensitiveness. Automatic machine for grinding levels vials.

New Types of Levelling Instruments Using Reversible Bubbles, T. F. CONNOLLY. Trans Opt Soc v25 1923–1924 p 21–37; v26 1924–1925, p 194–7. Describes the properties of reversible bubbles which can be used both graduated and ungraduated. Application of certain such properties to surveying levels.

Pratt and Whitney 15-inch Precision Level. Am Mach v58 Jan 11 1923 p 94–5. Of trussed frame construction providing lightness, rigidity, and comparative insensitiveness to temperature changes.

Société Genevoise 30 Deg. Precision Machine Level. Am Mach v60 May 1 1924 p 671. A graduated level vial is

pivoted on a heavy cast-iron base and is tilted by means of a worm and sector.

Bethel-Player Measuring Machine and Comparator. Am Mach v61, Sept 25 1924 p 521. Embodies tilting-level indicating device. Capacity 12 in. length, 9 in. radius.

Self-Adjusting Precision Level. Eng v119 June 12 1925 p 732–3 5 figs. Precision level made by E. R. Watts & Son, London, which is so conveniently designed that it is common practice for its users to test daily the accuracy of line of collimation; instrument is fitted with bubble, length of which remains invariable even under most drastic conditions.

Spirit Levels, S. WESTON, V. TOWNS. Optical Convention 1926 pt 2 p 642–52. The development of the spirit level is traced from the earliest to the present times. The principal object of the paper is to show how modern workshop methods and designs assisted by laboratory research have brought it to its present high state. Paper deals with regularity of the curve and mountings; mobility or responsiveness of the air bubble; varying length of the air bubble with change of temperature; method of observation. New types are described.

Examination of "Second" Levels (Untersuchungen), B. WANACH. Zeit für InstrumKde v46 May 1926 p 221–38 8 figs. Results of examination of some hundred levels for accuracy, geometric aspect; technical testing for error in curvature; static testing tables of results; shows that in imperfect level, errors in readings are accentuated when length of bubble is small; levels reading to one second and to two seconds of arc, with from 30 to 80 divisions.

Some Observations on Spirit Levels, K. LUDEMANN. Ziet für InstrumKde v48 Jan 1928 p. 31–9. The sensitivity of various types of level has been investigated. It is concluded that the form now in common use on surveying instruments, if used with care, is sufficiently accurate for its purpose. This type consists of a closed glass vessel with a flat top. It is displacing the older type consisting of a brass box with a glass lid. The great disadvantage of this latter is that, in the course of years, the liquid gradually evaporates, finding its way out through the cemented joint between the glass and the metal.

Airtight Spirit Levels, A. DE GRAMONT, G. MABBOUX. CR Acad Sci v187 Nov 12 1928 p 885–6. In order to keep the diameter of the air bubble constant the two glass discs are sealed by a bakelite cement to a metal barrel with a similar coefficient of expansion.

Double-Reflection Level, D. S. PERFECT. Opt Soc Trans v30 n3 1928–1929 p 126–9 3 figs. Level designed to assist the initial leveling of a floating system and to enable observations to be made on the constancy of level over extended periods of time. Its error may be determined by direct measurement and without reversal. The level in any direction is shown.

Measurement of Angles, W. BLOCK. Instrum v3 June 1930 p 363–8 3 figs. Measurement of angles of reflection-goniometer and by levels is described. Extract from Instruction Book for Engineers.

Starrett No. 199 Master Precision Level. Am Mach v73 Oct 9 1930 p 607. A level for set-up men and manufacturers of machinery has been developed. The main ground and graduated vial of 10 seconds accuracy has divisions equalling ½ thousandth of an in. per ft. An auxiliary level is provided to show position laterally. A special alloy iron is employed to obtain freedom from thermal effects. The length of the device is 15 in., height, 3 in., width, 1½ in.; and the weight, 5½ lb.

Measurement of Very Small Angles of Rotation, G. SIADBEI, CR Acad Sci v194 Apr 18 1932 p 1334–6; Zeit für InstrumKde v52 May 1932 p 234–5. A thin beam of light is reflected from the bubble of a liquid level attached to the object whose rotation is to be measured. Angles of half a second may be measured accurately.

Universal Level. Eng v146 n3792 Sept 16 1938 p 348; Engr v166 n4315 Sept 23 1938 p 343. Spirit level, which appears to have numerous uses in building and contracting work, consists of bar of hardwood 2 ft long, with sensitive bubble tube in center which can be used for checking level of horizontal surfaces; pair of sights is fitted to top of bar or leveling staff, and inclined mirror mounted over bubble tube enables bubble to be seen at same time.

Precision Levels for Engineering Workshops. Brit Stand Inst—BS 958: 1941 11 p. Recommended types; recommended scales and sensitivities; finish and accuracy of working faces; zero setting; calibration of; packing; marking; testing of precision levels.

Electrical Head for NPL Level Comparator, D. V. BLAKE, D. C. BARNES. Machy (London) v76 n1946 Feb 9 1950 p 205–7; Eng v169 n4393 Apr 7 1950 p 395–6. Range of comparator designed at National Physical Laboratory in 1919 has been extended and its sensitivity increased by replacing sensitive bubble tube of level comparator by specially designed electromagnetic head which can be used with standard "Taylor-Hobson" electrical indicating unit.

Level Vials—Their Manufacture, Use, and Peculiarities, D. L. PARKHURST. J Franklin Inst v264 n2 Aug 1957 p 105–16. Level vials have many potential uses because of extremely small and accurate measurements that may be made with them and their freedom from mechanical wear and error, but improvements must be made in methods of constructing and filling; improvement could be assured by vibrationless grinding; better filling liquids and improved filling processes; applications.

Remote indication of Angular Displacement, D.F.A. MACLACHLAN, A. M. SQUIRE, G. V. PLANER. Engr v214 n5559 Aug 10 1962 p 235. New instrument, Electrolevel, was developed by English Electric Aviation Ltd., and G. V. Planer Ltd; sensing head incorporates stable electrolytic cell in envelope of borosilicate glass with bubble which can be displaced in relation to 3 film electrode areas, forming active elements of a-c bridge; indicator incorporates transistor oscillator to generate sine wave signal across bridge network; applications in erection of structures such as aircraft wing/fuselage structures and certain types of machine tools.

Level Tester with Optimeter, A. P. SHOKHTIN. Meas Techns 1962 n12 July 1963 p 992 1 fig. Translated from Izmer Tekh n12 p 8 Dec 1962. Describes a level tester of rigid construction, providing stable readings of angles for tested levels of considerable weights. Has a scale factor from 8 to 2''.

Die Verwendung von Sekundenlibellen zur genauen Messung sehr Kleiner Neigungen (The Application of Seconds Levels to the Exact Measurement of Small Inclinations), A. TÁRCZY-HORNOCH. Acta Imeko (Stockholm) v3 n21–HU–158 1964 p 105–13 3 figs 3 refs. The exact knowledge of the deviation from the axial horizontal is necessary in the case of high accuracy instruments to be able to determine the corrections. There are other cases too when small deviations from the horizontal are to be determined. Second levels used for this purpose however have not the sufficient accuracy on account of polishing errors, etc. as experience has shown. On the basis of examinations performed in the last 8 years by the author and by Mr. Gy. Alpár, these angles can be determined with sufficient accuracy even with the use of lesser quality levels. On this problem some results have already been published by the author, among these an automatic level testing equipment. The paper contains a summary of these examinations together with further considerable results.

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6.8. Tapers

The Measurement of Taper Gages. Inspector v2 Dec 15 1919-Jan 15 1920 p 5–11 9 figs. Methods commonly applied by Gage Section, U.S. Bureau of Standards, for measuring simple tapered plug, plug having double taper, plug having triple taper, taper ring gages and profile gages having tapered surfaces. See also NBS Letter Circular L. C. 22 Aug 1919.

Die Messung von Aussenkegeln (The Measurement of External Tapers), O. KIENZLE. Der Betrieb v4 n9 Feb 11 1922 p 299–302 19 figs. The previously used standard gages for taper measurement left out the gradient completely. There are six indicated methods for the measurement of taper which may be developed into measuring instruments. One method is described in detail in which the top element of the taper lies horizontally. The tapered piece is supported on a smoothly operating slide that is pushed under an indicator, which thus establishes the deviation from horizontal.

Measuring Tapers by Means of Discs and Rods, R. J. WORTHY. Mech Wld v73 Jan 26 1923 p 50–1 5 figs Particulars are given for providing simple and rapid formulas.

La Mesure industrielle des dimensions et la verification des formes (Measurement of Dimensions and Checking of Forms), H. STROH. Genie Civ v86 Mar 7 1925 p 230–4 12 figs. Application of length measure for precision measuring of cones, conic plugs, etc., screw threads; checking by optical projection.

The Manufacture and Measurement of Angular-Form Gages, E. A. SWIFT. Machy (London) v29 Dec 2 1926 p 265–9 14 figs. Methods employed by author which have proved satisfactory. Methods of manufacture and measurement of taper plugs, grinding of taper plugs, sine-bar method of determining angular forms, checking taper ring gage by direct measurement.

Measurement of Tapered Fittings, H. S. KARTCHER. Trans SAE E22–II 1927 p 209–11 7 figs. Discusses dimensioning of tapers for consistency with methods of measuring.

Measuring Taper Gage. Machy (London) v33 Oct 18 1928 p 78–9 9 figs. Describes method of measuring a taper plug gage having beveled sides by means of balls.

A System for Measuring Tapers. Am Mach v69 Dec 13 1928 p 907–11, 10 figs. Application of new system for accurate measurement of master taper plug gages for cartridge and gun chambers, worked out by Winchester Repeating Arms Co., is described; system applicable to other taper gages; gagemaker should be furnished with definite dimension measurements not eliminated in finishing of gage and further available for check after gage is in service.

Methods of Measuring Tapered Bores, W. S. ROWELL. Machy (N.Y.) v36 Mar 1930 p 589–90 3 figs. Analysis of methods of measuring diameters of tapered holes, both in duplicating and in originating tapered bore.

Checking a Taper Gage. Machy (London) v36 n920 May 29 1930 p 263 2 figs. Description of method of checking angle and diameter of tapered disks; master taper gage with setting disks in place for checking working gages of male bevel-side type.

Methods of Measuring Tapered Bores. Machy (N.Y.) v36 Mar 1930 p 589–90 3 figs; Machy (London) v37 Dec 4 1930 p 294–5 3 figs. Analysis of methods of measuring diameters of tapered holes, both in duplicating and in originating tapered bore; use of balls in measuring taper bores and use of inside micrometer and guide.

Cone Measurements with Steel Balls, E. ELKINS, H. MELLOR. Machy (London) v56 n1443 June 6 1940 p 298–300. Formulas and dimensions (in inches) for checking internal cones using balls and mandrels.

Innenkegelmessung mit einem Bohrungsmessgeraet mit grossem direkten Messbereich (Internal Taper Measurement wth a Bore Measuring Instrument Having a Large Measuring Range), L. TSCHIRF. VDI Zeit v85 n17 Apr 26 1941 p 403–7. Description of new instrument for measurement of inside taper with great accuracy and for large range of diameters; optical system for transmitting feeler motion is based on Abbe principle; instrument suitable especially for deep conical holes; other types of gages and instruments for measuring taper are reviewed.

Taper Measuring Device. Engrs' Digest (Brit Ed) v5 n10 Oct 1944 p 295–6; Engrs' Digest (Am Ed) v1 n12 Nov 1944 p 686–7. Illustrated description of device which makes it possible to rapidly ascertain dimensions of tapered bodies by direct high precision measurement, no computations being required; chief feature of instrument is provision of self-adjusting rotatable feeler pads, their axes of rotation being tangential with piece to be measured. English abstract from Werkzeugmaschine v47 n6 Mar. 1943, p 136–8.

Measurement of Tapered Plugs; Alignment and Concentricity Plugs; and Receiver Gages. Ordnance Inspection Handb on Gages, p 847– 67 899.21– 899.30.

Taper Measuring Formulae and Methods, W. RICHARDS. Machy (London) v69 n1784 Dec 19 1946 p 786–91 2 figs. Derives basic formulas for measurement of internal tapers with spheres; spheres or discs flush with ends of taper; measurement of taper plugs by means of rolls.

Taper Production, Gauging, and Gauges, W. RICHARDS. Machy (London) v70 n1788 Jan 16 1947 p 67–72 3 figs. Describes the construction and application of a universal taper measuring gage; also degree of accuracy attained. The sine bar method of testing and measuring a taper plug gage. Measuring and testing taper ring gages. Accuracy of the sphere method of measuring taper ring gages.

Large Cylinder and Taper Comparator for Gauge Measurement, R. H. FIELD. Can J Res v25 n3 (sec F) May 1947 p 238–41 3 supp plates. Illustrated description of comparator for accommodating cylinders or cones with maximum diameters of 12 in. and lengths up to 48 in. designed and constructed during war at National Research Laboratories, Ottawa.

Effect of Taper Tolerance on Taper Gauge Measurements, W. RICHARDS. Machy (London) v71 n1815 Aug 7 1947 p 150–3 2 figs. Discusses general effects of taper tolerance upon measurements when using spheres or rolls; relation between taper and angular tolerance; testing taper plug gages with a sine bar.

Checking Tapers by Sine Bar Method, J. W. LEE. Tool Engr v27 n4 Oct 1951 p 44, 52. Equation for calculating sine of included angle; examples show how to find 5-in. sine bar constant for Jarno tapers and for American Standard Steep Machine tapers.

Problems in Metrology, C. MINAIRE. Am Mach v99 n8 Apr 11 1955 p 105–9. Ingenious solutions to awkward measuring problems; linear measurements on sine bar fixture; checking internal tapers; flatness checking blocks;

checking frustum of cone; outside taper gage; taper checkers; calipers for large diameters; no go bore gage.

Fehler bei der Kegelmessung mit Drähten und Endmassen (Errors in measuring tapers with wires and gage blocks), G. BERNDT. Werkstatt und Betrieb v91 n2 Feb 1958 p 69–72. Examination of errors due to differences in thickness of gage blocks, diameter of wires, and to fact that taper is not mounted perpendicular to its base.

Methods and Equipment for Checking External Tapers, C. MINAIRE, Machy (London) v92 n2363 Feb 28 1958 p 483–9, v93 n2382 July 9 p 93–4. Feb 28: Inspection operations for checking conical surface, verifying roundness of section, measuring angle of taper and checking diameters at both ends of circular portion; details of Micyl blocks and gages employed, July 9: Pair of Micyl blocks and gages of latest design described.

Measurement of Working Surface of Conoids by Comparison with Specimen, A. V. RUMIANTSEV, Meas Techns 1958 n1 Aug 1959 p 7–10 1 fig. Translated from Izmer Tekh n1 Jan–Feb 1958 p 7. Describes a new method of measuring on a special machine designed for measurement by comparison with a specimen.

Direct Measurement of Taper, G. GERSHMAN. Tool Engr v44 n1 Jan 1960 p 85–7. New taper micrometer has made it possible to measure taper directly and rapidly with single piece of relatively inexpensive equipment and without necessity of removing work from machine; micrometer, incorporating within itself sine-bar principle, gives

actual value of taper for small angles; parts inspected 10 times faster than with conventional methods.

Measurement of Inside Cones by Universal Instruments, A. S. CHICHEROVA. Meas Techns 1959 n5 June 1960 p 308–10 4 figs. Translated from Izmer Tekh n5 May 1959 p 7. Discusses various methods and sources of error.

Eine neue methode der Winkelmessung an Werkzeug-und anderem Kegeln mit Hilfe des Sinus-Lineals (New method for measuring angles on machine tapers and other tapers with aid of sine taper guide bar), L. GOLDES. Werkstatttstechnik v54 n5 May 1964 p 223–9. Advantages of method described over two classical measuring methods, are greater measuring certainty, and simpler calculation; numerical table for usual tapers and graphical illustrations for tapers with angle up to 45° are presented which make it possible to evaluate sensitivity and simplicity of method.

New Sine-Table Method of Measuring Angle of Male Tapers, L. GOLDES. Quality Engr v28 n6 Nov–Dec 1964 p 170–7. New method of self-deviation and compensation for measuring angle of male tapers is described; standard methods such as plain taper compensation and taper-plus-tilt compensation are discussed; in new method, cone rests on sine table and against flat stop attached to side of instrument; equations sufficient for solving problems of setting up nominal taper angle or determining actual taper angle are given; respective sequences of operation in application of method are shown; graphical solutions simplifying work are described.

Addendum to Section 6

6.5. Angle Measurement by Interferometry

On the Application of Interference Methods to Astronomical Measuremnts, A. A. MICHELSON. Phil Mag ser5 v30 n182 July 1890 p 1–21 11 figs; Nature v45 n455 Dec 17 1891 p 160–1 3 figs. When the cap of a telescope objective is provided with two slits adjustable in width and distance apart the instrument is converted into a refractometer. If such a combination be focused on a

star there will be a series of colored interference bands with white center, the bands being equidistant and parallel to the two slits. The method is applicable to the measurement of the angular magnitudes of very small or very distant sources of light, such as planetoids and satellites, or larger bodies, and the angular distances between very close double stars. See also H. N. RUSSELL, p. 41.

4.3. Calibration of Tapes

(Invar.) Nouvelles Recherches sur la Dilatation des Aciers au Nickel (New Research on the Dilatation of Nickel Steels), C. E. GUILLAUME. CR Acad Sci v136 Feb 2 1903 p 303–6. The production of alloys of small expansion depends upon the auxiliary substances, e.g., manganese, carbon, silicon. Has obtained an alloy of such small thermal variation that its amount cannot be measured with certainty. A table of values for various alloys between 0° and 38°C is given. See also Mettalographist v6 Apr 1903 p 162–5.

Changements Passagers et Permanents des Aciers au Nickel (Transitory and Permanent Changes of Nickel Steels), C. E. GUILLAUME, CR Acad Sci v136 Feb 9, 1903 p356–8. The 64–36 iron-nickel called invar was discovered and has proved of considerable scientific and practical interest because of its low coefficient of thermal expansion at room temperature. Bars of the alloys were kept for long periods at steady temperatures, and the variations of length, due to the after-effect of a previous heating, were observed. Alloys of different kinds were considered, and their suitability as standards of length were commented upon. The distinction (previously pointed out) between reversible and irreversible alloys was again remarked in these experiments.

Precise Measuring with Invar Wires and the Measurement of Kootenay Base According to the Method of the International Bureau of Weights and Measures, P. A. CARSON. Roy Astron Soc Canada Jan–Feb 1911.

The Dimensional Behavior of Invar, B. S. LEMENT, B. L. AVERBACH, M. COHEN. Trans Am Soc Metals v43 1951 p1072–97 11 figs 15 refs. The dimensional changes which occur during the aging of invar have been studied as functions of time, temperature, heat treatment and chemical composition. Starting from a quench-anneal, it is found that a contraction takes place on aging because of stress relief. However, there is also a superimposed expansion due to a lattice change which occurs on prolonged aging in the temperature range 20 to 95°C (70 to 205°F). The solubility of carbon in invar, as determined by X-ray diffraction, is 0.18 weight per cent at 830°C (1525°F), and is vanishingly small at room temperature. Any excess carbon exists as graphite. The expansion coefficient has been studied over the range -40 to $+40$°C (-40 to 105°F) as a function of composition and heat treatment, and a heat treatment which results in good dimensional stability and a low expansion coefficient has been devised.

Section 7. Measurements of Deviations from Geometrical Regularity

7.1. Planeness Measurement

Miscellaneous Papers on Mechanical Subjects. J. WHITWORTH. Longman, Brown, Green Longmans, and Roberts, 1858 183 p. Contains a paper on plane metallic surfaces or true planes.

Interference Bands and Their Applications, LORD RAYLEIGH. Nature (London) v48 p212 June 29 1893. Includes a discussion of the use of a free surface of water as a reference surface; also the formation of interference bands.

Interference Fringes with Glass Wedges, S. R. MILNER. Phil Mag v16 Sept 1908 p 429–36. If two pieces of ordinary plate glass of approximately the same thickness are placed one on the other, and the airfilm between them is observed by sodium light, the system of Newton's fringes, formed by the interference of the light reflected from the two surfaces of the air-film is seen. Occasionally, by very close inspection, another system of fringes may be seen which is found by the interference of the rays which have been farther reflected from the non-adjacent faces of the plates so as to meet again at the interface. These fringes become clearly visible if we cut off all the light reflected from the film except that by which they themselves are formed. The method of doing this and its application to the testing of plate glass sheet are explained in detail.

Testing Surfaces with a Glass Plate, L. P. ALFORD. Am Mach v34 Apr 13 1911 p 682–3 8 figs. Describes a simple and valuable method of testing plane surfaces as the surfaces of size blocks, by bringing them in contact with the accurate surface of a piece of glass and noting the bands, or fringes, of color.

The Testing of Plane Surfaces, P. E. SHAW. Roy Soc Proc Ser A v86 Feb 28 1912 p 227–34. The usual plane surfaces, originated by the triplicate method, may have minute undulations too small to be detected by the "raddle" process. The author's apparatus is a very sensitive spherometer of special form with which the plate under test is surveyed. The zero reading of the spherometer is determined by comparing it with a similar spherometer with which the surface has been surveyed. Actual tests are described. The mean error of a carefully scraped surface plate is given as 2×10^{-5} in. and of commercial plate glass from 3×10^{-3} in. to 3×10^{-4} in.

Note on a Sensitive Method for Examining some Optical Qualities of Glass Plates. Earl of BERKELEY, D. E.

THOMAS. Phil Mag v29 Apr 1915 p 613–17 3 figs. Describes the use of a Rayleigh interferometer for testing a glass plate. Method 30% more sensitive than Michelson's can be applied in construction of echelon plates.

Flatness Tests at Bureau of Standards, R. L. RANKIN, Am Mach v50 p 1218 June 26 1919. Gives account of optical true planes made and used at the Bureau of Standards.

The Optical Flat—A Practical Measuring Tool, H. L. VAN KEUREN. Am Mach v53 July 15 1920 p 107–12 8 figs. Describes optical flat and its use for shop measurements in considerable detail. The explanation is summarized in a series of 17 rules covering the use of the optical flat for shop measurements.

Van Keuren Optical Equipment for Comparison of Standards. Am Mach v53 July 22 1920 p 187. The equipment comprises two working optical flats, one master flat and one source of monochromatic light. Comparisons can be made in units of one-half wave length of light, which for daylight is approximately 0.00001 in. As it is easy to estimate with the eye one-tenth of the width of an interference band, the difference of 0.000001 in. may be seen. Any one of the three optical flats may be used for flatness tests, though only two are required for comparison of length. However, all the flats have one accurate surface and can be used to test each other by the method ordinarily used in originating surface plates. It is claimed that the accuracy of the working flats is within 0.000005 in. and that of the master flat is within 0.0000025 in.

Testing Plane Surfaces by Interferometer, C. G. PETERS, H. S. BOYD. J Opt Soc Am v4 Nov 1920 p 407–19 8 figs. In testing the planeness of an optical surface by interference fringes in monochromatic light it is generally assumed that straight fringes equally spaced indicate planeness, and curvature in the fringes departure from a true plane. These assumptions are correct for normal incidence, but when the surface is viewed obliquely they may introduce considerable errors in the determination of planeness. Theoretical discussion of the magnitude of errors introduced in specific cases. For one percent accuracy the obliquity should not exceed tan $^{-1}1/7$.

A New Interference Apparatus for Testing Haemacytometers, C. G. PETERS, B. L. PAGE. Sci Papers NBS n507 June 3 1925 p 221–36. Describes interference apparatus for measuring the planeness of cover plates and planeness

and parallelism of the surfaces of the supporting and central strips of the chambers within a few hundredths of a micron; also for measuring the depth of chambers.

Optical Measuring Tools. Machy (N.Y.) v32 June and July 1925 p 768–71 and 867–70 22 figs. Zeiss optical flats are described and their use to test the planeness of the anvil and spindle faces of a micrometer caliper is shown in Fig. 14.

Untersuchungen ueber die Genauigkeit von geschabten und geschliffenen Flächen (Accuracy of Scraped and Ground Surfaces), O. MACKENSEN. Werkstattstechnik v20 Sept 1 1926 p 526–8 3 figs. Examination of two ledges, one scraped, other ground, by means of optical ruler, showing great superiority of ground surface.

Testing Flatness with Gage Blocks, J. R. GODFREY. Am Mach v65 Dec 30 1926 p 1059. Method consists in placing a straight-edge on four equal gage blocks on surface to be tested.

Examination of Very Flat Surfaces for Interferometry, M. DUFFIEUX. Rev Opt v11 Apr 1932 p 159–66. The surfaces to be tested are resilvered with a layer which is semi-transparent and then examined in pairs with the help of a specially constructed interferometer. The methodical displacement of the interferometer allows the tracing of the fringes and thus the thickness of the air gap. Accidents of relief amounting to 3 mμ can be detected. The errors introduced by the silvering can be avoided or disclosed. The individual topography of the two surfaces can be found by graphical methods.

Determination of Defects in Flatness of Surfaces, A. BIOT. Ann Soc Sci de Bruxelles v52 June 8 1932 p 54–8. A comparison of two surfaces is made by selecting two points along a line for each surface. With these surfaces facing each other and using an interference method with transmitted monochromatic light, the distance apart of successive fringes is found. This process can be continued across the surface. A precision of $\lambda/200$ can be readily obtained. The process can be used to determine the three principal radii of curvature of a body.

Testing Planeness of Surface by Haidinger's Rings, O. SCHONROCK. Zeit für InstrumKde v 59 Jan 1939 p 31–40. The author develops the theory of an interferometer method for determining the deviation from planeness of the surface of a glass plate without reference to a plane liquid surface.

Method for Measurement of Flatness of Polished Surfaces, C. TUTTLE, R. CARTWRIGHT. J Opt Soc Am v30 n8 Aug 1940 p 348–50. Optical method providing for rapid inspection of extended surfaces described; two beams of parallel light are reflected by sample through cylindrical lens to form astigmatic image of source; if this image is single line, surface is flat within accuracy of instrument; inspection device for testing glass to be used for photographic purposes now in service.

Optical Flats. Aircraft Prod v3 n27 Jan 1941 p 34–5. With optical flats it is possible to gage surface inaccuracies which are too small to be checked by micrometer; use of optical flats is based on fact that if glass or quartz plate is put into close contact with surface of another plate, series of color fringes or bands will be visible and these will indicate inaccuracies of surface being checked.

Generating Flat Surfaces, E. V. WAIT. Eng v152 n3957 Nov 14 1941 p 381–3. Particular interest centers around Whitworth's three-plate method, because no machine made tools or instruments are necessary, and because plates of highest degree of accuracy can be generated; speaking generally, engineers are under mistaken impression that this process is much simpler in operation than it actually

is; this has been due to deficiency in published literature, which it is purpose of this article to make good.

An Interferometer for Controlling Large Mechanical Details, V. P. LINNIK, CR Acad Sci URSS v35 n1 p 16–9 1942. Describes an interferometer for the examination of long surfaces of linear nature (plane, cylindrical) for departures from rectilinearity. As compared with a previous arrangement described by the author in the same journal (32, 3, 1941), the present scheme is free from the drawbacks associated with aberrations due to superficial irregularities. As an example, the interference pattern obtained from a plate of mirror-glass 400 mm. long is reproduced.

Checking Micrometers with Optical Flats. Machy (London) v60 n1541 Apr 23 1942 p 353. Method of checking anvils of screw micrometer for flatness and parallelism with assistance of optical flats; sets of flats are made to nominal thicknesses of 1 in., 0.500, 0.5062, 0.5124 and 0.5186 in; working surfaces are flat to within 0.00001 in., and they are parallel to within 0.00002 in.

Auto-Collimator Test for Flatness, W. A. TUPLIN. Machy (London) v61 n1577 Dec 31 1942 p 729–34. Method of checking surface flatness, using optical instrument to measure rise and fall of reflected ray from tilted mirror on auto-collimator. Instrument is used for checking straightness of long narrow surface, such as lathe bed and determination of departures from flatness of surface, such as large surface plate.

On the Planenes of Interferometer Plates, E. K. RASMUSSEN. Danske Vidensk Selsk Mat -Fys Medd v23 n3 18 p 1945. Describes a method of applying interference fringes to measure the planeness of Fabry-Perot plates and discusses the accuracy of the method and the dependence of the resolving-power on the planeness. The use of a wedge between silvered plates is advocated for fine-structure observations on intense lines, using Fizeau fringes.

The Measurement of Finely Finished Surfaces by Optical Interference, C. J. TIMMS, Sci Instrum v22 p 245–6 Dec 1945.

Plane-Parallel Glass Indicators and Technical Interformeters, J. G. VOGL. Tekn Tidskr v76 June 29 1946 p 657–64 in Swedish. The principle of measurement of surface irregularities with interference by means of a plane-parallel glass plate is explained in detail and the contour mapping of the surface is described. Usual interferometers, including the Twyman-Michelson instrument, are described and various applications are explained, with illustrations.

Additional Interference Fringes Produced by Scattering and Reflexion, V. D. HOPPER. Nature London v158 July 20 1946 p 101. A double system of interference fringes, produced by a combination of multiple reflection and scattering similar to that suggested by Bauchwitz and Schoenberg was observed with an arrangement of aluminized and semi-aluminized optical flats with scattering scratches which is described.

Interference Fringes Produced by Scattering and Reflection, V. D. HOPPER. Proc Roy Soc Vict v58 Pts I–II 1947 p 69–80. When a partly polished optical flat was placed face downwards on a standard flat, and illuminated by a small bright white-light source, the pattern corresponding to the colours of thick plates was observed encompassing the image of the source. When the top surface of the standard flat was aluminized, the pattern was much more intense. A new phenomenon occurred when the pair of plates was illuminated by light from a Hg lamp which passed through a narrow slit, the single pattern giving place to two separate patterns, whose intersections gave the locus of the pattern observed with white light. When the scattering surface was made semi-reflecting, the double set of patterns became sharper, one set

being localized in the plane of the scattering surface, the other in planes corresponding to the position of the Newton ring pattern formed by multiple reflections. Various experiments are described for studying these patterns. It is concluded that all three systems of fringes are produced by multiple reflections between the two reflecting surfaces, the assumption of Stokes that the colours of thick plates could only be produced by light passing and repassing the same particle being unnecessary. It is considered that the pattern corresponding to the colours of thick plates is produced by the summation of the intensities of the light from a pair of separate patterns of the simpler Newton ring type, one set being produced by light scattered by the top surface and then suffering multiple reflections between the surface before reaching the observer, the other set being produced by light from the source suffering multiple reflections between the plates, and finally being scattered by the scattering centres.

Testing of Flatness by Beam Comparator Method, R. MARRINER, W. O. JENNINGS. Engr v 184 n4778 Aug 22 1947 p 164–5. Method described was devised at National Physical Laboratory and used for testing quickly and with reasonable accuracy large batches of surface plates of same size; it is particularly convenient for testing flatness of surfaces during manufacture; principle is that of comparing by means of sensitive dial indicator straightness of succession of generators in surface under test with that of known reference straightedge.

A Liquid Surface Interferometer, H. BARRELL, R. MARRINER, NPL. Brit Sci News v2 1948 p 130; Nature n4118 Oct 2 1948 p 52a. Describes a Fizeau type of liquid surface interferometer used at NPL.

Liquid Surface Interferometry, H. BARRELL, R. MARRINER, NPL. Letter in Nature v162 Oct 2 1948 p 529–30. The surface of liquid paraffin has been used to provide a reference plane up to 25 cm dia. For this dia. the earth's curvature produces a difference in height of only 12 A, while liquid paraffin has less capillary curvature than water, which has been used previously.

Testing of Polished or Fine Ground Surfaces for Flatness, A. J. ELLIOTT. Sci Instrum Phys Ind v26 Jan 1949 p 24. The testing of nearly flat surfaces by the astigmatism produced in a light beam reflected from the surface is discussed. The use of the test for ground surfaces is described, and attention is drawn to its use in the working of soft materials such as rock salt.

Test of an Optical Flat by the Fabry Perot Etalon, T. SAKURAI, K. SHISHIDO. Sci Rep Res Inst Tohuko Univ Ser A v1 May 1949 p 83–6. An application of Fabry's fringe method for the examination of optical flats. The flats are mounted as a Fabry-Perot, fringe order being changed by altering gas pressure between the flats. The accuracy of 1/50th of a light wave is claimed.

Zur Messung der Ebenheit von reflektierenden Flaechen mittels Interferenzen gleicher Dicke (Measurement of flatness of reflecting surfaces using interferences of equal thickness), R. LANDWEHR. Optik v5 n6 Sept 1949 p 354–64. Consideration of deviation of uniform and non-uniform spherical surfaces from flatness; formulas and nomograms for determining curvatures.

Improving the Quality and the Testing of Optical Flats, E. EINSPORN. Optik v7 n3 1950 p 147–68 in German. A discussion of the evaluation of slight curvature of optical flats by means of Fizeau fringes. The method is shown to be comparable to that using Haidinger fringes. A discussion is included on the effect of combining slightly curved flats.

Interferometer for Testing Measuring Gauges, Eng v170 n4417 Sept 22 1950 p 243–5. Instrument being manufactured by Coventry Gauge and Tool Co. under name of Matrix Interferometer; by means of instrument, deviations from flatness of order of one millionth of inch on highly finished surface may be seen by aid of interference fringes which they produce. See also discussion, by H. BARREL and J. PUTTOCK, in n4426 Nov. 24, p. 412.

Contour Mapping of Optical Surfaces with Light Waves, Glass Indus v32 n8 Aug 1951 p 409–11. Vacuum light interferometer developed by J. B. Saunders of National Bureau of Standards makes contour maps by photographing interference patterns formed when light waves are reflected from precise optical surfaces of specimen and standard reference of known shape; adding additional lines between half wavelength lines reduced spacing to 6 ten-millionths of inch.

Precise Topography of Optical Surfaces, J. B. SAUNDERS, J Res NBS v47 n3 Sept 1951 (RP2239) p 148–55. Unit of length usually used in measuring optical surface features, by interference of light, is one half wavelength of monochromatic light that is used; method is described in which unit of length is much smaller fraction of wavelength; topographic maps of optical surfaces are made in which contour interval is less than 1/30th wave length.

Determination of Planeness and Bending of Optical Flats, W. B. EMERSON, NBS. J Res NBS v49 Oct 1952 p 241–7. The true contours, undistorted by gravitational bending, were determined for four 10⅝ in. diameter standard optical flats of fused quartz. The bending deflections of these flats were determined by a method based upon the differential bending with thickness of the flats. Bending deflection curves of a flat supported at three points equidistant from the center of the flat and equidistant from each other were obtained. The locus of the bending deflections at the center of a flat, similarly supported but with supports at different distances from the center, approximates a straight line. This paper describes the method used to obtain the true contours and the bending deflection curves of the flats, and compares the bending values so determined with theoretically derived values.

Collimator and How To Use It, R. F. MITCHELL. Am Mach v96 n23 Nov 10 1952 p 161–4. Goniometer-Collimator for use in shop operations; collet and lathe tool angles easily checked; bedway flatness can be measured to 0.00007 in.; applications illustrated.

The Science of Precision Measurement. The DoAll Co. 1953. Chapter 6 covers applications of optical flats.

Why Don't We Standardize Surface Plate Specs? R. J. RAHN. Am Mach v97 June 8 1953 p 169. Suggests a form of specification.

A Micro-Reference Flat for Multiple Beam Interferometry, S. TOLANSKY, M. OMAR. Note in J Sci Instrum v30 Sept 1953 p 337–8. For high definition multiple beam interference fringes, the optical flat must approach very closely to the object. A micro-flat is described enabling close approach to selected regions of an object, such as a crystal, in which there are areas differing considerably in surface level. This flat consists of the polished tip of a small truncated cone. The cone tip (i.e. the flat) has a diameter of 1 mm or less. The mounting and method of adjustment are described. The technique is illustrated by use with diamond and silicon carbide crystal surfaces.

The Metrology of Surface Plates, J. C. MOODY. Sandia Corp., Oct 1953. Discusses application of the autocollimator. See also: Tool Engr Feb 1958 and Dec 1958.

Testing of Large Optical Surfaces With Small Test Plates, J. B. SAUNDERS, NBS, J Res NBS v53 n1 July 1954 (RP2514) p 29–34. With increased use of massive optical parts, there is need for practical method of testing large

optical surface with small standards, available in average optical shop; simplified formulas are used to apply statistical method for obtaining increased precision; practical example illustrating procedure for testing surfaces assumed to have revolution symmetry.

"New Look" in Surface Plates, A. P. DIEFFENBACH. Machine & Tool Blue Book v49 n9 Sept 1954 p 196–8. New forms of surface plates described and illustrated; long surface plate made up of three individual plates is used to check straightness on airplane wing struts; advantages of round type surface plate; Surface Floor Tee-Rail.

It Takes Three-Point Specification to Insure Surface Plate Flatness, R. J. RAHN. Tooling & Prod v20 n7 Oct 1954 p 123–5, 140. Details of specification for black granite surface plates produced by Rahn Granite Surface Plate Co., Dayton, Ohio; errors will be not over 100% of unit being used.

Precision Measuring Tools. Catalog and Handb n36 Appendix G Optical Flat Specifications and Data. The Van Keuren Co., Watertown 72, Mass. 1955. Discusses testing of flatness using an optical flat; testing of flat ring surfaces; and presents tentative optical flat specifications.

Surface Plates Compared by Physical Tests, R. MERRIAM. Tool Engr v35 n2 Aug 1955 p 99–100. Strength characteristics, compressibility and absorption, and thermal properties of granite and black granite plates; comparison with cast iron plates.

How to Calibrate Surface Plates in Plant, J. C. MOODY. Tool Engr v35 n4 Oct 1955 p 85–91. Method used in metrology laboratory at Sandia Corp, Albuquerque, NM is application and extension of procedures developed by K. J. Hume and involves no new principles; details of autocollimator employed; directions for converting autocollimator readings into linear displacement in hundred-thousandths of inch are given, accompanied by work sheets for calibrating 48 x 78 in. surface plate.

Control and Interferometric Measurement of Plate Flatness. P. D. CARMAN. J Opt Soc Am v45 n12 p 1009–10 Dec 1955. For two flatness requirements involved in the testing of air survey cameras special techniques are devised. Photographic plates used for camera calibration should be flat to one or two microns. To achieve this the ¼-in. plate glass supporting the emulsion is bent flat and held flat during exposure. Flatness is determined in an interferometer using infrared light. Camera register glass flatness is also checked interferometrically. Since counts of over 100 fringes are required, two monochromatic light sources are used, chosen to produce regular arrangements of black and coloured fringes which permit counting by groups.

Untersuchungen über die Eignung eines Flüssigkeitsspiegels als Ebenheitsnormal (Investigation on the Use of a Liquid Surface Mirror for a Flat Plane of Reference). R. BÜNNAGEL. Zeit Angew Phys v8 n7 1956 p 342–50 in German. Experiments are reported using paraffin, silicone oil and castor oil on mercury. Distortions produced on the liquid surface both by static charging and by temperature variations are studied. With a disc of 24 cm diameter at 4 cm from the edge the radius of curvature is 2×10^4 km. The influence of earth curvature is not established. The observed curvature is the same for the three liquids studied. Static charges can persist for several days and are formed even by the pouring of the oil on the mercury. To avoid this the oil used should have a conductivity of at least 10^{-11} ohm^{-1} cm^{-1}. With castor oil, a temperature difference of 0.01 °C at the ends of a 11 cm disk does not produce a detectable effect.

The Showing of the Degree of Planeness of a High Polish by Means of Surface Topography, R. SEGELETZ.

Optik v13 n2 1956 p 59–63 in German. A description of the best method for revealing clearly the topography of a large "flat" as derived from interfereuce fringe patterns. The method of computing the complexities of the topography in terms of contour lines 0.01μ apart is discussed. These contour lines are derived from ordinary fringe patterns.

Einfaches Verfahren zur topographischen Darstellung einer Optischen Planfläche (Simple Method for the Topographic Representation of au Optically Plane Surface), R. BUNNAGEL. Zeit Angew Phys v8 Feb 27 1956 p 447. Method is based on the evaluation of a unique photograph of Fizeau interference. (Partial translation available).

Intercomparison of Optical Flats, S. W. HUGO. Mech Wld v136 n3444 Apr 1956 p 150–2. Comparison of three flats, not supplied as set; flats comprise circular one, 2¼ in. diam by 7/16 in. thick and two rectangular ones, 2 in. by 1½ in. by ½ in. thick; deduction from results leads to establishment of test routine; several flats were intercompared but three described were selected as demonstration set in view of their particular contour.

Production of a Mercury Mirror which is Insensitive to Shocks and its Application as a Flatness Standard, R. BÜNNAGEL. Optica Acta v3 n2 June 1956 p 81–4 in German. A mercury mirror which is insensitive to vibration consists of a layer of mercury about 0.2 mm thick. The formation of such a thin layer is achieved by using a vessel of a metal which readily forms an amalgam. By silvering the inner surface of the metal vessel the mirror is made durable, and the formation of a skin on the mercury surface is prevented. The flatness of the mercury mirror has been tested by two different interferometric methods, and its suitability as a standard flat established. Multiple beam interferometry may be used to increase the accuracy of the testing for flatness. As every liquid mirror flows when its position is slowly changed, a firm mounting is necessary.

A Simple Technique for the Topographical Evaluation of an Optical Flat, R. BÜNNAGEL. Zeit Angew Phys v8 n9 Sept 1956 p 447–50 in German. A mercury surface is used as reference mirror. A geometrical method of deriving the topography of a nearly plane surface from the Fizeau fringe pattern is described. The limits of error are discussed.

Checking Flatuess of Plane Surfaces with Straight-Edges, C. MINAIRE. Machy (London) v91 n2335 Aug 16 1957 p 357–62. Wedge blocks for checking flatness, checking flatness of surface plate; topography of surface plate; obtaining true plane surface with minimum removal of material.

Interferometric Testing of the Planeness of Long Beds. K. KUHNE. "Optics of all Wavelengths" Meeting, Jena, 1958 p 362–8 in German. The testing of beds of some meters in length for precision machinery is described. An interferometric set up is used which employs Fizeau double slits and an autocollimation device. Constructional and operational details are given. As an example the testing of a 4 m long test-bed is illustrated.

Can You Prove Flatness of Your Flat Surface Plates? Here's How, E. W. PENNINGTON. Tooling & Prod v24 n2 May 1958 p 69–70, 72 74, 76. Planekator method devised by R. J. Rahn of Rahn Granite Surface Plate Co. for calibrating out-of planeness of surface plate is simple, accurate, and fast working; master geometrical reference plane which is "suspended in air" above surface plate can be established or located; procedures described.

Zur Steigerung der Genauigkeit mikrointerferometrischer Untersuchungen und zur einer Interferenz-Sphaerometrie (Improvement of accuracy of micro-interferometric exami-

nations and problem of interference-spherometry), R. LANDWEHR. Zeit InstrumKde v 66 n7 July 1958 p 134–S. Corrections to be considered in precise micro-interferometric work to determine form of objects, where double beam interference with conventional micro-interferometers is used; possibility of more accurate interference-spherometry. 17 refs.

Checking Flatness with Straightedges, C. MINAIRE. Machy (N.Y.) v64 n12 Aug 1958 p 99–102. Set of three special blocks used to check flatness instead of making up various gage block combinations, which requires more time; checking flatness of surface plate; obtaining true plane surface with minimum removal of material.

Applications of the Interference Strioscope to Metrology, M. PHILBERT. Rev Opt v37 n12 Dec 1958 p 598–608 in French. A simple apparatus is described, using interference between two beams formed by binefringence. Its application in wind tunnel work is given in detail and some results are shown. Other uses are the testing of the figure of optical surfaces and the detection of veins in optical materials.

Interferometer for Large Surfaces, J. B. SAUNDERS, F. L. GROSS. J Res NBS v62 n4 Apr 1959 (RP2943) p 137–9. Instrument described which permits testing of large areas, such as layout plates, obtains extension to large areas by causing collimated beam of light to reflect from specimen at large angle of incidence; resultant fringe pattern is contour map of surface relative to arbitrarily chosen plane and contour interval is function of wavelength and angle of incidence.

Instruments for Measuring Surface Irregularities and Alignments. Machy (London) v94 n2421 Apr 8 1959 p 775–6. Description of straight line interferometer capable of measuring profiles of surfaces up to 15 in. long with accuracy of 15 microin.; instrument has been applied, for example, for checking straight edges and precision surfaces of such parts as sealing rings for axial flow compressors.

Indicating Surface Flatness with Electronics., P. E. CARBONE, Tool Engr v43 n1 July 1959 p 57–8. To fulfill need for fast checking method, electronic straightedge was developed to measure flatness within 0.000025 in. over 120 in.

A Method of Testing Optical Flatness of Pre-polished Glass Surfaces, A. S. HAMEED, S. HARIHARAN. J Sci Industr Res v18A n7 July 1959 p 311–3. A method for the quantitative estimation of the form of an optical surface, just before polishing, is described. The optical layer with suitable modifications is used for the purpose, so that departures from a standard form, say an optical flat, can be evaluated in terms of wavelengths of light. This data will be helpful in correcting surfaces even in the pre-polishing stages. The time spent in effecting the corrections at this stage will be very much less than the time taken in the figuring stages, after polishing. The results obtained were verified by interference methods.

How to Calibrate Small Surface Plates, R. J. RAHN. Tool Engr v43 n3 Sept 1959 p 111–3. Dimensional variations as small as five millionths of inch can be measured with auto-collimator if instrument is used correctly; calibration with auto-collimator on plate and off plate; readings taken are shown and curves obtained illustrated.

Herstellung und Verwendung eines gegen Ershütterüngen unempfindlichen Quecksilberspiegels als Ebenheits normal (Production and Application of a Mercury Mirror Insensitive to Vibration as a Planeness Standard), R. BÜNNAGEL, PTB. Optics in Metrology. P. MOLLET. Pergamon Press 1960 p 172–8 2 figs 8 refs. Mirror consists of a layer of mercury about 0.2 mm thick. Thin layer achieved by using a metal vessel which readily forms an amalgam. The mirror is made durable by silvering the inner surface of the metal vessel, and the formation of a skin on the mercury surface is prevented. Flatness has been tested by two different interferometric methods, and suitability of the mirror as a standard flat established. As every liquid mirror flows when its position is slowly changed, a firm mounting is necessary.

Check Surface Plate Flatness by Applying Geometry of Sphere. R. J. RAHN. Tooling and Prod v26 n5 Aug 1960 p 41–4. Unusual approach to surface plate flatness based on premise that plane is actually sphere with infinite radius, and segment of sphere, having radius much less than infinity, would make very good surface plate; mathematical calibration of spherical surface; inspection of surface plate with ordinary tool inspection.

Fehlermöglichkeiten beim Messen Zylindrischer Teile mit Kugeligen Messflächen (Possibility of Errors in the Measurement of Cylindrical Parts with Spherical Measuring Surfaces), O. NIEBERDING, S. TROST. Zeit für Praktische Metallbearbeitung v55 1961 p 163.

Testing the Straightness of Lines and the Flatness of Surfaces, A. C. S. VAN HEEL and J. D. DE VEER. Optical Instrum Conf London 1961 p 383–405. By making use of conventional optical parts, alignment and the flatness of surfaces can be tested to within a few tenths of a second of arc by making use of spherical aberration and diffraction. The range in some cases is several hundreds of meters, and the brightness of the diffraction pattern is high enough for observation in daylight. Only flat and spherical surfaces are needed. The most simple form to test alignment is a sphere with a cap of the same material of very good homogeneity. A concave spherical mirror and a flat mirror were used in combination, in order to obviate the stringent requirement of homogeneity of the glass. Though the sphere with cap can be used also to test the flatness of surfaces, other means are more efficient. In the first place one spherical mirror with one minute light source (of white light) suffices to test the flatness up to distances of 20 meters with a precision below one second of arc. By combining a concave and a convex spherical mirror, precision can be lowered to a few tenths of a second of arc, while the observation distance is enlarged. The working of the mirrors is based on the forming of (colorless) "rainbows," a fact that is perhaps not well known. The diffraction pattern associated with these rainbows (Airy's fringes) makes it possible to attain the mentioned precision. Much time was given to testing the straightness of the line produced by the apparatus by independent means, a difficult process seldom applied by other workers.

Analysis in Use of Optical Flats, S. W. HUGO. Mech Wld v141 n3498 Jan 1961 p 6–10. Discussion of geometrical analysis of possible errors arising in lapping of gage surfaces and their comparison with reference standard by methods of comparative interferometry; methods are equally applicable to checking of slip gages and notes on checking of secondary gages are appended; illustrated with diagrams and calculations.

Investigation of Surface Deformation. L. GRUNBERG, D. SCOTT. K. H. R. WRIGHT. Brit J App Phys v12 n4 Apr 1961 p 134–40. Methods used in National Engineering Laboratory for studying surface deformation; enhanced photoelectric emission is studied with open-ended Geiger Mueller counters or electron multipliers; oxide films are studied by electron microscopy and changes in chemical reactivity by radioactive tracers; surface topography, important factor in lubrication and wear research, is studied with aid of interferometry, phase contrast and electron microscopy.

Optical Flats. Federal Specification GG–O–635 May 31 1960, Amendment 1 May 10 1961 6 p. Available from

General Services Administration Region 3, Federal Supply Service, Printed Materials Supply Division, General Services Regional Office Bldg., Washington, D.C., 20407. 5¢. Covers reference, master, and working flats. Material of fused quartz and borosilicate glass. Design, accuracy, and testing.

Multiple-Wavelength Multiple-Beam Interferometric Observation of Flat Surfaces, D. R. HERRIOTT. J Opt Soc Am v51 n10 Oct 1961 p 1142–5. Interferometric method which reduces contour interval between multiple-beam fringes to between 1/20 and 1/100 wavelength; application to critical examination of Fabry-Perot plates for use in continuous helium-neon optical masers.

Errors in Checking Linearity of Large Plates, K. I. ABADZHI. Meas Tech 1961 n2 Oct 1961 p 93–7 4 figs 7 refs. Translated from Izmer Tekh n2 p 3–6 Feb 1961. Discusses the relative merits of different methods of testing.

Flatness of Large Areas Verified Easily, J. H. WILSON. Machy (N.Y.) v68 n2 Oct 1961 p 110–4 ; Machy (London) v99 n2563 Dec 27 1961 p 1496–7. In lapping large ordnance parts, problem of controlling flatness to 50 millionths of inch on 7 ft table of Lapmaster machine had to be solved at General Electric's Pittsfield Ordnance Dept ; solution was found in development of beam type checking bar because it met joint demands of accuracy and speed ; 3 holes are tapped in bottom flange to accommodate 3 hardened spherical feet ; this arrangement permits fast setting of indicators and good repeatability in results.

Inspection of Flat Mechanical Parts, Determining Optimum Reference Co-ordinate Axes, M. FORESTIER. Microtecnic v16 n1 Feb 1962 p 1–6. Two methods described ; first is based on principles of least squares and utilizes exclusively means of computation ; second is based on opinion and is graphical process.

Multiple-Pinhole Multiple-Beam Interferometric Observation of Flat Surfaces, M. V. R. K. MURTY. App Optics (USA) v1 n3 May 1962 p 364–5. It is pointed out that in the testing of optical flats by multiple-beam interferometry it should be possible to use a series of off-axis pinhole sources and thus obtain several sets of fringes displaced relative to each other. This will simplify the use of the technique. Formulae are given for the relation between pinhole and uniform fringe spacing.

A Simple Machine for Testing Flatness Using Air Gauging, B. GALE, L. WILSON. J Sci Instrum (GB) v39 n12 Dec 1962 p 638–9. The machine consists of an accurately ground plate on which a carriage bearing a specimen can be positioned using lead screws. The deviations of the surface of the specimen are measured, with respect to a fixed pneumatic gauge head, with an accuracy of $\pm 1.5 \times 10^{-6}$ in.

Fire Polished Glass as an Optical Interference Reference Surface, S. TOLANSKY. Lab Prac (GB) v12 n8 Aug 1963 p 722–4. A smooth reference is a recognized essential for the study of surface microtopography or the structure and thickness of thin-deposited films. The author, in the course of his experience, has found that fire polished glass can have an extremely smooth surface, and in this paper explains its suitability for the purpose.

Interferometer for Testing Extended Surfaces Such as Surface Plates and Precision Ways, J. B. SAUNDERS, V. MCDERMOTT. J Res NBS v68C n2 Apr-June 1964 p 83–4 2 figs. A modification of the previously described "Interferometer for Large Surfaces" is described that permits the use of smaller prisms for a given sensitivity and a more practical arrangement of the optics. This arrangement allows for better structural connection of the elements into a rigid and moveable unit. This is obtained by a 90 degree rotation of the prism relative to the plane of incidence of the light.

7.2. Parallelism Measurement

Die Parallelität der Messflächen verschiedener Messgeräte, (The Parallelism of Measuring Surfaces of Different Measuring Devices) G. BERNDT. Zeit für Feinmech und Präzision v35 Oct 12, 26 1927 p 245–9, 256–9. Various methods of determining parallelism of contact faces on micrometers, measuring machines, snap gages and end-standards are described.

The Determination of the Parallelism of the Measuring Surfaces of Measuring Tools, G. BERNDT. Instrum v1 June 1928 p 263–70 12 figs. Description of various types of devices and instruments with two plane surfaces facing each other for measuring length such as vernier calipers, amplifying gages, dial gages, measuring machines and micrometers ; methods of determining parallelism of measuring surfaces ; advantages and disadvantages of different types for different purposes. Contains a detailed description of the application of the auto-collimating telescope to determination of parallelism and the measurement of angles.

Testing of the Parallelism of the Planes of Plates, C. MÜNSTER. Phys Zeit v33 July 1 1932 p 505–9. The methods depend on interference principles and the apparatus can be used for interferometer measurements.

Optical Tools for Inspection and Testing I–II, C. F. SMITH. Machy (London) v41 Nov 24 1942 p 209–12, and Dec 15 p 309–12. Nov 24 : Operating principles and application of instruments made by A. Hilger for checking angles and parallelism. Dec 15 : Testing flat surfaces with Angle Dekkor and interferoscope ; accuracy of glass straight edges and set squares.

Mirror Prism for Use with Angle Dekkor in Checking Parallelism of Micrometer Anvil Faces. Machy (London) v65 n1678 Dec 7 1944 p 636–8 ; Automobile Engr v34 n457 Dec 1944 p 535–6. Reflecting prism, used with Hilger Angle Dekkor, is so designed that it checks parallelism in all planes simultaneously ; prism splits parallel beam of light so that it is directed towards two micrometer faces from which light will be reflected back, two beams being exactly parallel to each other and on same axis.

Improved Interferometer for Determining Parallelism Errors in Long End-Gauges, L. G. TURNBULL. Can J Res v25 n3 (sec F) May 1947 p 242–55 2 supp plates. Interferometer designed for determination of parallelism of working faces and end gages up to 24 in. in length ; it incorporates kinematic principles and features to permit easy adjustment and operation ; by addition of sensitive level vial, difference in length of nominally equal end gages can be determined to accuracy of 1 or 2×10^{-6} in.

Optical Method of Setting Two Opposed and Opaque Mirrors Parallel, D. S. PERFECT. J Sci Instrum v25 n1 Jan 1948 p 15. Inclined partially reflecting plate introduced between mirrors divides collimated beam into two components both of which ultimately enter viewing telescope ; one is simply transmitted by plate, other is reflected successively by two mirrors ; condition for parallelism of mirrors is coincidence of two images of pinhole source.

Interferometer for Checking Parallelism of Slip Gauges, J. B. SAUNDERS, NBS. Machy (London) v92 n2361 Feb 14 1958 p 375–7 ; Engr v205 n5334 Apr 18 1958 p 595–6. New interferometer developed by U.S. National Bureau of Standards enables parallelism of working faces of gages

to be checked more conveniently and accurately than by previous methods; arrangement of principal components of instrument; double image Koesters prism comprises two 30–60–90° prisms cemented together.

Interferometer Checks Gage-Block Accuracy. Tool Engr v41 n2 Aug 1958 p 70–2. Design and operation of interferometer development at National Bureau of Standards, which makes possible more rapid and convenient measurement of parallelism of opposite gage block faces; instrument is adjusted by simple controls, and angle between gage block surfaces is read directly on calibrated scale.

Parallel Testing Interferometer, J. B. SAUNDERS. J Res NBS v61 n6 Dec 1958 (RP2917) p 491–8. Features of interferometer for measuring parallelism of gage blocks and other bodies of any reasonable length without necessity of wringing operation; two forms of instrument used are one for testing long blocks and other for short blocks.

Determination of Parallelism of Work Pieces up to Several Meters in Length with the Help of Optical Interference, M. DUHMKE. Optik v16 n10–1 Oct–Nov 1959 p 646–9 in German. Industrial comparators can be used only up to 20 cm. With a Köster's double prism a 4 meter length can be examined and adjusted for parallelism. A Michelson interferometer system is also described for the purpose. It is useful for matching the parallelism of the ends of an end standard of several meters in length.

Ein interferenzoptisches Geraet zur Unparallelitaetsbestimmung an Endmassen bis 4 m Laenge (A Parallel Testing Interferometer for Slip Gauges up to Four Meters Long.), M. DUEHMKE. Zeit fuer InstrumKde v67 n11 Nov 1959 p 273–6. Parallel testing interferometer for slip-gages up to lengths of 1000 mm, operating without high monochromatic light-source; accuracy of measuring is plus or minus 0.02 um.

Interferometer Method of Determining the Parallelism of Large Block Gauges, V. P. KORONKEVICH, V. P. GOLUBKOVA. Meas Techns 1961 n5 Dec 1961 p 346–7 2 figs 5 refs. Translated from Izmer Tekh n5 p 5–7 May 1961. Describes a method and interferometer which proved to be particularly useful in checking gauges under production conditions, since determining the difference in the length of the gauge along one of its sides only requires a few minutes. The errors in determining the parallelism of block gauges 100 to 1000 mm long does not exceed 0.05μ. The maximum measurable lack of parallelism amounts to 1.5μ.

Improved Checking of Parallelism in Micrometer Operating Surfaces, G. I. SIMONENKO, Meas Techns 1962 n1 June 1962 p 16 1 fig. Translated from Izmer Tekh n1 p 14 Jan 1962. Describes the use of a glass parallel with the micrometer mounted vertically in a special fixture. Interference bands on anvil and spindle are observed simultaneously.

New Method for Determining Parallelism of Block Gauges, V. P. KORONKEVICH, V. P. GOLUBKOVA. Meas Techns 1962 n4 Sept 1962 p 276–7 4 figs 3 refs. Translated from Izmer Tekh n4 p 7–8 Apr 1962. Describes a modified Michelson interferometer which uses white light without a reference gage.

Device for Testing Parallelism of Measuring Surfaces in Flat Micrometers, S. I. IZOTOV. Meas Techns 1963 n2 Aug 1963 p 117 1 fig. Translated from Izmer Tekh n2 p 21–2 Feb 1963. It is possible to check the parallelism of the operating surfaces of flat micrometers in the range from 75 to 1000 mm in any position of the microscrew by means of the hole-gauge extension pieces. The parallelism of measuring surfaces in micrometers with a range exceeding 1000 mm can be measured by means of two micrometer hole gauges.

7.3. Straightness and Surface Topography

Straightness Test for Beds of Machines, Edges, etc. Mr. ATWELL. Eng v100 July 23 1915 p 92. A straight edge or bar is supported on the bed by two gage blocks differing in height 0.01 in, mounted at the same distance from either end of the bed. Other gages differing by small steps are slipped into this space and their spacing is noted. Operation is repeated with bar turned over and thickness variations in bar are also determined.

Use of Monochromatic Interference Rings for the Measurement of Curvature, S. D. CHALMERS. Phys Soc Proc v29 Aug 1917 p 362–5. Shallow convex surfaces can be compared directly with a plane surface, and if the plane surface be placed uppermost, supported at the edge with soft wax, there is only one curved surface to consider. Monochromatic light is used with a measuring microscope, and readings are taken at the diameters of the 3d and 20th rings. Details of method are given, and limits and precautions briefly discussed.

Micrometer Straight-Edge, H. HUMPHREYS. Am Mach v62 Apr 30 1925 p. 705. Combination of a dial gage and straight edge for checking the surfaces of planer rails, milling machine tables, and similar parts of other machines. Two feet are adjustable along the beam and are provided with clamp screws. A dial gage is mounted on a slide.

Prüfung der Gradlinigkeit und Ebenheit (Testing of Straightness and Planeness). F. H. BOPP. Zeit für Feinmechanik v34 June 3 1926 p 111 4 figs. Long trussed straight-edge on which are adjustably mounted two steel cylinders. Between them an indicating mechanism is mounted. Work is tested by contact on the cylinders and indicator.

The Contouring of Smooth Surfaces, J. P. ANDREWS. J Sci Instrum v5 July 1928 p 209–13. By the employment of a very narrow intense beam of light, the shapes of smooth surfaces may be investigated. Describes appropriate experiments, and gives the necessary calculations for regular spherical and cylindrical surfaces; a complete, nearly circular cylinder, and a metal surface of no prescribed figure. An accuracy comparable with an interference method is attainable.

Ein Optischer Flucht- und Fuehrungspruefer (Optical equipment for measurements of proper alignment of guides). Maschinenbau v13 n9–10 May 1934 p 265–6. Detailed description of equipment developed by Zeiss, Jena.

Industrial Optical Testing and Gauging Instruments, H. ALQUIST. Eng Progr v17 n5 May 1936 p 111–6. Description of German equipment for examination of surfaces, measurement of form and contour, comparative and direct length measurement, and checking straight lines, angles, and directions.

Visiervorrichtung fuer das Ausrichten von Lagern (Sighting equipment for alignment of bearings), W. FRANKZENBURG. Werkstattstechnik und Werksleiter v32 n20 Oct 15 1938 p 451–3. Details of equipment.

Asymmetrical Broadening with Multiple-Beam Interference Fringes, J. BROSSEL. Nature London v157 p 623 May 11 1946. When using multiple-beam Fizeau fringes of equal thickness for the study of surface topography it is necessary to know which parts of the fringe system represent a projection or depression on the surface. By using a slightly extended source in place of a pinhole, the

fringes spread asymmetrically towards the region of greater air-film thickness. The increase of intensity enables measurements to be made on the sharp side of the fringe with precision nearly equal to the narrow fringes.

A Wavefront-Shearing Interferometer, W. J. BATES. Proc Phys Soc London v59 Nov 1947 p 940–50. A new type of interferometer is described by means of which the asphericity of an optical wavefront can be measured, by testing it against itself with lateral displacement or shear. Continuous control of the amount of this shear, and the meridional or sagittal fringes is obtained in white light.

La régle optique et ses applications (Optical rule and its applications), B. CUNY. Rev Universelle des Mines v4 n2 Feb 1948 p 193–5. Description of new precision device for checking flatness and alignment, whose only support is test piece itself and requiring neither regulation nor image adjustment; it is designed for accurate inspection of surface plates and machine tool slide bars.

Optical Testing of Straight Slideways, J. TERRIEN, T. MOREAU. Microtecnic v2 n1 Feb 1948 p 13–20. Comparison of several methods of measuring vertical deviations of straight slideways of precision comparator bed; use of autocollimator furnishing tilt angles of carriage resting on slideways, Koesters double prism, duplicate image instrument, and optical straightness tester made by Société Jobin and Yvon.

An Instrument for Automatically Recording Waviness of Surfaces, C. W. MEDHURST. J Sci Instrum v28 July 1951 p 211–4. The instrument is of robust construction suitable for everyday production tests on surfaces and yet is of such form that it will not harm the surfaces. Its outstanding feature is that it charts the waviness of surfaces in only 5% of the time it takes when using a simple Ames dial instrument.

Apparatus for the Control of Straightness, A. MIRAU. Rev Opt (Theor Instrum) v30 Aug–Sept 1951 p 357–65 in French. A long tube contains seven pivoted, partially reflecting mirrors and an autocollimator. The deflections of the mirrors can be read simultaneously in the eyepiece. The apparatus is adjusted on a flat surface and when placed upon the test piece the deflections give a measure of the profile. Constructional details are given and the accuracy (about 1 sec of arc) is compared with that of other methods of measuring straightness of flat tables, tubes, etc. The speed and ease of operation are features of this method.

Contour Mapping of Optical Surfaces with Light Waves. Glass Indus v32 n8 Aug 1951 p 409–11. Vacuum light interferometer developed by J. B. Saunders of National Bureau of Standards makes contour maps by photographing interference patterns formed when light waves are reflected from precise optical surfaces of specimen and standard reference of known shape; adding additional lines between half wavelength lines reduced spacing to 6 ten-millions of inch.

Precise Topography of Optical Surfaces, J. B. SAUNDERS. J Res NBS v47 n3 Sept 1951 (RP2239) p 148–55. Unit of length usually used in measuring optical surface features, by interference of light, is one half wavelength of monochromatic light that is used; method is described in which unit of length is much smaller fraction of wavelength; topographic maps of optical surfaces are made in which contour interval is less than 1/30th wave length.

On the Examination of Nearly Straight Edges (Rulers) and of Nearly Plane Surfaces, R. E. H. RASMUSSEN. Fysisk T v51 n5–6 1953 p 129–42 in Danish. Formulae are derived for deducing the deviations from a straight line (plane) of an approximately straight edge (approx. plane surface) from measurements of gaps between three edges (surfaces) taken two at a time. Formulae for the

standard deviation in the final results arising from errors in the individual gap measurements are given. Illustration by means of an example in which interference fringes were used to measure the gaps.

Two Methods of Measuring Degree of Straightness of Microscope Stage, R. M. TENNENT. J Sci Instrum v30 n3 Mar 1953 p 89–90. First of two techniques described makes use of Michelson interferometer and measures contribution to overall noise level made by stage; second depends on artificially produced straight line as standard and includes contribution due to observer errors as well as that due to stage.

Testing Methods for Production of Accurate Machine Slideways, G. N. LEVESQUE. ASME Paper No. 53–A–69 July 29 1953. The problem of making accurate machine slideways is intimately tied to that of making accurate straightedges and master planes. Paper deals only with cast-iron machine ways and straightedges.

Surface Curvature, A Tool for Engineers, E. WILD-HABER. Industrial Mathematics, Detroit, v5 1955 p 91–116 22 figs. The usual mathematical treatment of surface curvatures employs plane sections laid in various directions through the surface normal at a given mean point. The more direct treatment presented employs tangent cylinders to define a curvature surface. Subject headings are : surface elements ; a pair of component elements ; the surface normals ; principal directions ; line of contact with a tangent cylinder ; curvature of tangent cylinder ; more than two elements ; addition of an element to a pair of contacting surfaces ; equidistant or parallel surfaces ; conical surfaces ; surfaces of revolution ; summary ; applications. Condensation of article appears in Product Eng v27 n19 May 1956 p 184–91, 12 figs.

An Interferometer for "Straightness" Measurement, J. DYSON. Letter in Nature (London) v175 Mar 26 1955 p 559–60. An interferometric system is described which is of use in checking the straightness of a mechanical motion such as that of a lathe-cutting test. The system is based on two identical concave mirrors separated by their common radius of curvature. The reference straight is defined by a line joining the two centers of curvature. Between the mirrors is a Wollaston prism. A fringe system is formed which moves if the Wollaston prism is displaced at right angles to the axis but not for displacement in any other direction, and this is the straight. A sensitivity of 0.00008 in. per fringe has been obtained.

A Non-Contact Interference Method of Checking Spherical Lens Surfaces. YU. V. KOLOMIĬTSOV, I. I. DU-KHOPEL. Optika i Spektrosk v1 n1 1956 p 94–101 in Russian. Superposition of a test piece when checking spherical surfaces of lenses is a method having certain shortcomings. The paper describes an equipment in which the lens is supported clear of a test surface. A system of interference rings is observed from which it is possible to determine with high precision not only deviations of the radius of curvature of the surface from the nominal value but also local errors of the surface. Illustrated with diagrams and photographs.

Multiple-Beam Interference and Equidensities, W. KRUG. Optik v13 n1 1956 p 25–33 in German. A general survey of the principles of multiple-beam interferometry as applied to the study of surface topography. This is followed by a description of the equidensity technique. In this interference fringes are photographed with two-beam systems and then the photographic plate is examined by a light-scattering technique which reveals the edges of the broad fringes as sharp lines. Comparison is made between the two systems and the information content in the multiple-beam fringes and in the equidensity fringes is discussed.

Einfaches Verfahren zur topographischen Darstellung einer optischen Planfläche (Simple Process for the Topographical Representation of an Optically Plane Surface), R. BÜNNAGEL. Zeit für Angew Phys v8 1956 p 447.

Pomiary prostoliniowosci i plaskosci metodami hydrostatycznymi (Application of hydrostatic methods for measuring straightness and smoothness), B. D. NIKITIN. Mechanik v30 n10 Oct 1957 p 413–6. Open hydrostatic systems and systems with closed circuit and constant level. Adapted from Stanki i Instrument.

Double Interferometer for Series Control of End Measure Gauges, G. VOGL. Microtecnic v12 n1 Feb 1958 p 8–10. Instrument built for series control of planeness and parallelism of slip gages; apparatus incorporates two Fizeau type interferometers built into one another, and two standard plates between which are put comparison piece and piece to be measured; 90° prism is used for observation of rear surfaces.

Micro-Interference as an Aid to Testing the Shape of Aspherical Surfaces, R. LANDWEHR. Ann Phys (Leipzig) Folge 7 v4 n1–5 1959 p 154–66 in German. The testing of the strongly curved aspherical surfaces of rotation now so widely used can be carried out with a micro-interference method. Measurements made over small regions permit an analysis of the whole. The theory of the method is developed in detail and the equations of the interference curves are derived. Interference curves are given for a paraboloid viewed in various zones and special cases are numerically evaluated. It is shown that the interferometric results are in agreement with spherometer measurements.

Interferometric Measurement of Straightness of Plug Gauges, F. R. TOLMON. Machy (London) v94 n2412 Feb 4 1959 p 275–7; Engr v207 n5374 Jan 23 1959 p 136–7. Apparatus described consists of Fizeau-type interferometer and microscope with micrometer-controlled graticule for viewing and measuring fringes; results of test on ¾ in. diam by ½ in. long plug, and of independent test on different generator of same ¾ in. diam plug.

Measurement of the Waviness of Bearing Rings, G. S. SIMKIN, O. P. FOMINA. Meas Techns 1958 n2 Aug 1959 p 131–3 4 figs. Translated from Izmer Tekh n2 Mar–Apr 1958 p 11. Describes device which makes it possible to measure the waviness on the working surfaces of the main groove tracks of antifriction bearing rings. Discusses four main points which must be considered when developing instruments for measuring the waviness of bearing rings.

Interference Method for the Examination of the Surface Waviness of Balls, IU. V. KOLOMIITSOV. Meas Techns 1958 n3 Nov 1959 p 300–4 2 figs 4 refs. Translated from Izmer Tekh n3 May–June 1958 p 43. The device and method described enable to clear presentation of the profile of the ball surfaces being examined, and the measurement of the depth of local deviations of this surface from a perfect sphere, with an error of 0.03–0.1μ to be made. An observation of rings is useful for a rapid qualitative assessment of the ball, while the measurement of the depth of local irregularities on its surface is determined with a higher accuracy from the distortions of the "straight" bands. The method can be recommended for the selective inspection of balls during their manufacture and also for use in the assembly of precision bearings. The use of this method can considerably increase the accuracy of the investigation of deformations on the surfaces of balls during the operation of the bearings.

The Measurement of Geometrical, Dimensional, and Positional Errors of Technical Bodies by Means of the E-System, H. VON WEINGRABER. Microtechnic v14 Aug 1960 p 173–80. Discusses form error, dimensional error, and positional error.

An Optical Instrument for Measuring Generator Form on Large Rolls, P. W. HARRISON, NPL. Optics in Metrology. P MOLLET. Pergamon Press, 1960, p 383. Instrument measures the camber on the surface of rolls such as those used in paper and steel mills, which may be as much as 7 m (24 ft) long and up to 4 m (14 ft) in diameter, to an accuracy of ±10 microinches under optimum conditioning. Applies Young's interference fringes.

An Instrument for Controlling Waviness and Deviations from the Correct Geometrical Shape, T. S. LOPOVOK. Meas Techns 1960 n5 Jan 1961 p 381–2 3 figs. Translated from Izmer Tekh n5 p 9–10 May 1960. An instrument for checking the waviness and shape of cylindrical details 70 to 700 mm long and 10 to 70 mm in diameter. The instrument provides measurements of longitudinal and transverse waviness as well as deviations from the correct cylindrical shape, such as a tendency to become oval, polyhedral, tapered, etc. It is also possible to determine by means of the instrument complex deviations along the axis of the cylinder, such as the runout of one shoulder with respect to another, difference in diameters, etc. For the evaluation of the tested dimensions, a micron indicator is included in the instrument.

Determining the Waviness of Raceway Surfaces in Frictionless Bearing Races, B. E. BOLOTOV. Meas Techns 1960 n5 Jan 1961 p 383 2 figs 1 ref. Translated from Izmer Tekh n5 p 10–11 May 1960. The IV–1 instrument described provides, in practice, a measurement of the height of waves in the range of 0.05 to 1μ. Depending on the initial gap between the plates of the transducer, this range can be extended to 20μ. This device is based on the measurement of small displacements by means of a capacitative transducer.

Optische precisiemetingen op civiel en werktuigkundig gebied in de praktijk (Optical precision measurements in civil and mechanical engineering), S. H. LIEM. Ingenieur v73 n8 Feb 24 1961 p 033–42. Precision alignment methods developed by Van Heel, which permit three points to be put in straight line with accuracy better than 0.2 second of arc, appear to be practical, accurate and simple; optical instrument for measurements on experimental runways at Schiphol airport described.

Recording Method for Surveying the Relief of Highly Plane Surfaces, G. KOPPELMANN, K. KREBS. Optik (Germany) v18 n8 Aug 1961 p 349–57 in German. In order to investigate the topography of accurately plane surfaces, a photoelectric measuring device was developed, the main part of which consists of a pressure scanning Fabry-Perot interferometer. In this instrument multiple beam interference is used under favourable conditions, i.e. high accuracy of parallelism of the reflecting surfaces, utilization of the steep slopes of the Airy intensity distribution and direct calibration of the scale of surface elevations. Thus very high accuracy of measurement (±λ/1000) and fairly high speed of recording can be achieved. A corresponding photographic method is also described.

Precise Measurement of Straightness of Cylindrical Surfaces, R. G. N. HALL. Engr v212 n5508 Aug 18 1961 p 273–5; Quality Engr v25 n5 Sept–Oct 1961 p 151–5. Interferometric method, using simply constructed equipment, by which straightness of generator of cylindrical surface up to 12 in. in length may be measured, without damage, to accuracy of plus or minus 5μin. even when total error may be as much as 100μin.; pen recording enables magnitude and sign of errors to be deduced directly; helices ruled on cylinders are used in production of diffraction gratings.

Measurement of Wave Fronts Without a Reference Standard: Part 1. The Wave-Front-Shearing Interferometer, J. B. SAUNDERS. J Res NBS v65B n4 Oct–Dec 1961

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p 239–44 4 figs 5 refs. The wave-front-shearing interferometer may be used to test any converging wave front regardless of whether or not it is symmetrical. A mathematical operation is described that permits complete analysis of the data. This operation yields values of the deviations of wave fronts under test from a close fitting sphere. The reference surface may be chosen statistically so that the results are the deviations from a best fitting sphere.

Radial Shearing Interferometer, P. HARIHARAN, D. SEN. J Sci Instrum v38 Nov 1961 p 428–32 8 figs 8 refs. A new type of wave-front-shearing interferometer is described in which two images of the wave front under test which are of different sizes are made to interfere. When the centers of the two images are made to coincide, this results effectively in shear along the radial direction. It is shown that the interpretation of the resulting interferogram is comparatively easy. The instrument is extremely convenient to handle, since all the adjustments can be made with a white light source.

The Testing of Shape with Micro-Interference. A New Surface Interferometer, R. LANDWEHR. Zeit Angew Phys v4 n10 1952 p 377–86 in German. The Linnik type of micro-interferometer is modified to accept and examine relatively large workpieces. By the introduction of a long dividing prism interferometric tests can be carried out over a surface length of 12 cm. An instrument is described employing the proposed modification. The workpiece can be traversed over the full length and the system has industrial and technological applications. A comprehensive bibliography is included. Interferometric accuracy is 0.03μ.

Measurements of Wave Fronts Without a Reference Standard: Part 2. The Wave Front-Reversing Interferometer, J. B. SAUNDERS. J Res NBS v66B n1 Jan–Mar 1962 p 29–40 13 figs 6 refs. Interferometers permitting the measurement of shape and altered distribution of fringes are usually used to compare either an unknown wave front with a known one or an unknown surface with a standard reference surface. Any error in the reference surface introduces a corresponding error in the results sought. This paper describes an absolute measuring interferometer and the associated mathematical operations necessary for analysis of the data. The reference surface is purely mathematical in nature and is therefore free from error. Deviations of converging wave fronts from perfect spheres, paraboloids or ellipsoids are readily measured without the use of tangible reference surfaces. The equation of the reference surface may contain one or more parameters whose value is sought. Thus, the eccentricity of the conicoid that best fits a mirror and deviations of the surface from the true mathematical curve are obtained simultaneously. The sensitivity of the test can be varied so that when testing large aspherical elements which depart very far from spheres the number and width of the fringes can be adjusted to any desired values.

Mapping of High-Quality Optical Flats Without Reflection Coating, F. L. ROESLER. J Opt Soc Am v52 n4 Apr 1962 p 471. A pair of optical flats is enclosed in a pressure chamber. The pressure is adjusted so that $\mu l = \frac{1}{4}(n + \frac{1}{2})\lambda_0$ when the intensity of monochromatic reflected light varies most rapidly with l. A photomultiplier is used to measure the fluctuations in intensity when the plate is scanned by a beam from a movable slit.

Distribution of Depression in Paper Surface: A Method of Determination, B.S. HSU. Brit J App Phys v13 n4 Apr 1962 p 155–8. When ink is applied to a paper surface from a smooth plate the area which becomes coated is well known to depend on the thickness of the ink film on the plate. A simple, two parameter relation is found which describes this dependence, and it is shown that this effect provides a convenient method of determining the topography of the surface of a paper. A treatment was developed whereby the frequency distribution of the depth of depression in a paper surface can be determined by measuring the areas covered with ink when films of different thicknesses are applied. The area coated may be measured directly or found by observation of the diffuse reflectance of the printed paper: an equation is derived whereby the distribution of depression can be calculated to a reasonable accuracy from measurements of the diffuse reflectance. Typical distribution curves obtained by this method show maxima near the shallow end—at about $0.2\mu m$ for coated papers and at about $1\mu m$ for newspapers.

Testing Straightness of 40-inch Ways to ± 3 Microinches, E. G. LOEWEN, B. L. BARLOW. ,ASTME Creative Mfg Seminars—Tech Paper SP63–92 Feb 1963 10 p. Design of new precision ruling engine at Bausch & Lomb called for pair of machine ways 4 ft. long, which had to be straight within $20\mu in$. over 40-in. segment of length; measuring system capable of detecting surface displacements of $2\mu in$. or less was required; Davidson Optronics Model D–665 Automatic Autocollimator was selected for inspection; lapping of ways; direct recorder of surface profile; results given; advantages of surface inspection technique described over conventional methods.

Raising the Efficiency of Testing Straightness by the Microleveling Method, L. L. MEDYANTSEVA, V. V. GORBACHEVA. Meas Techns 1962 n8 Feb 1963 p 646–8 2 figs. Translated from Izmer Tekh n8 p 22–3 Aug 1962. Microleveling is the most common method of testing the straightness of large-sized bed-plate guides. The main defect consists of the large time required for testing, since the air bubble becomes agitated each time the level is displaced and a certain time is required to bring it to rest. The time spent on checking linearity by the microleveling method and the effect of external conditions can be reduced considerably if the microlevel is displaced along the tested surface uniformly by means of a special device instead of being displaced by hand. The improvement of the microleveling method provides higher accuracy in measurements and other advantages.

Rapid Testing of Maximum Straightness Ways, E. G. LOEWEN. Standards and Metrology Div, AOA May 16, 1963. Evaluation of direct optical and indirect straightness measurement methods.

Multivariable Curve Interpolation, J. FERGUSON. Assn Computing Machy–J v11 n2 Apr 1964 p 221–8. Generalized method for solving problem of defining smooth surface through array of points in space is presented to include cases where point arrangement is topologically equivalent to planar rectangular grid, and resulting solution is smooth composite of parametric surface segments; solution is readily applicable to variety of problems, such as closed surface body definitions, pressure envelope surface definitions, numerical control milling, Newtonian impact, and boundary layer.

Optical Systems for Observing Surface Topography by Frustrated Total Internal Reflection and by Interference, C. W. McCUTCHEN. Rev Sci Instrum v35 n10 Oct 1964 p 1340–5. Distortion and tilting of image to which Gaussian approximation applies, appear when optical system is arranged with its axis parallel to emerging light, and can be avoided by making axis of optical system normal to object plane; system must then deal with light entering it at greater than critical angle; this can be done with special device for adapting conventional microscope for study of topography; method is illustrated by examples of application to dielectric and metallic surfaces.

7.4. Roundness and Concentricity Measurement

A New Form of Contour Caliper, W. F. DURAND. Sibley J Eng v13 Jan 1899 p 129–35 6 figs. An instrument devised to determine whether or not the contour or cross section of a pin, axle, or spindle is circular, and if not, the finding where it departs from the true or circular outline. Comprises 3 micrometers spaced at 120° about a ring, fig. 5. Thus discriminates between a circle and other figures of constant breadth.

A Three-Point Micrometer and Its Use. Machy (N.Y.) v19 May 1913 p 688 3 figs. Describes a micrometer caliper for determining roundness of crank pins which may have a tri-lobed shape.

Zusammenhang zwischen Kraftfluss, Wälzlager und Passungen (Correlation Between Magnetic Flux, Antifriction Bearing and Fits), J. KIRNER. Betrieb v4 n20 July 8 1922 p 459–64 16 figs. In three parts. Part 3: Indication on the necessity for differentiation between thickness and roundness. Description of regular and irregular surfaces and bodies which are in no way round but instead are of equal thickness in every direction. Introduction of the designation "the equally thick". The hazard of un-roundness. Testing of roundness. Figs. 6–16 show such figures.

Factors Governing "Out-of-Roundness" Measurements, A. H. FRAUNTHAL. SAE J v13 Nov 1923 p 370–4 7 figs. Types of out-of-roundness and those peculiar to certain machines; three-point measuring system; errors of V-block method; use of V-block for elliptical objects; other methods of checking elliptical forms and indicator-reading correction; three items for instrument improvement are suggested. See also Trans. S.A.E. 1923, Part II, pp. 600–613.

Ammco Round-O-Meter Gage. Am Mach v73 Dec 11 1930 p 945–6. A direct reading indicator for checking roundness and size of objects from ¾ to 6 in. in diameter has been announced. Readings are accurate to 0.0005 in. By using "Ammco" gage setting rings, the "Round-O-Meter" can also be used for direct measurement and comparative checking. Gage setting rings are furnished on special order in any specified diameters, over-sizes or under-sizes, within the above range.

Multipoint Gages, H. SHAW. Am Mach v75 n2, 4 and 5 July 9 1931 p 44–6, July 23 p 173–5 and July 30 p 208–11 42 figs. Possibilities of error in checking roundness with 3-point gages; great variety of non-circular shapes will fit perfectly all positions of micrometer; initial position of gage arms in relation to triangular path of center controls limiting length of arm.

Über Gleichdicke (Regarding Equal Thicknesses), A. E. MAYER. VDI Zeit v76 Sept 10 1932 p 884–6. Analysis of difference between circle and constant diameter figures with particular regard to formulation of maximum difference. For supplementary note see VDI Zeit, v77, n6, 153, Feb. 11, 1933.

Constant-Diameter Figures, F. W. SHAW, H. SHAW. Machy (London) v40 Sept 22 1932 p 777–9 and 41 Oct 13 p 40–2, Nov 24 p 223–5; and Dec 22 p 349–51. Sept 22: Geometric characteristics of various types of constant-diameter figures from viewpoint of checking roundness; polygrams as evolutes of figures of constant diameter. Oct 13: Figures with curvilinear evolutes; stages in evolution of constant-diameter figures from curved centrode; figures whose contours are wholly involutes of circles. Nov. 24: Application of constant-diameter figures in design of cams, gears and levers. Dec. 22: Effect of inaccuracies in balls and rollers; quasi-spheres of constant diameter.

Messen und Pruefen des Unrunde (Measurement and Testing of Out-of-Roundness), K. DRESS, VDI Zeit v84 n47 Nov 23 1940 p 909–12. Causes of imperfect roundness and methods of its determination; instruments for checking roundness; proposed roundness tolerances.

Messung der Aussermittigkeit von Kreisen und der Neigung von Flaechen in bezug auf die Drehachse (Measurement of eccentricity of circles and inclination of planes about rotating axis), E. STUMPP. Archiv Tech Messen n123 Sept 1941 p T119 (2 p) (V8224–3). Theoretical study of method; additional computation in case number of points are insufficient for plotting diagram.

Cylinder Wear and Distortion as Measured With Cylinder Contour Gage, M. E. ESTEY. SAE J v56 n9 Sept 1948 p 30–4; Diesel Power v26 n6 June 1948 p 54–8. Gage consists of 0.0001 in. reading dial indicator on lower end of 2½ in. diam. tubular gage shaft; shaft is so mounted that it may be centered accurately in cylinder, then raised, lowered or rotated to bring indicator into position; optical system provides enlarged view of indicator dial; application procedure; examples of abnormal cylinder contour.

Precision Measurement of Circularity, Concentricity, and Straightness of Plain and Tapered Rings and Plugs, M. J. PUTTOCK, NPL. Machine Shop Mag Oct 1948 6 p.

Roundness Measurement. Aircraft Prod v14 n163 May 1952 p 151–3. Talyrond high precision instrument for checking departures from circular form of parts such as balls, rollers, ball and roller races, pistons and cylinders, developed by Taylor, Taylor & Hobson, Ltd.

How Round Is Round?, A. C. SANFORD. Am Mach v96 n23 Nov 10 1952 p 124–6. Definition of out of round; double electronic gage head and differential classifier methods for out of round checking on automatic basis.

Precision Measurement of Cylindrical Bores, J. C. CHERNA, B. GOODE. Tooling & Prod v21 n10 Jan 1956 p 73–5. Study made for resolving difficulties associated with diametrical measurement of bores or holes; determining major deviations from true circle; methods examined by which these deviations might be detected and measured; Etalon Ingage developed as result of study makes possible detection of sources of geometrical error.

What Makes Precision Spindles Precision Spindles?, E. W. PENNINGTON. Tooling & Production v23 n10 Jan 1958 p 84–6. Illustrated description of "zero spindle" used by N. A. Woodworth Co., Detroit, which permits checking of workpieces for true concentricity; spindle is truly cylindrical and concentric with its own geometrical axis; simplicity of design noted.

Zur Steigerung der Genauigkeit mikrointerferometrischer Untersuchungen und zur einer Interferenz-Sphaerometrie (Improvement of accuracy of micro-interferometric examinations and problem of interference-spherometry), R. LANDWEHR. Zeit für InstrumKde v66 n7 July 1958 p 134–8. Corrections to be considered in precise micro-interferometric work to determine form of objects, where double beam interference with conventional micro-interferometers is used; possibility of more accurate interferences spherometry. 17 refs.

"And Must Be Round Within." Am Mach v102 n7 Dec 1 1958 p 109–20. Symposium on basic problems of measuring out-of-roundness; .XXXX'' Full Indicator Reading, W. G. CANFIELD; Critical Remarks, F. MEYER, JR.; V-Block for Roundness Check in Toolroom, A. N. APPLEBY; V-Block Angle Depends on Number of Lobes, J. WORTHEN; Adjustable V-Block for Machine Checkup, C. A.

WHITNEY ; Electronic Gages Check Crankshaft Roundness, P. E. CARBONE ; Lobing of Cylindrical Features and Its Measurement, W. J. DARMODY ; Lobing Measurements in Metrology Laboratory, R. MAHLMEISTER ; Measurement of Roundness to Millionths, E. J. SCHNEIDER ; Roundness Measurement by Radial Means, F. W. WITZKE.

Rundlaufabweichung und Unrundheit (Revolving Deviation and Out-of-Roundness), R. NOCH, PTB. Wiss Zeit der Tech Hochschule Dresden v9 n4 p 975–80 1959/60. Lists several references.

The Assessment of Roundness of Workpieces, R. E. REASON. Taylor, Taylor, and Hobson. Feb 13 1959 9 p 7 figs. The assessment of the roundness of workpieces, the standardization of cut-off frequencies ; the true mean circle ; the assessment of spindle errors.

Measurement of the Eccentricity of Articles Mounted at the Center, A. D. RUBINOV, Meas Techns 1958 n1 Aug 1959 p 13–7 4 figs. Translated from Izmer Tekh n1 Jan–Feb 1958 p 12. Discusses measurement of eccentricity of cylindrical articles mounted on centers using a single indicator and taking into account deviation from circularity. Three cases are considered in some detail.

Theory and Practice of Gaging Pseudoroundness, L. A. BOLDIN. Meas Techns 1958 n3 Nov 1959 p 307–12 5 figs 3 refs. Translated from Izmer Tekh n3 May–June 1958 p 48. Develops mathematical theory of lobed figures.

An Interferometer for Testing Sphericity, J. W. GATES. Optics and Metrology. P. MOLLET, Pergamon Press 1960 p 201–4 6 figs 3 refs. Instrument shows directly the departures from sphericity of convex surfaces up to 13 mm radius. A solid angle of nearly 2π is covered at one time. The problem of correcting the distortion caused by projecting a spherical surface on a plane is briefly discussed.

Onrondheidsmetingen, A. VISSER. Ingenieur v72 n16 Apr 15 1960 p 01–4. Out-of-roundness measurements ; by using gaging tip and that flat anvil or gaging tip and Vee-block true indication of out-of-roundness of cylinder cannot always be obtained ; Talyrond instrument designed by British firm of Taylor, Taylor & Hobson, makes it possible to obtain graphic representation of variation in radius of cylinders and borings.

A Pneumatic Detector for the Control of Coaxiality of Two Surfaces, A. V. VYSOTSKII. Meas Techns 1959 n5 June 1960 p 311–2 2 figs. Translated from Izmer Tekh n5 May 1959 p 9. Describes a device for measuring coaxiality by means of a special pneumatic detector, which is free from imperfections of the "wobble" method of measuring the coaxiality. The use of two carriers moving in a mutually-perpendicular direction and contacts in the form of cylindrical surfaces, permits the obtaining of correct measurement results by geometric addition, independently of the direction of the maximum eccentricity of axes.

Measurement of Surface Waviness of Rolling-Element Bearing Parts, O. GUSTAFSSON, U. RIMROTT. SAE Paper n195C for meeting June 5–10 1960 13 p. Principle of waviness testing to evaluate irregularities of surface of rotation ; current method of vibration testing ; correlation between waviness and vibration ; ball waviness tester, applied in SKF Industries, Philadelphia, Pa., consists of true running spindle driven at constant speed of 740 rpm, velocity sensitive pickup, and ball seat ; displacement and velocity reading instruments ; waviness tests in determining parts responsible for excessive vibrations ; calibration method.

Pneumatic Roundness Measuring Instrument, C. A. SCOLES. Machy (London) v96 n2485 June 29 1960 p 1648–53. Description of instrument developed from experimental vertical air bearing made at National Engineering Laboratory ; experimental unit, consisting of simple shaft supported pneumatically in vertical brass bearing, was constructed to enable performance data of such bearings to be determined ; details of air bearing unit ; pneumatic measuring head ; pneumatic circuit ; performance of instrument.

Rotors in Polygons and Polyhedra, M. GOLDBERG. Mathematics of Computation v14 n71 p 229–39 July 1960. Lists 36 references including a patent on a method of measuring out-of-roundness of machined parts.

Selecting a Method of Reference in Measuring the Undulation of Antifriction Bearing Races, V. V. MATVEEV, V. L. RYASKOV. Meas Techns 1959 n11 Sept 1960 p 855–7 5 figs 3 refs. Translated from Izmer Tekh n11 Nov 1959 p 18. Advantages of making recordings with reference to mandrel surface, in order to determine size of undulations, deviations of ball race track from circular shape to oval one, and its eccentricity with respect to fitting surfaces.

Errors in Determining Regular Undulations of Cylindrical Surfaces, Z. P. GROZINSKAYA. Meas Techns 1960 n9 Apr 1961 p 730–3 6 figs. Translated from Izmer Tekh n9 p 3–5 Sept 1960. Discusses various methods of measuring lobing.

Investigating the Effect of the Microinterferometer Aperture on the Accuracy of Measuring the Height of Irregularities in a Triangular Profile, I. I. DUKHOPEL. Meas Techns 1961 n7 Dec 1961 p 517–20 3 figs. 6 refs. Translated from Izmer Tekh n7 p 3–6 July 1961. It has been established experimentally that a reliable evaluation of the value of an interference fringe irregularity can be made only when the width of the fringe visible at the side of the groove amounts to at least 0.3–0.4 mm. On machined surfaces this condition is met with a microinterferometer magnification of the order of 300–400.

On the New Measure of Roundness, M. IDO, R. NAGATA, T. HAZI. J Japan Soc Prec Eng v28 n10 1962 in Japanese. A new measure of roundness corresponding to the amount of approach to true circle is given by introducing the conception of information theory, and is compared with that of roundness popularly used at present. The characteristics of the new defined measure of roundness are as follows : 1. Each datum obtained by measuring is regarded as sampling function from an ensemble. 2. The number of measuring points is decided by limiting bandwidth of irregular circle. 3. The factor of error is contained. 4. By expressing quantitatively the amount of approach to a true circle, the comparison between two and more data becomes possible. 5. This new measure is extended to the definition of sphericity.

High Precision Roundness Inspection—Production Applications, F. W. WITZKE, L. M. NELSON. SAE Paper 509A for meeting Apr 3–6 1962 7 p. Accurate measurement of roundness is obtained by use of precision spindle roundness gage with polar recording device, developed by Cleveland Instrument Co. ; advantages of precision spindle roundness gaging over other methods are shown by examples relating to grinding, ball and roller bearings, etc. ; in addition to roundness rotating table polar graph roundness gage can be used for concentricity, squareness, flatness, and other geometric relationship measurements.

Determining Roundness from Profilograms, M. A. PALEI. Meas Techns 1962 n3 Sept 1962 p 188–91 3 figs. 1 ref. Translated from Izmer Tekh n3 p 9–11 Mar 1962. Develops rules for evaluation from the profilogram of the nature and value of deviations from roundness.

How to Measure Roundness, F. W. WITZKE. Tooling & Prod v28 n8 Nov 1962 p 65–8. Main characteristics of most common methods for determining roundness of parts, including diametrical comparison. Vee block measure-

ments, bench center radial measurements, radial comparison to master round, and radial comparison to ultra-precision spindle; their limitations and advantages.

The Measurement of Geometric Shape of Cylindrical Components, C. A. SCOLES, Nat Eng Lab. Paper n11 p 357–400 24 figs discussion of the accuracy of industrial measurement of length and diameter, NPL Conf n14, Her Majesty's Stationery Office London, 1963. Contents: Introduction; errors in geometric shape; elementary methods of form measurement; ideal method of form measurement; performance accuracy; commercial instruments; interpretation of circular records; the effect of roundness errors on performance; terminology and future trends in roundness measurement; conclusions; discussion.

Roundness Deficiencies, Their Functional Effect and Methods of Measurement, F. FARAGO. ASTME Tech Paper SP64–31. 1963–4 18 p 5 figs 2 tables. Suggests general rules of procedure for the selection and application of the best suited roundness measuring process.

Microscope for Measuring Small Diameter Holes and Their Concentricity, S. L. GONIK. Meas Techns 1962 n8 Feb 1963 p 648–9 2 figs. Translated from Izmer Tekh n8 p 23–4 Aug 1962. Describes the design of a microscope for measuring small diameter holes and determining the concentricity of two hole diameters in the body of a tractor jet atomizer.

Measurement of Macrodeviations in External Surfaces of Cylindrical Components, T. S. LOPOVOK. Meas Techns n8 Feb 1963 p 649–51 3 figs 1 ref. Translated from Izmer Tekh n8 p 24–6 Aug 1962. Discusses relations of macrodeviations of external surfaces and errors in the center holes of the measured component.

Measuring Roundness. Production Technology v1 n1 Apr 1963 p 29. Talyrond machine, developed by Rank Taylor Hobson Div of Rank Organization, is linked to special reference computer which, while profile graph is being plotted, analyzes profile and computes reference circle based on principle of "least squares"; having drawn profile graph, instrument proceeds to draw circle on chart during next revolution; from reference circle it is easy to spot highest peak and deepest valley and measure their sum as maximum peak-to-valley height of profile; reference computer is also capable of separating ovality from other irregularities, and then plotting "least-squares" ellipse as reference line; other modes of operation.

The Master Circle, L. G. WHITTEN. Y–KE–43 May 10 1963 11 p 9 figs, publ by Union Carbide Nuclear Co., Oak Ridge, Tenn. Describes an accurate 12 in. round disc designed to check the accuracy of roundness measuring equipment. It also provides an overall check of machine accuracy. Combining slide inaccuracies, slide squareness, and spindle accuracy. Presented at the 18th Annual Meeting of the Standards and Metrology Division, American Ordnance Association.

Errors in Measuring Waviness of Cylindrical Surfaces, Z. P. GROZINSKAYA. Meas Techns 1963 n2 Aug 1963 p 101–4 5 figs. Translated from Izmer Tekh n2 p 9–11 Feb 1962. Provides calculations which determine the errors produced in measuring the waviness of external cylindrical surfaces which are due to errors in the geometrical form of the components and inaccuracies in setting them during checking. In each case when considering the ef-

fect of one type of error in the geometrical shape the effect of all other types of errors was excluded. Considers effect of eccentricity and effect of oval shape.

Instrument for Measuring External Dimensions of Oval Bodies. B. A. SHIPILEVSKII. Meas Techns 1963 n2 Aug 1963 p 118–20 1 fig. Translated from Izmer Tekh n2 p 22–3 Feb 1963. Measurements are made of the external perimeter of oval bodies with an error not exceeding ±15μ by comparing the tested dimensions with the dimensions of a reference cylinder, whose perimeter is inscribed on it for a corresponding mean section and external diameter. The deviations of the tested body mean diameter are determined by dividing the perimeter deviations by π.

Measurement of the Roundness of Center Holes, G. S. BIRYUKOV. Meas Techns 1963 n8 Feb 1964 p 657–8 2 figs. Translated from Izmer Tekh n8 p 21–2 Aug 1963. The production methods of the component's center holes should ensure their coaxiality with minimum deviations, for which purpose it is necessary to machine the centers and after thermal treatment grind simultaneously both center holes on special center-grinding machines with the rotating component in the horizontal position. After grinding, the holes should be lapped by means of cast-iron laps.

Device for Measuring the Degree of Faceting in Wires, V. V. PEN'KOV. Meas Techns n9 Feb 1964 p 737 1 fig. Translated from Izmer Tekh n9 p 15 Sept 1963. A handy device for measuring the lobing in wires in the range 0.118 to 7 mm without the use of special inserts and without resetting for wires of different diameters.

Methods for Assessment of Departures from Roundness. Brit Standards Instn—Brit Standard 3730 1964 37 p. Publication is concerned with assessment of roundness errors expressed in terms of variations in radius of part measured from common selected center, and with instrument requirements to be met in provision of these measurements; it embraces all instrumental and workshop methods capable of providing required data.

Telescopes for Measuring Linearity and Coaxiality of Medium-Size Articles by the Sighting Method, E. I. ROZENBERG, I. E. ÉFROS. Meas Techns 1963 n11 Apr 1964 p 903–5 2 figs 4 refs. Translated from Izmer Tekhn n11 p 10–1 Nov 1963. Sighting characteristics of several simplified sighting telescopes are tabulated. Two basic designs are described: (1) a double-image telescope for measuring the linearity and coaxiality of medium-sized articles, and (2) three varieties for measurements at large distances.

Concentricity Gaging Problems Solved by Electronics, R. J. SPIKOWSKI. Machine & Tool Blue Book v59 n12 Dec 1964 p 115–17. Measurement of concentricity depends on establishment of datum axis to which all readings may be compared; this requirement can be met by electronic radial roundness gage such as Indi-Ron, made by Micrometrical Div of Bendix Corp; this gage generates on polar chart imaginary centerline of part where engineer began his drawing; in using it, workpiece is mounted on gage spindle and adjusted so that axis of part and axis of spindle are perfectly aligned; this establishes datum axis for part, imaginary centerline without which measurements can be inaccurate or misleading.

Addendum to Section 7

7.1. Planeness Measurement

Ausmessung der Planheit von Flächen bis auf ein Milliontel Millimeter (Measurement of the Planeness of Surfaces to a Millionth of a Millimeter), O. SCHÖNROCK. Zeits

Instrumkde v25 n5 May 1905 p 148. An interference method in which the reference optical flat is supported on three small steel balls.

Raster Method for Measuring Waviness and Deviations from Flatness in Machine Components, I. V. KRAGEL'-SKII, A. A. PRIBYLEV, L. A. GOGAVA. Meas Techns n7 Feb 1965 p 586–9 7 figs 1 ref. Translated from Izmer Tekh n7 p 23–5 July 1964. Experience has shown that the greater part of deformations in joints is not due to microirregularities, but is produced by the waviness of the coupled surfaces. Therefore, the study of the surface waviness of machine components is a very pressing problem. The raster method of determining waviness has the facility for investigating a considerable section of a machine component and at the same time providing a graphic picture of the surface under consideration. This method is based on the use of an illuminated raster grid which produces shadow patterns resembling Moire fringes.

7.2. Parallelism Measurement

Über eine neue Interferenzerscheinung an planparallen Glasplatten und eine Methode, die Planparallelität solcher Gläser zu prüfen (Regarding a new Interference Phenomenon with Plane-Parallel Glass Plates and a method for testing the Plane-Parallelism of such Glasses), O. LUMMER, Ann Phys Chem v23 n9 Aug 1884 p 49–84 4 figs 7 refs. Describes an optical system in which circular interference fringes are produced. Theory is developed.

Interferometer Methods for Evaluating Deviations from

Flatness and Parallelism of Large Block Gauges, V. P. GOLUBKOVA, V. P. KORONKEVICH. Meas Techns n9 Mar 1965 p 765–8 5 figs 11 refs. Translated from Izmer Tekh n9 p 9–12 Sept 1964. Reviews modern methods for an interferometric evaluation of the paralleleism of long gage blocks which have aimed at eliminating highly monochromatic sources of light. These methods are generally based on differential interferometers, in which the interference pattern is formed by a part of the tested gage and not a reference plane.

Section 8. Measurement of Profiles

CONTENTS

8.1. Measurement of Radius or Profile by Mechanical Methods

Lens-Curve Tester, G. HALLE. Zeit InstrumKde v15 Aug 1 1902 p 142–3. A kind of spherometer with lever and scale reading for measuring curvatures.

On a Revolving Table Method of Determining the Curvature of Spherical Surfaces, G. F. C. SEARLE, A. C. W. ALDIS, G. M. B. DOBSON. Phil Mag v21 Feb 1911 p 218–24 2 figs. Method has the advantage that the radius is found directly from two readings on a straight, uniformly divided scale, without corrections or calculations. Describes principles of method and details of equipment.

Simple Method of Determining Radius of Curvature of Spherical Surfaces, W. C. BAKER. Nature v95 May 13 1915 p 288 1 fig. The small lens or object to be tested rests on a ring on a little frame. A small three-legged optical lever is then placed in two positions whose spacing, s, is fixed by the arrangement of the frame and can be measured by a microscope. The angle θ corresponding to these two positions is noted by the optical lever; hence the radius desired is given by $P=s/\theta$.

Contour and Radius Measuring Instrument. Machy v24 June 1918 p 898– 9. Designed by J. H. WILHELM for Frankford Arsenal. Universal type for measuring irregular profiles, radius gages, and contours that cannot be tested by ordinary devices.

The Measurement of Gauges, E. A. FORWARD. Engr v127 Mar 21 and 28 1919 p 282–3 and 294–5 24 figs. Methods used for measuring three classes of gages: (1) plate or form gages the profiles of which are combinations of straight lines and curves; (2) conical plugs, rings and disks, combinations of cones with cylinders and planes, and castellation gages; (3) position gages.

Refinements in Spherometry, G. W. MOFFITT. Phys Rev v13 Apr 1919 p 261–71 8 figs. Precision in mechanical methods is asserted to decrease rapidly as radius becomes larger; by auto-collimating method, up to limit of slide on turntable, precision is said to be high and independent of radius; methods are found to possess high degree of precision of measurement for concave surfaces of any radius and for measurement of convex surfaces to decrease in precision with increase of radius.

The Measurement of Radii on Profile Gages. NBS Letter Cir LC 20, June 21 1919. Describes methods of measuring large and small radii.

Use of Microscopes in the Gage Section, Bureau of Standards, R. L. RANKIN. Am Mach v51 Sept 18 1919 p 581–2. Discusses use of microscope in linear measurements on gages, etc.

A Spherometer of Precision, J. GUILD. Sci Am Supp v88 Sept 20 1919 p 184–5 3 figs. Designed with a view to obtain greater accuracy in determination of exact point of contact of micrometer leg with surface of lens or flat under examination than is usually obtained with spherometers of existing patterns. Paper read before Optical Society.

Profile-Curvature Gage, W. SOUDER, NBS. Am Mach v53 n16 Oct 14 1920 p 732 1 fig. Describes a convenient arragement of instruments for measuring the curvature of an arc.

Curvature Measurements, J. GUILD. Opt Soc Trans v22 1920–1921 p 127–38. Description of the arrangements of well-known optical methods of spherometry which the author has found most suitable for accurate determinations, and also of a new microscope method suitable for medium and large curvatures.

Precise Inspection of Large and Irregular Curves, E. O. BROWER. Am Mach v54 Jan 13 1921 p 60–4. In this method only one of the sides which must be measured directly is long, while the others are comparatively short and easily measured.

Finding Dimensions of Profile Gages, W. G. HOLMES. Am Mach v54 Mar 31 1921 p 567, Apr 7 1921 p 614–5. Gives formulas for cases where side of an angle joins a circular arc.

A Modified Spherometer, H. S. ROWELL, Sci Instrum v1 Oct 1924 p 17–20. An inherent lever in the spherometer is utilized to magnify the readings obtainable by making one outer leg micrometric while the others are fixed. Suggested that a unit of curvature is desirable.

Inspecting Large Radius Gages. Machy (London) v27 1926 p 754; C. KUGLER, Machy (N.Y.) v32 Jan 1926 p 403–4 May 1926 p 736. Describes method of deriving radii of large gages by applying rolls and precision gage blocks to measure height of arc over a distance between the rolls. The rolls are soldered to a base.

Measuring Machine Simplifies Laying Out of Dies and Gages. Am Mach v67 Dec 1 1927 p 843–4 4 figs. National Cash Register Co., Dayton, Ohio, has built measuring instrument termed laying-out machine; by its use average laying-out time for work has been cut to approximately one-third of that taken by former methods, with added advantage of producing more accurate layout.

(Ueber die genaue Messung grosser Durchmesser) (Precise Measurement of Large Diameters), H. SCHMIDT.

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Maschinenbau v7 Aug 2 1928 p 720–1 2 figs. Mathematical discussion comparing precision of direct micrometer measurement with indirect method by rise of arc ; finds latter is less precise of two.

The Inspection of Form Gauges. Machy (London) v32 Aug 9 1928 p 609–10 7 figs. Method of inspecting form gages and calculations involved are described.

Sur un Procédé optique de Localisation des Surfaces polies, et son Application à la Mesure des Rayons de Courbure. (Optical Procedure for Testing Polished Surfaces and its Application for Measurements of Radii of Curvature), A. ARNULF. CR Acad Sci v187 Dec 3 1928 p 1044–6. Microscope is used to view two sets of cross wires, one of which is illuminated. The more distant one is viewed by a powerful Ramsden eyepiece. The virtual image of one set of cross wires serves as an object for the surface tested, and a position is found such that its image in this surface coincides with the image of the other set of cross wires. The application of the method for the measurement of radii is discussed, and its freedom from the usual faults of auto-collimation.

Annular Spherometers, A. BIOT. Ann Soc Sci de Bruxelles v49 Dec 1929 p 251–7. The author discusses fully the accuracy obtainable with the usual type of annular spherometer and the advantages and disadvantages attendant upon its use. In putting forward the superiority of the special form using three non-tangential spheres it is claimed that the magnitude of the likely error can be reduced from 1/5 to 1/10 of that of the ordinary instrument, and, further, that the measurements can be more easily made.

An Instrument for the Measurement of the Contour of Fibres and Filaments, S. G. BARKER, M. H. NORRIS. J Sci Instrum v7 Jan 1930 p 22–4 3 figs. It is necessary for purposes of wool examination, and to be able to examine fiber at all points along its length, and at the same time to examine filament completely at any point by rotating it through 360 degrees and for this purpose fiber rotator has been designed ; it comprises improved form of existing apparatus (Polikeit) and is capable of taking fibers up to 10 in. in length and of smaller lengths down to less than 1 cm.

Markings on Bullets and Shells Fired from Small Arms, C. O. GUNTHER. Eng Soc Boston J v1 May 1930 p 7–25 16 figs. ; Mech Eng v52 Dec 1930 p 1065–9 14 figs. Study of engravings made on cylindrical portions of bullets by lands and groves of bore of automatic pistol and of breechblock and firing pin imprints on cartridge cases and primers.

Spherometers, A. BIOT. Ann Soc Sci de Bruxelles v51 Mar 12 1931 p 5–12. Description of a spherometer employing the compass principle. Classification of spherometers according to the geometrical formula on which they are based.

Detection and Measurement of Longitudinal Curvature of Small Surfaces of any Cross Section, H. E. GAUSS. J Sci Instrum v11 May 1934 p 157–62. Methods of illumination of grooves for microscope work are reviewed and a new method described for detecting and measuring undulations that are too small to be resolved. Formulas are obtained for determining the curvatures from the observations.

How to Lay Out Optical Systems, R. C. HITCHCOCK. Prod Eng Dec 1934 p 450–1. For a given magnification, projection distance, image size, and type of lamp, alinement chart gives the optical efficiency, the diameter of the lens or reflector, and its focal length.

Radien-Messungen (Measurement of Radii), K. GIESS-BART, Archiv Techn Messen v44–5 n85 July 1938 p T89–

90 (4 p). An account of the methods of determining radii of curvature, chiefly of lenses, by calculation and by direct and indirect measurement.

Curved Rulers, F. EMDE, Zeit InstrumKde v58 Oct 1938 p 409–11. With curves of slowly varying curvature a useful method of representation is a series of circular arcs, since at any point a fairly long portion of the curve nearly coincides with an arc of a circle of some definite radius. When the curvature varies rapidly, a knowledge is required of the radii of curvature at a series of points along the curve, together with the rate of change of the radius. Assuming as is usually the case, that only the convex edge of the ruler is used and that the radius continually increases, a spiral of some sort is obtained. It appears very desirable that this should conform to some simple equation. Typical forms are the logarithmic spiral and Cornu's spiral. The properties of these are briefly discussed and three illustrations are given of curved rulers based on what is called the "sici" spiral. A point on this curve is defined by the relation

$$x + iy = -L \int_0^\infty \frac{e^{i\phi}}{\phi} d\phi = L ci\phi + iL si\phi$$

where the functions CI and SI denote the integral cosine and integral sine respectively. The values of these functions can readily be obtained from Jahnke-Emde tables and hence curves of any required length and curvature variation can quickly be drawn, using the relations $\phi = L/R$, $x = L$ CI ϕ and $y = L$ SI ϕ. Such curves have been in use for a considerable time and have proved extremely useful.

Neuer Profilmesstand (New type of profile measuring equipment), A. METZ. Werkstattstechnik und Werksleiter v33 n16 Aug 15 1939 p 400–1. For measurement and testing of thread cutting tools and similar equipment.

Improved Spherometer, J. L. HOUGHTON. J Sci Instrum v18 n8 Aug 1941 p 167–8. Spherometer is described which is fitted with device for indicating point of contact ; plunger passes up center of screw and on contacting surface to be measured, rises relatively to screw ; upper part of plunger carries small glass disk which, when it rises, touches convex glass surface fixed to screw and so produces Newton's rings ; spherometer can be used for measuring finely ground or opaque surfaces.

Radius-of-Curvature Measurements, H. C. SCHEPLER, Am J Phys v12 Apr 1944 p 107–8. Method uses a point source of light, a card having a hole in it, a collimating lens, and a steel scale.

Profile Gages (Measurement). Ordnance Inspection Handb ORD–M608–5 1 July 1945 p 899.0–899.18. Various methods of checking radii and profiles are described.

Measurement of Radius of Curvature of Concave Spheres, D. H. RANK, J Opt Soc Am v36 Feb 1946 p 108–10. In the method of measuring the radius of curvature of a sphere with an autocollimating microscope it is claimed that the substitution of an Abbé for a Gauss eyepiece leads to an improvement in ease of manipulation and accuracy. Abbé eyepieces manufactured by Gaertner are described and their method of use detailed. The sensitivity of the method is also discussed.

The Measurement of the Radii of Curvature of Convex Spherical Surfaces by Autocollimation, B. JUREK, F. KAUTSKY, Rev Opt (Théor Instrum) v27 June 1948 p 369–70. in French. The difficulties encountered in the precision measurement of the radius of curvature, r, using objectives of small size and small numerical aperture, due to the high values attained by a in the formula $r = (D' - a^2)^{1/2}$ and the slow change in quality of the returned image with displacement of the moving part of the instru-

ment used, are discussed, and the errors they introduce examined experimentally. It is concluded that a should be made as small as possible, and the errors introduced by its non-zero value controlled by a modification of the microscope.

Remarks on Precision of Optical Spherometer, B. JUREK. Microtecnic v2 n5 Oct 1948 p 215–21. Description of instrument; experimental determination of error limits with consideration of diffraction, spherical aberration, eye accommodation and reading error.

Measurement of Radii or Large Diameters, C. MINAIRE. Machy (London) v94 n2414 Feb 18 1949 p 380–2. Methods of determining radii described for cases where difficulties may arise owing to lack of sensitivity, or expansions of micrometers or other instruments employed, and in instances where it is necessary to check radii of arcs on work surfaces, which extend over less than 180°.

The Determination of Radii of Curvature by Mechanical Methods of Measurement and a Comparison of Their Accuracies, H. JENSEN. Optik v6 n5 1950 p 261–72 in German. A brief illustrated review of the various mechanical instruments, including templates, test curves and spherometers.

Accuracy of Spherometer Measurements, H. SCHULTZ. Optik v9 n4 1952 p 164–6 in German. For a ring type spherometer head, the radius of the ring cannot be taken as constant when the highest accuracy is required. The apparent radius has been found to vary in a linear fashion with the radius of the surface being measured. A correction chart for the spherometer head can be drawn.

Accuracy of Spherometer Measurements, E. HEINEMANN. Optik v9 n11 1952 p 525–6 in German. The results of Schultz are confirmed and re-arranged to give a more convenient practical formula for the correction to the radius measured with a spherometer.

The Effective Radius of Curvature of Knife Edges, G. F. HODSMAN, F. A. CHAPPELL. J Sci Instrum v29 Oct 1952 p 330–2. Knife edges used as bearings in fine chemical balances exhibit a finite radius of curvature. This radius affects the precision of the instrument and its magnitude is of interest to the balance designer. A technique is described for the measurement of this "effective" radius. Some results are given for brass and agate knife edges, values in the range 1–3 μ being obtained in the latter case.

The Measurement of the Radius of Curvature of Test Glasses with the Ring Spherometer, J. PICHT. Optik v10 n9 1953 p 423–5 in German. When measuring the radius of curvature of a pair of test glasses known to have the same curvature, by interference, it is usual to substitute the arithmetic mean values of the sagitta and the ring radius in the spherometer equation. It is shown that a geometric mean value of the inner and outer ring radius should be used and that the value of the correction form is then very small.

The Measurement of the Vertex Radius of Curvature of Parabolic Surfaces with a Moffitt Traversing Spherometer, J. PICHT. Optik v10 n11 1953 p 557–63 in German. The spherometer measures the position of a central probe held in contact with the parabolic surface. The probe ends in a small sphere and the relationship between the probe position and the zone radius is derived in terms of the parameters of the parabola and the probe radius.

On a Method of Measuring the Radii of Curvature of Spherical Surfaces by Comparison, A. BIOT. Atti Fonderie Ronchi, v8 Mar-Apr 1953 p 114–17 in French. By means of the Newton rings appearing between two spherical surfaces in contact it is possible to find the difference ΔR between the two radii of curvature. With an ordinary microscope, provided with a micrometric eyepiece, the radii of any two rings can be measured, using nearly monochromatic radiation (wavelength λ). If $n'-n$ is the difference between the orders of interference of the two rings considered, then $\Delta R = \dfrac{\lambda(n'-n)R^2}{r'^2-r^2}$

The Production and Inspection of Aerofoil Models, R. S. MARRINER, NPL. Machy (London) v83 Aug 14 1953 p 327–9. Describes process of machining delta wing type where the section progressively diminishes from root to tip. Inspection was by means of SIP universal measuring machine type MU214B.

The Accuracy of Spherometer Measurements, S. MOHOROVIČIĆ. Optik v11 n11 1954 p 493–5 in German. Previous methods of using spherometer measurements have required the approximate value of the radius of curvature to be used in a small correcting term. A re-arrangement of the equation is suggested which requires only measured values and the spherometer constants to be inserted to obtain an accurate value of the radius of curvature.

The Measurement of Radius of Curvature of Proof Glasses with the Spherometer, H. JENSEN. Optik v 11 n11 1954 496–8 in German. The suggestion that the geometric mean of the internal and external radii of the spherometer ring should be inserted in the spherometer equation is criticized. It is said that either the arithmetic mean radius or the mean square radius gives smaller errors than the geometric mean radius.

The Measurement of Radius of Curvature of Proof Glasses with the Ring Spherometer. II, J. PICHT. Optik v11 n11 1954 p 499–504 in German. An extension of the examination of the criticism by Jensen. The residuals arising from various methods of using the spherometer ring radii are calculated.

Measurement of Radii, K. W. B. SHARP. Machy (London) v84 n2146 Jan 1 1954 p 15–20. Various methods for determining radius of circular arc on component; apparatus for measuring radii of plate gages; measurement with surface plate and rollers; depth micrometer for obtaining arc height; methods using optical instruments; coordinate method; equations given and degree of accuracy attainable with each method indicated.

A Precision Spherometer, J. W. GATES, K. J. HABELL, S. P. MIDDLETON. J Sci Instrum v31 Feb 1954 p 60–3. The instrument described has been developed from the design of Guild; it is suitable for the accurate measurement of the curvature of transparent lenses and test plates, and particular attention has been given to protecting the surfaces measured from risk of damage. A brief comparison with other spherometers is made, and, in conclusion, attention is drawn to the convenience of specifying optical surfaces by their curvatures, rather than by radius of curvature.

A Note on the Design of the Spherometer, H. S. C. CHEN. Am J Phys v22 Sept 1954 p 374–5. A discussion is made of the errors involved in the use of a spherometer, and it is shown that the accuracy is limited by the accuracy with which the radius of the base circle is measured. A suggested change in design is given, which promises to mean easier manufacture and higher accuracy.

A Note on the Accuracy of Measurement of Radius of Curvature of Proof Glasses with a Ring Spherometer, V. BLUMOVÁ, J. HRDLIČKA. Optik v13 n3 1956 p 122–7 in German. Previous papers have discussed the best approximation to the ring radius to be used in calculation of results of spherometer measurements. An exact equation is derived and this is shown to give most accurate results if the mean square value is used to obtain the first approximation to the radius of the proof glass.

The Accuracy of Optical Measurement of Radius of Curvature, K. ROSENHAUER. Optik v13 n1 1956 p 5–6 in German. Mechanical measurements of radius of curvature of proof plates have an accuracy of about 1×10^{-4} of the radius. An optical method is described which depends upon bringing two reflected images to coincidence, and is said to have an accuracy of $\pm 1 \mu$ or 1×10^{-5} of the radius of 100 mm.

Correction Tables for the Measurement of the Radius of Curvature of Proof Glasses with the Ring Spherometer, Z. CZERSKI. Optik v13 n8 p 369–74 1956 in German. Numerical tables to assist in the rapid calculation for the cases considered by Jensen and Schulz are presented.

New Instrument for Measuring Camber on Large Rolls, P. W. HARRISON. Machy (London) v89 n2287 Sept 14 1956 p 642–6; Engr v202 n5250 Sept 7 1956 p 327–9. Instrument designed at National Physical Laboratory to measure camber of top surface on very large rolls such as those employed in paper making industry; instrument makes use of Young's interference fringe patterns to provide optical datum plane to which surface contour can be referred; design details; method of use; performance of apparatus.

Precision Measurement of Small Radii of Curvature, R. N. WILSON. J Sci Instrum v33 n12 Dec 1956 p 487–8. Conditions for accurate measurement of small radii of curvature by microscope methods; relevant formulas; reference to work of J. Guild inasmuch as recent requirements for precision measurement of radii of order of 5 mm have led to reassessment of techniques available; applicability in optical industry.

Praezisionsmessungen mit Ringsphaerometern, K. ROSENHAUER. Optik v14 n7–8 July-Aug 1957 p 328–34. Precision measurement with ring spherometers; discussion of differences between mechanical and optical calibration of ring radius of spherometer; it is possible to make precise measurements of radius of curvature provided that effective radius of ring is calibrated optically.

Method for Measuring Plane Curves by Series of Straight Lines, K. MIYAZAKI. Japan Soc Mech Engrs Trans v24 n138 Feb 1958 p 93–8. Theory and experimental results for testing plane curves given as profile curves of templets, etc. based on principle of curves as series of straight lines; relative errors of curves compared with standard curves by use of simple instrument. (In Japanese).

Bestimmung des Kruemmungshalbmessers von Kugel (flaeche) n mittels Sphaerometers (Determination of curve diameter of spherical surface by means of spherometer), G. BERNDT. Dresden. Tech Hochschule Wiss Zeit v8 n4 1958–59 p 801–28, n5 p 1001–11, v9 n1 1959–60 p 77–92. Critical study of method and instrument; estimate of errors involved; determination of curve diameter by direct measurement; method for determining curvature by means of difference measurement.

Measuring to Millionths with Standard Equipment, L. KICKMAN, M. HOSKINS. Tool Engr v42 n3 Mar 1959 p 117–19. Conventional electronic gaging components and fixtures can be used for measuring spherical and circular parts to six figure accuracy; setup at Eli Whitney Memorial Laboratory, Sheffield Corp, Dayton, Ohio for measuring template having arc of approximately 100° with 4 in. radius is described; instrumentation consists of two Accutron amplifiers and Electroject cartridge or pickup unit.

An Optical Device for the Measurement of the Radius of Curvature, A. I. OMEL'CHENKO, A. V. MOKHOV, Meas Techn 1958 n1 Aug 1959 p 20–1 1 fig 2 refs. Translated from Izmer Tekh n1 Jan–Feb 1958 p 18. The paper describes the construction and principle of a new and original optical instrument based on the optical section

principle and designed for the control of objects whose surface radius of curvature is small.

The Measurement of Geometrical, Dimensional, and Positional Errors of Technical Bodies by Means of the E-system, H. VON WEINGRABER, PTB. Microtechnic v19 n4 Aug 1960 p 173–180 12 figs. Starts by considering the geometrically perfect form of a technical body to provide a unified spacial reference system for all errors of form and position. Defines form error, dimensional error, and positional error.

Investigation of Method for Measurement of Convex Surfaces, Z. REZNIK. Machy (London) v97 n2499 Oct 5 1960 p 786–8. In connection with need for measuring radii of large circular segments, instrument was made which comprised two balls carried by light rigid frame with dial gage located centrally between them; data presented which enabled instrument to be correctly designd and dimensioned; examples show procedure to be followed; method described could also be used to check gages already in stock to determine their suitability for particular measuring applications.

Kinetic Circuits of Devices for Continuous Testing of Components, N. M. KARELIN. Meas Techns 1962 n3 Sept 1962 p 181–4 5 figs 3 refs. Translated from Izmer Tekh n3 p 4–6 Mar 1962. The article deals with kinematic schemes which can be used in designing testing devices for measuring component profiles described by curves which are widely used in production. Such curves include the ellipse, parabola, hyperbola, synoid and in particular cases limacon and cardioid. Profiles whose components are described by the above curves include elliptical wheels; elliptical webs of crank-shafts; parabolic templets in secondary instruments for linearizing quadratic relationships, for instance, between the flow and pressure difference; parabolic profiles, for instance, those of control gauges used in the optical industry; cardioid cams in automatic machines, etc.

Investigation and measurement of the Cutting Edges of Razor Blades, E. V. LORENTS. Meas Techns 1962 n6 Dec 1962 p 464–5 1 fig. Translated from Izmer Tekh n6 p 15–6 June 1962. The author used a method based on the utilization of diffracted rays by illuminating the cutting edge from one side.

Primenenie metoda vytertykh lunok i ottiskov k izucheniyu iznashivaniya, V. P. MITROVICH, M. K. FOMICHEVA. Zavodskaya Laboratoriya v29 n2 1963 p 217–18; see also English translation in Indus Laboratory v29 n2 Feb 1963 p 202–4. Use of scuffed-pit and replica methods in investigation of wear; method used in investigation of wear to lead-screws of precision metal-cutting machine tools combine scuffed-pit and replica techniques and is suggested for measuring small wear, and profile of worn surfaces.

Metrology for Ground Cams and Shapes, C. J. GREEN. Machy (NY) v69 n6 Feb 1963 p 83–93, 129. Three typical optical cam-contour reading devices which permit making extremely accurate and consistent readings; types of tappets and their relative accuracy; checking cam contours in toolroom; quality check and control; contour, angularity and timing checks; cam ramp design and how to measure base diameters; new far superior cam contour composed of infinite series of instantaneous radii of curvatures.

Measurement of Small Radii of Curvature, I. M. PASTUKHOV. Meas Techns 1962 n8 Feb 1963 p 652–3 2 figs. Translated from Izmer Tekh n8 p 26–7 Aug 1962. Describes contact indicating gage for checking radii of curvature between 0.03 and 2 mm.

Computer Corrects Gaging Bias, J. R. GILSON. Tool & Mfg Engr v50 n3 Mar 1963 p 61–5. Studies made of

contour measuring systems at Livermore Laboratory, Sandia Corp, to determine what problems must be solved to increase gaging accuracy, data bias resulting from misplacing part in coordinate reference frame of gage; mathematical repositioning; application of computer analysis to gaging data permits increased inspection accuracy while reducing dependence on operator skill; it eliminates need for nonfunctional datums previously used to ease fixturing problems; other advantages.

Effect of a Surface Shape Error on the Precision of Measuring a Circular Profile Radius, D. I. KOLPAKOV, V. V. MATVEEV. Meas Techns 1963 n3 Sept 1963 p 192–4 2 figs. Translated from Izmer Tekh n3 p 10–1 Mar 1963. A method for evaluating a radius by the chord and the height of segment cannot be recommended for testing ball bearing races because the radius evaluation error may be more than 8 times greater than the geometrical shape error which produced it.

Kinematic Effects of Cam Profile Errors, M. D. ROGERS. R. R. SCHAFFER. ASME—Paper 63–WA–269 for meeting Nov 17–22 1963 8 p. Numerical analysis of profile errors has been developed; computer program conducts analysis of regularly spaced polar coordinate specifications of cam profile; errors introduced in rounding off theoretical curves in incremental cutting are shown to correlate with accelerations determined from experimentally measured cam profile.

Measuring the Critical Profile of Barrel Bearing Rollers with Microinch Sensitivity, F. FARAGO. Gen Motors

Eng J v11 n1 1964 p 17–23 14 figs. 1 ref. Describes a process for measuring the form of accurate surface elements of barrel bearing roller components by tracing a single surface element in rigorously controlled relation to other significant dimensions of the part.

Two methods for Determining Minimum Radius of Curvature of Disk Cams, N. E. REID. ASME—Paper 64–MECH–20 for meeting Oct 19–21 1964 7 p. Analytical method of determination of minimum curvature radius of cycloidal disk cam without use of computer is given for case of flat-faced follower; numerical values of minimum radius are obtained and tabulated for various values of parameters involved; method is not suitable for cycloidal and harmonic disk cams when used with radial roller followers; instead, solutions are obtained by using computer to solve equations and then tabulating minimum values.

Recent Developments in Cam Profile Measurement and Evaluation, J. H. NOURSE. SAE—Paper 964A for meeting Jan 11–15 1965 47 p. New techniques are presented for cam profile measurement and evaluation based upon recently derived analytical methods and electronic computer programs; new methods include mathematical refinement of profile raw lift data and obtain following advantages, namely, accuracy, repeatability, evaluation and efficiency; new acceptance criteria for cam profile quality control, and direction for further development of cam profile measurement and evaluation methods and techniques are suggested.

8.2. Contour Measurement by Optical Projection

The Projecting Lantern, J. B. TAYLOR. Illum Eng Soc Trans v 11 May 1 1916 p 414–35 12 figs. The early part of the paper summarizes the fundamental principles of optical projection, and also describes the means by which solid objects may be projected. L. C. Porter discussed the conditions in which electric glow lamps may be used for projection. Deals mostly with projection of slides.

Note on Setting Up and Using the Gauge Projection Lantern. NPL. Jan 20 1917.

Projection Method of Testing Screw Threads, F. D. JONES. Machy (NY.) v24 Apr 1918 p 735–8 8 figs. Arrangement and use of projection apparatus as applied to inspection of thread gages for munitions manufacture. Methods used in the New York Lab of the British Ministry of Munitions.

Optical Projection Apparatus for Testing Gages. Engr. v125 Apr 19 1918 p 346–7 3 figs; Sci Am Supp v85 June 15 1918 p 380–1 3 figs. Details of British Horizontal projection apparatus and the requirements and use. Extracted from "Notes on Screw Gages" by the staff of the National Physical Laboratory, Nov 1917.

Projection Lantern for Thread Measurement, H. L. VAN KEUREN, E. C. GRIESS. Am Mach v49 n18 Oct 31 1918 p 805–11 11 figs. The measurement of screw threads presents more kinds of difficulties than almost any other machine part. The apparatus here described has been developed at the Bureau of Standards and is proving very satisfactory, and in common with all developments of the bureau it is free to be used by anyone. The apparatus is easily handled and is well worth careful consideration.

Optical Projection for Screw-Thread Inspection, J. HARTNESS. Mech Eng v41 Feb 1919 p 127–35 10 figs; Iron Age v103 Feb 6 1919 p 357–8 2 figs. Analysis of screwthread elements essential to strength and dependability; description of method for their accurate inspection.

Optical Projection Applied to Inspection, H. S. BEAN. Inspector v1 Sept 15 1919 p 25–30 7 figs. Description of apparatus developed and used by Bureau of Standards.

Some Optical Aids for the Engineer, A. C. BANFIELD. Machy (London) v14 Sept 18 1919 p 737–40 10 figs. Description of Wilson projection comparator. Operator avoids distortion by special twin optical system of such a nature that respective optical centers are adjustable to diameter of screw under test. See also p 613 650 705.

Optical Aids for the Engineer, R. J. WHIBLEY. Machy (London) v15 Jan 8 1920 p 451–9 18 figs. Optical methods that have been developed at National Physical Laboratory, Teddington, England, for aiding inspection work in metrology department.

Vertical Gauge Projecting Apparatus, National Physical Laboratory . Eng v109 Feb 27 1920 p 273–6 14 figs. Standard type designed in National Physical Laboratory, England, Nov 1917.

Improved Type of Optical Projection Apparatus, L. A. FISCHER. Am Mach v53 Dec 16 1920 p 1158; Sci Am v124 p 94 1921. Description and illustration of horizontal projection lantern developed by the Bureau of Standards.

Increasing the Scope of Projection Apparatus, L. E. KING. Machy (NY) v 27 Jan 1921 p 463–4 3 figs. Describes improvement of gage holder for measuring distances on thin flat work; also a chart for measuring center distances.

New Lantern for Screw Testing. Sci Am v124 Jan 29 1921 p 94. Description of Bureau of Standards horizontal type projection lantern, which incorporates the protractor for measuring the thread angle of screws as a component part of the lantern.

Mesure de l'Usure ou de la Déformation d'une Pièce (Measurement of the Wear or Deformation of a Mechan-

ical Piece), P. BEURET. Rev Metallurgie v18 Mar 1921 p 157–60 7 figs. Photographic projection of gears, screws, etc.

Use of Optical Instruments in Machine Work. Am Mach v56 May 11 1922 p 697–701 19 figs. Describes the use of the microscope and projector in checking the shapes of formed tools and their products. See also Contour Measuring Projector by the Bausch and Lomb Optical Co.

Inspecting by Optical Projecting. Machy (N.Y.) v28 Aug 1922 p 984–8 6 figs. Description of methods, with particular data on screw and gear inspection. Bausch and Lomb contour measuring projector which can be used to measure thread gages, but is furnished with a universal screw holder and adjustable thread chart which permits its use as a projection comparator for inspecting screws in quantity.

New Projector Measures Wide Range of Precision Parts. Automotive Indus v49 Aug 23 1923 p 364–7 9 figs. Describes contour measuring projector, an instrument developed by Bausch and Lomb Optical Co., for visual inspection of screw threads, forms of gear and cutter teeth, and other parts; accuracy of 0.0001 in. can be attained; separate attachments make photographs.

A New Projection Microscope. Eng v137 June 27 1924 p 728. Description of Vicker's projection microscope in which the image is projected upon one of two ground glass screens, and on the other screen a microscopic transparency of a standard specimen is projected so that it may be readily compared with the object under examination.

Optical Method for Testing Wire Mesh, D. P. MUIR-HEAD. Am Mach v62 May 14 1925 p 785. Optical projection apparatus for determining number of meshes per inch.

Measurement by Optical Projection, G. A. TOMLINSON. Optical Convention Proc Part I 1926 (3d London). p 311–26. The paper commences with a brief history of the development of the method of projection at the N.P.L. leading on to a description of the two types of apparatus, horizontal and vertical of N.P.L. design now widely used. A series of examples are then given, illustrating the wide range of the utility of the apparatus. Other projection apparatus of British manufacture is described, including the Wilson screw thread projector and the Beck projection microscope for fine wire measurement. In conclusion the theory of the formation of the image is considered briefly.

Some Applications of Optical Projection to Engineering Practice, C. F. SMITH. Machy (London) v27 Jan 7 1926 p 473–5 6 figs. Describes instruments manufactured by scientific instrument makers, Adam Hilger, Ltd.

Zeiss Measuring Machine. Machy (London) v27 Mar 18 1926 p 815–6 5 figs. Details of design; principle of optical system.

A Screw Projector, C. F. SMITH. Machy (London) v29 Oct 28 1926 p 103 3 figs. Instrument designed by writer to deal with screws of diameters varying from 2 to 10 inches in lengths between centers up to 16.5 inches of parallel or taper form; illuminating system is arranged so that light may be directed along helix and lamphouse is pivoted about center approximately coincident with second nodal point of lens.

Profile Measuring by Projection. Automobile Engr v20 Mar 1930 p 108–9 6 figs. Contour measuring projectors consist of highly perfected optical system and suitable mechanical parts to protect and support system, to hold work in position, and to provide necessary adjustment

and means for making measurements; work is illuminated by single-filament 108-watt Mazda lamp, in conjunction with transformer on alternating current.

Projection Testing Apparatus, C. F. SMITH. Machy (London) v37 n954 Jan 22 1931 p 547–8 6 figs. Projector made for Coventry Gauge and Tool Company, by A. Hilger, Ltd. as applied to projection of contours of anvils used in Wickman screw gages.

Vickers Contour-Projection Appartus. Eng v139 n3609 Mar 15 1935 p 280–1. Apparatus made by Cooke, Troughton and Simms intended for accurate gaging of screw threads, irregular templets and parts, cams, etc, and consists of optical system which projects magnified image of part to be gaged on to horizontal translucent screen, on which measurements can be made by scale or in other ways.

Die Projektion in der Messtechnik (Projection in measuring technique), P. NICHTERLAIN. Werkstattstechnik und Werksleiter v31 n23 Dec 1 1937 p 534–9. Optical and mechanical principles governing correct measurement; influence of optical methods on accuracy and efficiency; ideal objects, such as templets, and sheet metal parts.

Optical Projection, H. F. KURTZ, Mech Eng v60 n6 June 1938 p 469–73. Possibilities and limitations of most modern optical projection apparatus in industry considered; optical systems for use in projection; results of projection test; optical projection as means of comparasion; contour projector used as measuring device, Before Am Soc Mech Engrs.

Jewel Inspection Microscope, F. E. J. OCKENDEN. J Sci Instrum n7 July 1939 p 228–30. Microscope incorporating objective with built-in illuminator and illuminating system described; use of this device greatly facilitates measurement of radii of polished spherical surfaces by optical means, particularly when of order of 0.1 mm or less.

Die mikroskopische Abbildung von Zylindern und Gewinden (The Microscopic Imaging of Cylinders and Threads), N. GUENTHER. Zeit InstrumtKde v59 n8 Aug 1939 p 315–21. The object of this paper is to derive those illumination apertures by which the geometrical data for cylinders and screw threads may be obtained within the limits afforded by the microscope. The mathematical treatment deals with the physiological shading limits, the shade limits of geometrical optics, the most favorable stops, and the determination of flank diameters and angles of threads. From a large number of measurements with different apertures, interpolation and error formulas have been derived.

Measurement by Projection. Aircraft Prod v3 n33 June 1941 p 262–3. Description of Dekkor microprojector for measuring and checking machined parts.

Dekkor Universal Measuring Projector, Eng v151 n3934 June 6 1941 p 446–7. Principle embodied in instrument is that of making all linear measurements with aid of slip gages and micrometers, combined errors of which do not exceed 0.0001 in; angular measurements are made by protractor having very high order of accuracy; no drawing is required.

Measurement by Projection. Automobile Engr v31 n412 July 1941 p219–20. Instrument and method suitable for large contours illustrated and described.

Optical Sections. Aircraft Prod v4 n48 Oct 1942 p 610–11. Principles and applications of Taylor-Hobson section projector by means of which it is possible to take optical

sections in any plane through all types of gears, splines, and similar objects.

Ueber ein interferentielles Verfahren zur Bestimmung der Formfehler an Bohrungen und Innenkegeln (Interferential method for determination of form defects in drilled holes and internal cones), K. HOLECEK. Werkstattstechnik und Werksleiter v36 n23/24 Dec 1942 p 481–86. Definition given of form tolerance and error; method described for determination of total form error for cylindrical and tapered holes, by comparing specimen with optically produced nominal form.

Hilger Large Toolmaker's Projector. Machy (London) v62 n1591 Apr 8 1943 p 381–3. Illustrated description of projector which retains all mechanical advantages of toolmaker's microscope, and embodies stage of entirely new design capable of carrying work of considerable size and weight; entire stage can be rotated over small angle enabling lining up to be quickly and accurately carried out.

Optical Problems in Design of Comparator, F. J. ACTON. Machine Design v15 n10 Oct 1943 p 81–4. Illustration, drawing and description of Postman optical comparator capable of handling parts of size formerly considered outside of range of optical inspection apparatus; development of increased object-to-lens distance for greater optical and mechanical capacity and increased illumination; flatness problem solved by use of thick mirrors.

Inspecting Turbosupercharger Blades—By Optical Projection Comparator, E. C. POLIDOR. Iron Age v159 n3 Jan 16 1947 p 40–4; Machy (NY) v53 n5 Jan 1947 p 185–8. Fast and accurate method of inspecting blade and bucket profiles, using newly developed Pant-O-Jector; operating principle is based on use of simple pantograph X and Y; Motion, tracing path of scribing end of pantograph on projection instrument at known magnification; using beam of light to trace profile on special comparator chart indicates form of blade and also locates it in relation to center of gravity.

New Machine Speeds Turbine Blade Contour Measurement, W. A. LLOYD. Iron Age v162 n6 Aug 5 1948 p 76–8. Features of measuring machine employing combination of optics, light beams and photography, to measure and dimensionally record contours and angular twists of mixed flow and axial flow compressor and gas and steam turbine blades; machine will mechanically measure to ±0.00025 in. across width of blade in increments of either 0.0125, 0.025 or 0.050 in. at speed of approximately 0.375 in. per min; setup and operations detailed.

Société Genevoise Contour Projector for Turbine Blades. Machy (London) v74 n1907 May 12 1949 p 637–9; Aircraft Prod v11 n129 July 1949 p 234–6. Description of type AP–14 profile projector developed by Société Genevoise d'Instruments de Physique, Geneva; design incorporates same optical system as firms AP–6 projector; on new projector entire blade contour at any selected section is shown on screen at one time; photographs, sketches.

Precision Measurement of Rockwell Hardness Diamond Penetrators, F. R. TOLMON, J. G. WOOD, NPL. Eng v172 n4460 July 20 1951 p 89–90. Photographs taken on Linnik interference microscope gave clear general impression of shape and surface of tip of penetrator over restricted distance corresponding to axial depth 0.002 in. from apex of penetrator; photomicrographs.

Inspection by Optical Projection Methods, E. C. POLIDOR. Tool Engr v27 n2,3 Aug 1951 p 43–6, Sept p 52–4. Recent developments in contour measuring projectors; arrangement of optical elements indicated; requirements of projector used for inspection; laying out of chart by drafting board technique and by scribing machine methods; new types of chart lines facilitate accuracy and

bring about other improvements; advantages of this inspection method; planning for typical part; importance of size and dimensions of parts; illustrations.

Evaluation of Small Radii of Curvature Using the Light-Profile Microscope, S. TOLANSKY, M. OMAR. Letter in Nature (London) v170 Nov 1 1952 p 758–9. The light-profile microscope is applied to the measurement of the radius of curvature of a small metal sphere, calibration being performed by means of Newton's rings with a 0.6 mm sphere. Accuracy of 1% is attainable.

The Optical Projection of the Profile of an Article at a Given Cross-Section, F. G. MORTON, V. E. GOUGH. J Sci Instrum. v30 Aug 1953 p 277–80. Two types of projector are described which permit the continuous observation of the sectional shape of a rod-like or thread-like object, of substantially constant cross-sectional shape, as the object is passed through the projector. The article may be of any length and may be flexible or rigid. The projection of sectional shape may be accomplished by two distinct methods. The first employs the projection of light scattered from the surface of an illuminated peripheral band of the object. In the second method the object is placed co-axial with a projection lens which receives scattered light from all points on the surface of the object under examination. The lens selects a thin section of the object and projects the peripheral shape of this section on to a screen. The application of these projectors to the continuous gauging of the outside dimensions of rubber tubing is described.

Two Precision Projectors. Engr v196 n5091 Aug 21 1953 p 252. Measuring projectors made by Hilger and Watts; universal instrument performs normal comparison of projected image with template, and makes precise measurements in two mutually perpendicular directions over distances greater than area projected on screen; lathe projector can do most of work required from normal projector; profile of work, magnified to suitable degree, is clearly shown on screen together with cutting edge of tool.

Inspection of Prismatic Bodies by means of an Optical Section and Application of this Method to Turbine Blades, J. TURRETTINI. Eng Dimensional Metrology, Proc of Symposium at NPL Oct 1953. Her Majesty's Stationery Office. Describes method of controlling optically intermediate sections of prismatic bodies.

Variants of a New Spherometer Method, B. JUREK. Letter in Czech J Phys v4 Feb 1954 p 97 in German. Two alternative layouts of a double prism attachement, allowing the accurate measurement of radii of curvature by autocollimation, are described.

Photometry of Microscope with Special Reference to Projection, G. E. J. OCKENDEN. J Sci Instrum v 31 n9 Sept 1954 p 309–13. Transmission losses in microscope optical systems and their effect on brightness of both visual field and projected images estimated; it is shown that production of large, well illuminated, projected images by means of microscope is subject to limitations for which only solution is provision of illuminants having higher intrinsic brilliance than any at present available.

Blade-Profile Inspection. Aircraft Prod v16 n9 Sept 1954 p 373–5. Comparator, based upon optical principles, and built by Taylor and Hobson, Leicester, for inspection of turbine blade profiles; instrument is designed to project profiles of either shrouded or unshrouded blades upon ground glass screen, at magnification of ×10.

Some Usual and Unusual Tool Room Measurements with Contour Projector, A. R. FULTZ. Tooling & Prod v20 7, 8, 9 Oct 1954 p 72–3, Nov p 61–3, Dec p 65–8 134. Measuring screw machine circular form tool on contour projector; solution for overcoming phenomenon known as "wall

effect" which is found wnen flat surface lies along line of light projection; inspection by contour projection of single point turning tool for side rake angle; method for examining punch and die indicated.

An Optical Show-casting Miscroscope, S. TOLANSKY. Lab Prac v3 n10 Oct 1954 p 405–9. The heights of small objects can be measured from long shadows cast by illuminating at a grazing incidence less than 5°. It is essential that the objects should rest on a specially prepared surface which scatters light up into the microscope. The technique is described in detail and is used with shadow magnifications up to ×2500. The technique is extended to include features on crystal surfaces by producing the appropriate scattering surface in situ on the crystal. Examples from diamond, quartz and zinc crystals are illustrated. In addition to measuring surface structural features, local enhanced contrast of topographical features results.

Anisotropic Projector, R. B. LEIGHTON. Rev Sci Instrum v27 n2 Feb 1956 p 79–82, Optical projector having different magnificatons, 5× and 50×, in two rectangular directions; although designed principally for rapid measurement of cloud chamber track curvatures, it has been applied to various situations in which plane-to-plane imaging at constant magnification is desired; simple plano-convex cylindrical lenses are used as image forming elements.

Measurement of a Profile in Coherent Light, J. C. VIÉNOT. Rev Opt v35 n10 Oct 1956 p 517–25 in French. The measurement of the diameter of a small object, such as a thread, is difficult with incoherent light because of the out of focus images of the third dimension. The diameter can be measured more precisely from the diffraction fringes formed with coherent light. Conditions are obtained for best definition and most accurate measurement. Sample results are quoted.

Precision Measurement of Small Radii of Curvature, R. N. WILSON. J Sci Instrum v33, n12 Dec 1956 p 487–8. The conditions for the accurate measurement of small radii of curvature by microscope methods are discussed and the relevant formulae stated.

On the Improvement of the Precision of Microinterferometry. Investigations Concerninng Interference Spherometry, R. LANDWEHR. Zeit InstrumKde v66 n7 Aug 1958 p 134–8 in German. A geometrical analytical examination concerning the calculation of corrections in exact two-beam interferometry. The displacements arising both from the small angle of inclination between the surfaces and also from the finite angles of the incident cone of light are computed. Tables of corrections are given for numerical apertures up to 0.65. The applicaton of these computations to the possibility of accurate interference spherometry is discussed.

Microinterference as an Aid to Testing the Shape of Aspherical Surfaces, R. LANDWEHR. Ann Phys (Leipzig) Folge7 v4 n1–5 1959 p 154–66 in German. The testing of the strongly curved aspherical surfaces of rotation now so widely used can be carried out with a microinterference method. Measurements made over small regions permit an analysis of the whole. The theory of the method is

developed in detail and the equations of the interference curves are derived. Interference curves are given for a paraboloid viewed in various zones and special cases are numerically evaluated. It is shown that the interferometric results are in agreement with spherometer measurements.

Precision Measurement. Aircraft Prod v24 n1 Jan 1962 p 18–20. Trioptic-machine built by Soc Genevoise Instrum Phys, Geneva, Switzerland, for measurement in 3 axes; direct readings can be made to 0.0005 in. (0.001 mm) and estimated to ⅕ of direct readings, accessories include feelermicroscope, goniometric microscope and illuminating-table; readings of carriage and inspection-head movement are displayed on projection screens; for longitudinal and transverse movement there are 2 dial indicators reading to 0.05 in. (or to 1 mm); accuracies for ʔ ordinate movements shown.

New Comparator Gages-Photos on Glass, E. C. POLIDOR. Am Mach/Metalworking Mfg v106 n15 July 23 1962 p 79. With special photographic process, glass chart gages are produced at Automation Gages that, inserted in optical comparators, give extreme accuracies needed to inspect jet engine blades; more permanent than plastic charts, new chart gages are also cheaper and easier to prepare than conventional etched glass gages.

High-Magnification Optical Projector, W. G. RIDGE. J. E. FURSE, P. W. HARRISON. Machy (London) v103 n2593 July 25 1962 p 181–4. Reference made to prototype high magnification projector of horizontal type, described in article by F. R. Tolmon, J. G. Wood; projector was now redesigned; with aid of accurately flat mirrors, optical path has been folded so that projector appears in rigid compact form; observer can take readings and adjust position of object while sitting in front of screen; optical system described; 2 special attachments of fine wire were made for projector.

Accuracy in Measuring the Dimensions of Components by the Shadow Projection Method, V. P. KORONKEVICH, L. YA. GUSTYR'. Meas Techn 1962 n5 Nov. 1962 p 362–5 7 figs. Translated from Izmer Tekh n5 p.5–9 May 1962. Article shows that, providing the illuminator is correctly adjusted, the accuracy of the shadow-projection method is higher than that of the blade method.

Advanced Optics Solve Quality-Control Problems. Machy (NY) v70 n7 Mar 1964 p 132–3. Timken Roller Bearing Co, having one of finest tool and gage laboratories in country, uses universal measuring microscope called UMM, manufactured by Zeiss in West Germany; its basic function is measurement of irregular profiles, angles, radii and threads; typical application is in measuring threaded components; one instrument can check all thread dimensions; it is also used in maintaining accuracy in master gages; various applications of UMM, pertaining to manufacture of precision bearings, are given.

Ein Objective für Profilprojektion (An Objective for Profile Projection), L. CANZEK. Optik (Germany) v21 n12 Dec 1964 p 672–5 4 figs 1 ref in German. An objective for profile projection (magnification ×50 and object—image distance about 1000mm) is described. Methods of correction are given and the state of correction is discussed.

8.3.   Measurement of Involute Contours

All references under this heading are given in subsection 10.2.1.

Addendum to Section 8

8.1.   Measurement of Radius or Profile by Mechanical Methods

Measurement of Macrodeviations in External Surfaces of Cylindrical Components. T. S. LOPOVOK. Meas Techns 1962 n8 Feb 1963 p 649–51 3 figs 1 ref. Translated from Izmer Tekh n8, p 24–6, August 1962. Microprofilo-

grams of external surfaces are distorted because of errors in the center holes of measured components. The technology of producing better center holes was studied.

Section 9. Measurement of Screw Threads

CONTENTS

9.1. General

A Microscope for Measuring Screw Threads. Am Mach v27 pt1 n3 Jan 21 1904 p 78 7 figs. Illustrations show the microscope, the arrangement of the cross wires, and various adjustments. Instrument made by the Cambridge Scientific Inst. Co. for the Small Screw Gage Committee of the British Association, by whom it was placed in the custody of the National Physical Laboratory.

A Device for Measuring Screw Threads, M. E. ANDERSON. Am Mach v32 Oct 14 1909 p 665–8 11 figs. Illustrates and describes roller calipers which can be conveniently adjusted to suit any angle of helix and to measure accurately threads of any lead. System evolved to meet the needs of the S. S. White Dental Mfg. Co. 12 or 15 years ago.

Instruction a L'Usage des Etablissements Constructeurs pour la Réception des Vis et Écrous au Filetage (Instruction on the Usage of the Etablissements Constructeurs for the Receipt of Threaded Screws and Nuts), S. I. Ministere de la Guerre, Artillerie, Dec 23 1913. Includes a description of a comparator for checking pitch diameter of screw threads, which embodies V-shaped anvils for contact with thread. Also includes description of a lead tester.

New Measuring Instruments and Measuring Methods in Automobile Manufacture. Horseless Age Aug 12 1914. Deals with the measurement of screws and gears.

How to Measure Screw Threads. Greenfield Tap and Die Corporation Bul n1 Jan 1917 p 1–15. Gives methods of measuring screw threads.

Gaging and Inspecting Threads, D. T. HAMILTON. Machy v23 n6 Feb 1917 p 477–86 Front 15 figs (half-tones sections etc.) tables ni–ix; the same, ii. Machy v23 n7 Mar 1917 p 581–6, 7,000 words Figs 16–34 (half-tones, sections, etc.). Table i. British standard Whitworth threads.—Tolerances for bolts.—ii. British standard Whitworth screw threads. iii. Allowances to compensate for errors in pitch of British standard Whitworth screw-threads. iv. Tolerances on included angle of screw threads. (The Engineering Standards Committee). v. Tolerances on pitch diameters of U.S. Standard screws, taps and gages (loose fit tolerances). vi. Tolerances of pitch diameters of U.S. Standard screws (taps and gages close fit tolerances). vii. Propositions for Briggs standard reference pipe ring gages (Cadillac Motor Car Co.). viii. Propositions for Briggs standard reference pipe plug gages (Cadillac Motor Co.). ix. Dimensions of ball points used in measuring screw threads. Part 2 consists of a general survey of devices for testing lead of taps and screws.

Subjects taken up: simple device for testing lead of screw threads; Well's indicator for testing lead of screws and taps; indicating comparator for testing lead; Wolfe dial indicator for testing lead of taps; testing included angle of thread; limit working and inspection thread gages; limit, snap and plug gages for thread work; limit snap gages for testing lead and pitch diameter; indicating gage for inspecting lead and pitch diameter; inspecting die chasers; microscope for measuring screw thread gages; projection method for measuring screw threads.

Screw Thread Measurement, A. BROOKER. Eng v103 n 2666 Feb 2 1917 p 113–6; n2667 Feb 9 1917 p 139–41; 2668 Feb 16 1917 p 165–6. Figs 1–28 (half-tones diagrs section etc.) formulas. Contents: Section I. Introduction.—Section II. Definitions, p 113.—Section III. Methods of measurement. 1. Measurement of elements by microscope micrometer, p 114–6. 2. Diametrical measurements by floating micrometer, p 139. 3. Optical projection apparatus. 4. Measurement of pitch by mechanical means, p 165. Section iv. Concluding remarks, p 165–6. This paper was read before the Liverpool Engineering Society. Deals with the Whitworth standard system, and with the methods of measurement. See also Cambridge Scientific Instrument Co., title no. 79. First installment. Gives Engineering Standards Committee definitions of configuration of screw and threads (effective diameter, core diameter, etc.) Author describes measurements of elements by microscope micrometer method. In the second installment are described measurements of core diameter and effective diameter by floating micrometers. This is a method which makes possible taking measurements on the lathe during screw cutting operation, and also serves to check optical methods. Under projection apparatus method of testing form at root and crest of thread described, with suggestions as to use of photography. Third installment, describes new method for micrometric measurement applicable to male and female screws with addition of special optical device to indicate when thread of rotating screw has reached exactly same phase as at preceding measurement. Discusses importance of close measurement. Includes comparative illustrations. Table showing constants of 10 screw thread systems.

The Microscope for Inspecting Screws, F. R. WILLIAMS. Am Mach v46 n17 Apr 26 1917 p 736 350 words 1 half-tone illus. The microscope and the fixtures used in adapting it for testing threads. Author treats on accurate checking of hobs, taps, thread chasers, forming cutters and a number of other tools with cutting edges. . . . He also refers to the chapter on "The use of the compound microscope in the toolroom" in the work under the title: Accurate tool work, by Goodrich and Stanley.

The Inspection of Screw Gages for Munitions of War, H. J. BINGHAM-POWELL. Am Mach v47 n25 Dec 20 1917 p 1065–73 incl figs 1–5 (half-tones). Contents: The measurement of the pitch. Devices for measuring pitch.— Pitch from thread to thread.—Leveling operations. Ring screw gages. Plug screw gages. The thread-micrometer principle. One wire better. Tolerance allowed. Illustrations: 1. National Physical Laboratory projection machine. 2. Bingham Powell pitch machine. 3. Apparatus for taking true casts or ring screw gages. 4. National Physical Laboratory screw measuring machine. 5. Attachment placed in Pratt & Whitney measuring machine. Aim of author is to assist screw-gage manufacturers in their work of making gages for munitions of war, which have to be accurate within very low tolerances.

Measurement of Internal Threads, W. S. ROWELL, Machy v24 n5 Jan 1918 p 429 incl 2 figs formulas. Recommends the use of an inside micrometer with ball points to assist in making and gaging internal threads.

Precision Screw Measuring Machine. Machy (London) v24 Feb 1918 p 494–5 4 figs. Describes precision screw measuring machine made by the Cambridge Scientific Inst. Co. Ltd. for the Small Screw-Gage Committee of the British Association. For measuring major diameter, pitch diameter, lead, and angle of commercially produced screw threads and taps.

The Measurement of Thread gages, H. L. VAN KEUREN, Chief of Gage Section, NBS. ASME J v40 n11 Nov 1918 p 913–8 Trans ASME v40 1918 p 827–49. Contents: Measurement of plug thread gages, pitch, form and angle of thread, core diameter, full diameter, effective diameter. Choice of wires, standardization of wires, computation of effective diameter, precautions in making three-wire measurements. Test of ring thread gages: Measurement of pitch or lead, angle, thread farm, full diameter, core diameter, and effective diameter.

A Machine for Measuring Screws, P. E. SHAW. Eng v107 Jan 24 1919 p 104–8 16 figs. Methods described depend upon a simple point contact in all cases. The machine used deals with the diameters and the pitch and is of a simple type, easy to use. Mechanism consists of a beam rotating about its center, one end bearing by a special pin on the thread surface, the other end bearing by another pin on an optical lever. Beam has two motions, a rotation and a sliding action parallel with the axis of the screw being measured. Especially adapted to measuring ring gages.

The Precision Measurement of Thread Gages. Can Machy v21 Jan 30 1919 p 113–5 4 figs. Commercial equipment manufactured by Arthur Knapp Eng Corp after models developed by Bur. of Standards. Automative Indus v39 p 1008–10.

A New Screw-Measuring Machine, P. E. SHAW. Eng v108 Dec 19 1919 p 816–7 4 figs. Suggested simplification of machine described in Eng Jan 24 1912 p 104. Principle employed is to measure profile of imaginary axial section of screw whether plug or ring.

Messen und Prüfen von Gewinden (Measuring and Verifying of Screw Threads), F. MEYER. Betrieb v2 Feb 1920 p 136–9 9 figs. Discusses measurement of pitch diameter, lead, and thread angle by means of a screw thread measuring microscope in which knife edges to contact the thread surfaces are used.

Screw Thread Measuring Instruments. Eng Prod v1 June 1920 p 221–5 13 figs. Machines designed by Metrology Department of National Physical Laboratory, England.

Measuring Templets and Screw Threads with a Microscopic Measuring Machine. Am Mach v53 July 22 1920 p 187; Eng Prod v2 Jan 13 1921 p 40–4 12 figs.; Machy (NY) v24 May 1918 p 791–3 5 figs. Construction and adjustment of Alfred Herbert design of measuring machine and application for testing accuracy of templets or contour gages and screw threads.

Zwei Apparate zur Messung von Gewinden and Lehren (Two Apparatus for the Measurement of Threads and Gages), F. GÖPEL. Werkstattstechnik v14 Nov 1 1920 p 559–63 14 figs. Description of a measuring machine with spirit-level indicator for determination of pitch of thread; and an anglemeter for chasing tools based on principle of goniometer.

The Bath Internal Thread Micrometer. Am Mach v54 n25 June 23 1921 p 1102; Machy (N.Y.) v27 July 1921 p 1070. An internal micrometer having sliding-wedge-operated threaded measuring jaws available with any number of threads per inch in sizes from 1 to 5 inches in diameter.

Die Messung des Flankendurchmessers (The Measurement of the Pitch Diameter), G. BERNDT. Betrieb v4 n3 Nov 12 1921 p 70–81 26 figs; n10 Feb 18 1922 p 333–8 7 figs German. Nov 12: Critical considerations regarding errors occurring in the measurement of flank diameter by different methods (thread micrometers, special micrometers) wire methods and optical measurement. Application of the results to the allowable error in the measurement of pitch. Feb 18: in the comparison of thread gages with standard gages by means of thread micrometers, in measurement with a micrometer having ball contacts. Error of an inaccurate adjustment or positioning of the thread axis in the vertical plane in the measurement of flank diameter or pitch. It is absolutely necessary to measure on 2 oppositely leaning flanks and to take the mean.

Gewinde-Messkomparator (Screw-Thread Measuring Comparator), C. BÜTTNER. Betrieb v4 Feb 11 1922 p 289–93 11 figs. Describes construction and function of a new Zeiss optical screw-thread measuring machine for maximum accuracy, with which all thread dimensions can be determined.

Sine Bar Fixture for Accurately Checking Thread Angles, Machy (NY) v28 May 1922 p 722. A sine-bar fixture attachment for a bench lathe comprising a pivoted plate carrying at one end a contact point accurately ground to the basic thread angle and at the other end a plug or button, which, with the plate pivot, comprises the sine bar, screws for adjusting the angular position of the plate, and a fixed block opposite the plug on the plate which serves as a reference point for taking micrometer measurements over the block and button. The fixture is first set to a master groove cut on a cylinder by aligning the contact point with the conical sides of the groove, and a micrometer reading over the block and button is taken. The master is then replaced by the work to be checked, and from differences between measurements taken when the sides of the contact point are aligned, first with one side of the thread and then with the other, the error in thread angle is determined.

Work at the National Physical Laboratory. Machy (London) v20 Aug 3 1922 p 558–61 7 figs. Internal effective diameter measurement of screw threads.

Thread Measuring Devices, B. M. W. HANSON. Machy (N.Y.) v29 Aug 1923 p 946–8 4 figs. Describes different devices with special reference to lead-measuring machine.

Inspection of Taper Thread Gages. NBS Letter Cir n13 Oct 20 1923 27 p 15 figs. Describes methods of measuring taper screw thread gages, with seven tables of wire sizes, constants and other data.

Über Fortschritte in der optischen Gewindemessung (Regarding Progress in the Optical Measurements of Screw

Threads), O. EPPENSTEIN. Zeit Feinmechanik v32 June 5 1924 p 115–7 6 figs. Communicated from Zeiss works in Jena. Discusses measurement of pitch diameter, using knife edges.

Zeiss Thread-Measuring Instruments. Am Mach v62 May 28 1925 p 861–2 5 figs. Describes several thread-measuring devices, including screw-thread micrometer caliper, thread-profile gage, optical thread caliper and toolmaker's microscope.

Herstellung der Gewindelehren (Manufacture of Screw Thread Gages), E. KREIS. Technik und Betrieb v2 n8 Aug 1925 p 253–62 22 figs 7 refs (In German). Describes measuring methods. For highest accuracy of measurement of thread elements of thread gages, author advocates use of optical means such as the Zeiss universal measuring microscope with contacting knife edges. Discusses inadequacies of wire measurements.

The Measurement of Screw Threads. Mech Wld v81 Feb 11 Mar 4, 25 May 6 and June 24 1927 p 103–4, 159, 211, 320–321 and 446–447 18 figs. Coarser and finer tests; causes of inaccuracy; temperature changes. Mar. 4: Origination of screws; evolution of thread sections. Mar. 25: Pitch errors; effective diameter. May 6: Adjustment of external gages, snap type of thread gage; snap limit gage. June 24: Microscopic methods of determining errors in screw threads.

Devices for Thread Measurements—Methods and Equipment for Accurately Gauging Tap Threads, A. L. VALENTINE. Machy (London) v31 Dec 29 1927 and Jan 14 1928 p 417–21 and 476–8 14 figs. Dec. 29: Accurate measuring devices suitable in quantity production plant; Hanson device measures to 0.000025 in.; Wickman machine measures all dimensions of tap and other external and internal dimensions on plain, threaded, and tapered work; measuring pitch diameter with wires and micrometers; measuring root diameters with micrometers. Jan. 14: Four gages for resharpened taps; Wickman go and not-go gages; device for measuring odd-fluted tools in process of manufacture; standard micrometer head, specially designed anvils and wires used; formulas for taps with five flutes and Whitworth form of thread; and international forms of threads; formulas for three-fluted taps; errors in measuring pitch diameter with wires; device for measuring outside and pitch diameters of taper taps.

The Measurement of Taper-Screw Thread Gauges, J. E. BATY. Machy (London) v32 Aug 16 1928 p 617–21 13 figs. Methods of inspecting outside, effective, and core diameters of taper screw plug gages, which are applicable to British Standard pipe. Briggs, American Petroleum Institute or any other standard thread and taper; measuring fixture described and formulas for each computation given.

Ein neues Verfahren zum Messen von Innengewinden (New Method for Measuring Internal Threads), A. HAERTEL. Zeit InstrumKde v49 n6 June 1929 p 301–4 4 figs. Principles of F. D. Jones, Machy v24 1918 p 35, have been improved by equipment described, which allows positive casting of small inside threading to be taken out undistorted in two parts.

Machine for Measuring Up to One Hundred Thousandths of an Inch. West Mach Wld v20 n9 Sept 1929 p 329–30 4 figs. Description of Zeiss universal optical measuring machine for measuring dimensions of screw thread, including correct pitch diameter, and for checking, laying out, or spotting of all kinds of jigs, templets, and forming tools, measurements being made up to 0.00001 in.; comparison made with mechanical methods of measuring pitch diameter.

Die Prüfung konischer Normalgewinde (Testing of Conical Standard Threads), F. GÖPEL. Werkstattstechnik v23 Oct 15 1929 p 586–90 7 figs. Communication from German Governmental Phys Inst; new equipment for measuring conical pipe-threading gages and results obtained with this; testing of threads was carried out on basis of pipe specifications of American Petroleum Institute and directions of U.S. Bureau of Standards.

The Measurement of Internal Threads by Means of Casts, G. BERNDT. Mech Wld v86 Oct 25 1929 p 395. Method devised for measuring internal threads by means of casting; some form of material used by which diameter, pitch, and angle of thread can be measured, and tools for making correspondingly correct external threads can be designed. From Werkzeug, p 157–63.

Gewinde-Prüfmethoden (Screw-Thread Testing Methods), H. PAMPEL, A. SOMMER. Automobiltechnische Zeit v32 n30 Oct 31 1929 p 689–93 13 figs. In connection with recently conducted investigations of thread tolerances, authors present detailed description of measuring and testing methods and equipment.

Methods of Measuring Odd-Fluted Taps. Am Mach v71 n23 Dec 5 1929 Supp No 17 p 945 8 figs. Five methods of measuring type taps are described. Condensed from Nat. Screw Thread Commission Bulletin No 143 Oct 22 1929.

Verbessertes Gewindemessgeraet (Improved Screw-Thread Measuring Equipment), F. GOEPEL. Zeit InstrumKde v50 Jan 1930 p 33–42 10 figs partly on supp plate. Measuring equipment described in Zeit Feinmechanik und Praezision 1924 has been improved; equipment and its applications are described.

Ein neues Verfahren zur Messung von Innengewinden (New Method for Measuring Internal Threads), G. BERNDT, E. BOCK. Zeit InstrumKde v50 n6, 7 June 1930 p 375–84, and July p 407–16 7 figs. Principles of measuring methods based on use of balls and prisms and Universal measuring microscope, developed by University of Dresden and Zeiss Co., mathematical analysis of accuracy and errors; tables give instrument correction for Whitworth and metric thread.

Flankenmessungen an Schnecken und Trapezegewinden (Measurement of Pitch Diameter of Worms and Trapezoidal Threads), A. RICKENMANN. Maschinenbau/Betrieb v10 n19 Oct 1 1931 p 619–20 4 figs. Describes a special micrometer having three conical contacts for measuring worm and trapezoidal threads. Discusses measuring errors.

Die Pruefung Konischer Innengewinde, (The Testing of Internal Taper Threads), A. WERNER, G. BOCHMANN, R. LEHMANN. Zeit InstrumKde v1 Jan 1932 p 14–9. Methods and equipment for measuring internal dimensions of ring gages for taper threads developed by Physikalische-Technische Reichsanstalt, according to specifications of American Petroleum Institute.

Die Messung des Flankendurchmessers dreinutiger Gewindebohrer (The Measurement of Pitch Diameter of Three-Fluted Taps, G. BERNDT. Zeit InstrumKde v52 July 1932 p 307–19, and Aug p 353–64; Sept p 408–16. Mathematical analysis of accuracy of methods of measuring diameter of taps with three flutes, including use of wires, cones, cylinders, prisms, etc.; experimental verification.

Fortschritts und Forschungen auf dem Gebiete des technischen Messwesens (Progress and Research in Field of Technical Measuring Methods), G. BERNDT. Maschinenbau v12 n5 Mar 2 1933 p118–21. With particular regard to equipment for measuring screw threads and gears. Bibliography.

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Das Messen von Saegegewinden (Measurements of Buttress Screw Threads), W. KNEDEL. Werkstattstechnik und Werksleiter v29 n3 Feb 1 1935 p 50–2. Outline of measuring methods with data on calculation of face diameter and of gage wire.

Optical Inspection of Screw and Worm Profiles, C. F. SMITH. Machy (London) v46 n1179 May 16 1935 p 185–9. Limitations of optical thread inspection; method of determining whether interference is present; optical system providing compensation for varying helix angle; Matrix projector.

Untersuchungen von Gewinde-Rachenlehren (Study of Screw-Thread Micrometer Calipers), H. SCHORSCH. Wertstattstechnik und Werksleiter v29 n21 Nov 1 1935 p 419–21. New method recommended for adjustment of calipers in which natural weight is changed by additional weight. Also published separately as a book.

Gewindemessungen (Screw Thread Measurements), G. BERNDT. VDI Zeit v80 n48 Nov 28 1936 p 1455–60. Outline of various methods and equipment at present available for measurement of screw threads. Bibliography.

Measuring Plating on Screw Threads, E. C. ERICKSON. Bell Lab Rec v15 n6 Feb 1937 p 187–9; Wire & Wire Prod v12 n3 Mar 1937 p 144–5. In absence of any standard gaging apparatus which could be used to make determinations accurate for ascertaining thickness of coatings on finished screw threads, optical contour projector was devised to determine such measurement; apparatus and methods used, with special reference to screws used in telephone apparatus.

The Measurement of Pipe Threads, B. B. WESCOTT, Am. Petroleum Inst June 3 1937. A critical discussion of the various instruments available for the purpose and suggestions regarding a proposed standard measuring practice.

Machine for Measuring Plug Screw Gauges in Quantities, F. H. ROLT, A. TURNER. Machy (London) v52 n1352 Sept 8 1938 p 701–2. Illustrated description of machine for measuring diameters of batches of gages of same nominal size; machine closely resembles floating micrometer type of screw measuring machine; only difference is in fittings of upper measuring carriage; in present machine these units are replaced by adjustable anvil and measuring indicator.

Begriffsbestimmungen in der Gewindemesskunde (Definitions in the Science of Thread Measurement), G. DIETTRICH, Maschinenbau v18 n11/12 June 1939 p 289–93. Measurement of screw threads; geometric relations explained and universal rules generally applicable in measuring practice given.

Genaue Innengewindemessung durch ausschraubbare Gewindeabguesse, L. TSCHIRF. Werkstattstechnik und Werksleiter v33 n19 Oct 1 1939 p 467–9; Pratique des Industries Mechaniques v23 n4 Jan 1941 p 89–91. Accurate measurement of internal screw threads by molds which can be unscrewed; descriptions and principles of system.

X-Ray Measurement of Internal Screw Threads, R. C. WOODS, E. K. HIGHT. Aero Digest v38 n5 May 1941 p 199–200. Methods used at Bell Aircraft Laboratories for measurement of internal screw threads; radiographic procedure as routinely applied is illustrated.

Optical Projector for Measuring Tapered and Square Threaded Screws, J. W. DRINKWATER. Machy (London) v62 n1590 Apr 1 1943 p 353–4. When measuring effective diameter of tapered screw plug gage, it is essential to relate measurements to position of thread along taper; optical projector described is used in conjunction with thread form layout, to find start of thread on tapered screws.

Measurement of Large Ring Screw Gauges, J. W. DRINKWATER. Machy (London) v64 n1638, 1647 Mar 2 1944 p 238–40 and (discussion) May 4 p 49–56. Illustrated description of omtimeter (E. H. Jones, Ltd.) which is optical comparator arranged for measurement in horizontal plane; principle of measurement is to compare ring under examination with assembly of Matrix slip gages and pair of adapters arranged to simulate perfect ring gage.

Measurement of Screw Thread Gages. Ordnance Inspection Handb on Gages, ORD–M608–5–Sec 800 Sept 1944 p 110–11. Inspection Gage Sub-Office, Office of Chief of Ordnance, U.S. Army. Describes measurement of thread plug, ring, and snap gages.

Simplified Inspection of Thread Gages F. W. BOECKEL. Tool Engr v14 n11 June 1945 p 29. Illustrated description of simple fixture, in combination with three wire method, which provides easy checking of pitch diameters of pipe thread gages; method provides accurate means of analyzing many perplexing problems associated with pipe thread inspection.

Two Screw Thread Measuring Devices. Eng v181 n4703 Mar 1 1946 p 208. Brief illustrated description of simple means of measuring effective diameter of screw thread, introduced by Thos. Firth and John Brown; first is by means of ascertaining points on flanks of thread vee where width is half of pitch; second effective diameter measuring instrument is comparator arranged for use by setting with standard thread. See also Machy (London) v68 n1757, p 756–7, June 13, 1946.

Internal-Thread Comparator. Eng v162 n4201 July 19 1946 p 55. Illustrated description of instrument developed by Machine Shop Equipment, Ltd, for rapid and precise measurement of effective diameter of internal screw threads; it consists of beam, on which slide pair of heads carrying brackets furnished with projecting ball tips, and dial indicator.

Measurement of Straight - Flanked Helicoids, J. W. DRINKWATER. Machy (London) v69 n1762, 1764, 1767, July 18 1946 p 77–82, Aug 1 p 139–43, Aug 22 p 235–40. Methods of mathematical treatment for determining relations existing between radius and rake of measuring cylinder, thread form, effective diameter and helix angle; effect of helix angle from zero to 90°, including straight splines; thread angle in axial, normal and transverse sections considered for screw threads, taps, hobs, spiral broaches and gears.

On the Influence of Periodic Screw-Error on the Density Distribution in Spectroheliograms, V. VON KEUSSLER, Zeit Astrophys v24 n3–4 p 233–9 1948 in German. Even small periodic errors of the order of 0.002 mm prove very disturbing. A new device for testing measuring-spindles is described.

Gauging of Precision Screw Threads, A. C. PRULIERE. Microtechnic v2 n2, 3, 5, 6, Apr 1948 p. 71–8, June p 115–22, Oct p 222–8, Dec p 234–40. Description of different methods such as Zeiss measuring prism method, optical-mechanical and mechanical method; illustrated description of measuring apparatus.

Comparator-Chart Inspection of Tapered Pipe-Thread Gages, K. A. CLARK. Machy (NY) v54 n12 Aug 1948 p 165–7. Inspection practice at Lockheed Aircraft Corp., in use of comparator charts to check pitch diameter, gaging notch diameter, taper, angles, and forms of pipe thread production gages; charts are designed to provide all contours and check points necessary for inspection of

Ein stufenloses Schaltgetriebe höher Genauigkeit (A Stepless Switchgear of High Accuracy), A. BUDNICK. Werkstattstechnik und Maschinenbau v39 n2 1949 p 45–8. High precision apparatus with stepless switchgear for measuring cylindrical milling cutters and spiral shaped objects; indicator motion in measuring slide by precision spindle screw and frictional transmission; indicator is set up at angle by set of permanent and varying gears with holes on rim; measurement errors do not exceed 4×10^{-5} in.; photographs, table.

Gauging and Measuring Screw Threads. NPL Notes Appl Sci n1 1951 109 p 7 supp plates. General definitions and symbols; gaging of parallel screw threads; errors of screw threads; control of accuracy of pitch; hardness of screw gages; measurements of parallel screw plug and ring gages; inspection of parallel screw ring gages with check plugs; testing of screw caliper gages; optical projection apparatus; gaging of taper screw threads; measurement of taper screw plug and ring gages. (See also 1958 edition.)

Interferometric Calibration of Precision Screws and Control of Ruling Engines, G. R. HARRISON, J. E. ARCHER. J Opt Soc Am v41 Aug 1951 p 495–503. A new device is described with which screws of any length can be calibrated rapidly for both periodic and cumulative errors in terms of interference fringes. It can also be used to plot correction curves to remove fixed errors of translation or rotation, and to monitor the operation of an engine while ruling diffraction grating or scales, correcting by automatic feedback differences between the actual carriage position and its proper position as shown by an optical interference field. The "Commensurator" (i.e. for over-coming the incommensurability of the wavelength of the light used for calibration and the lead of a screw) consists principally of a screw drive system, eight-figure dials, and a generator, geared together in ratios that can be controlled to one part in 10^8. Fringes produced by a Michelson interferometer are changed photoelectrically to a wave train that measures translation to within 0.1μ in. A second wave train of almost identical average frequency is produced by the Commensurator generator to measure screw rotation, and the two trains are continuously compared by means of a phase-sensitive amplifier and motor to within 1/100 cycle or fringe. Corrections for changes in barometric pressure or in temperature can be introduced during operation. Transient as well as fixed errors of run and period can be automatically compensated for. If the fringe system is lost, it can be re-established from the Commensurator record, so that controlled ruling of gratings wider than any available coherent fringe-field appears possible.

Die optische Messung von Aussengewinden (Optical Measurement of External Threads), G. BERNDT, K. H. KUEBLER, Dresden. Tech Hochschule Wiss Zeit v2 n2 1952–53 p 199–213, n3 p 467–78, n6 p989–1000. Part 1: Measurements of threads with symmetrical profile. Part 2: Threads with asymmetrical profile. Part 3: Measurement of identical threads.

Screw Gauge Measurement Gives Continuous Record, P. W. HARRISON. Mach Feb 14 1953 p 250. An electric measuring head replaces the indicator of the floating micrometer-diameter measuring machine designed by the National Physical Laboratory. It thus shows variations in effective diameter to be continuously recorded.

Methods and Instruments for Thread Gauge Inspection, C. A. LE BOURHIS (Laboratoire Central de l'Armement, France). Proc of Symposium on Eng Dimensional Metrology, H. M. Stationery Office, v1 Paper 5 Oct 21–24 1953 p 81. Describes some methods and instruments which have proved efficient in daily practice.

Methods and Equipment of the Physikalisch-Technische Bundesanstalt for the Inspection of (A.P.I.) Taper Thread Gauges, K. BÜRGER, M. GARY. Proc of Symposium on Eng Dimensional Metrology, H. M. Stationery Office, v1 Paper 6 Oct 21–24 1953 p 97. Discusses measurement of pitch cone diameter, lead, taper of ring gages, and thread angle, 14 refs.

Effect of Differences Between U.S. and British Practices in Measuring Screw Gauges for Unified Threads, L. W. NICKOLS. Machy (London) v90 n2315 Mar 29 1957 p 723–5. American and British methods of measuring effective diameters of screw plug gages and setting plugs; effective diameter measurements made at single specified position on each of five screw plug gages having unified threads in order to determine experimentally effect of differences between two methods.

The Effectiveness of Various Contacting Elements Used for Gaging and Measuring Pitch Diameter, S. G. JOHNSON. Johnson Gage Co. Bul n400 May 15 1957. Contrasts cone and-vee method against three-wire method of measuring pitch diameter.

Thread Gage Measurement, G. H. STIMSON. Automatic Machining Mar 1958 p 31. Points out some of the conditions which contribute to inaccurate results, and the measures which must be taken to avoid them.

Screw Thread Flank Tester, O. ENDŌ, N. HOSHINA, Y. YOKOYAMA, M. SAWABE, S. SUKIGARA. Rept Central Inspection Inst of Weights and Measures, Japan, v9 n4 rept 24 1960, v10 n3 rept 27 1961 in Japanese. A new screw thread flank tester is developed in order to determine the flank profile and the half-angle of the thread. The tester consists of bed, sine-table, column, carriage, electronic micrometer and pen-recorder. The measuring method is as follows. A screw threaded gauge to be examined is set on the sine-table which can be inclined by the nominal half-angle of the thread by using the angle gauge block. Then the generator of the upper flank of the thread which lies in the vertical plane containing the line of the greatest slope of the sine-table is to become parallel to the direction of the displacement of the carriage carrying the detector. The stylus of the detector is brought into contact with the upper flank and the carriage is driven horizontally by the feed motor. The deviation of the profile of the flank from that of ideal one is detected by the differential transformer. The recorded profile of the flank has the vertical magnification of 3200 and the horizontal magnification of 50.0. The error of the half-angle of the thread may be determined by the ratio of the deviation from the horizontal line to the horizontal displacement of the stylus. The measuring error of the half-angle of the thread due to the fact that the line of the direction of the stylus displacement does not literally intersect the center line of the gauge is estimated. The measuring accuracy of the flank profile being able to be kept within $\pm 0.3\mu$, the half-angle of the thread can be measured with an accuracy within $\pm 2.0'$ in the case of the ring of the diameter 50 to 600 mm or the plug 50 to 140 mm. Lastly there are given some illustrations on several flank profiles which are recorded by the tester of some screw thread gauges. In the measurement of the half-angle of the thread carried out by a screw thread flank tester developed at the NRLM, it is unavoidable that the line representing the direction of the stylus displacement can not literally be made to intersect with the axis of the screw thread and, therefore, an unnegligible error produces, especially when the diameter of the screw thread is small. A procedure for correcting the above mentioned error is found out by treating this measuring method mathematically, and yet this correction is able to be given by a convenient nomogram.

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Microscope for Measuring Internal Threads, A. I. OMEL'CHENKO. Meas Techn 1959 n8 July 1960 p 584–6 4 figs. Translated from Izmer Tekh n8 Aug 1959 p 7. The described microscope for measuring internal threads provides better measurements than other methods of the three basic internal thread elements with a nominal diameter of 18 mm and over. The instrument is based on the double microscope of Academician V. P. Linnik.

Note on Measurement of Rake Angle and Relief Angle of Taps and Dies, K. EDENSOR. Machy (London) v97 n2507 Nov 30 1960 p 1237–9. Measurement requires setting of graticule cross line so that it is tangential to circle, method described provides means for positive location of tangent.

Further Report on the Effect of Differences between U.S. and Britsh Practice in the Measurement of Screw Gauges for Unified Threads, P. W. HARRISON. Machine Shop v22 n4 Apr 1961 p 207.

Measuring the Profile Angle of Internal Conical Threads, A. A. KHAIROV. Meas Techns 1961 n7 Dec 1961 p 521–4. Translated from Izmer Tekh n7 July 1961 p 6–7. Describes an electrical contact instrument for measuring half the profile angle of internal threads with a pitch of 6 and 6.35 mm. With an appropriate change in the dimension of the electrical contact head it is possible to measure profiles of threads with a pitch of 5 mm.

Measurement of a Large-Size Internal Buttress Thread Mean Diameter, N. V. SERGEEV. Meas Techns 1963 n2 Aug 1963 p 100 1 fig. Translated from Izmer Tekh n2 Feb 1962 p 8. Describes a micrometer hole gage for measuring a buttress thread 600 mm in diameter.

Interference Method for Measuring Thread Elements, V. P. KORONKEVICH, L. YA. GUSTYR', A. N. RAZUVAEV. Meas Techns 1963 n2 Aug 1963 p 100–7 5 figs. 8 refs. Translated from Izmer Tekh n2 Feb 1963 p 8–14. If the distance between the first fringe and the edge of the shadow contour is evaluated, it becomes possible for this fringe to be used as a setting line instead of the graduation of a measuring knife-edge. The application of interference fringes for measuring the mean thread diameter and the dimensions of components which have a curvature along the optical axis is beset with certain difficulties which, in the first place, consist of the effect of microscope focusing on the distance to the first interference fringe and of the effect of the light-beam aperture on the interference pattern. This article aims at elucidating the effect of these factors.

Technique for Calibraton of Large Thread Gages, H. E. BROUSSEAU. ASTME Tech Paper 590 1964 14 p 6 figs 1 ref. Annular shaped thread gages remain mounted on the arbor as processed in manufacture. The arbor center holes locate the axis of the gage, permitting measurement of lead and helical variation. Gages over 8 in. in diameter are inspected on a modified optical comparator. Special holding fixtures and underside projection are used.

Combined Micrometer and Sensitive Indicator Unit, W. F. ATKINS. Quality Engr v28 n4 July–Aug 1964 p 118–9. Combined micrometer and fiducial indicator unit capable of measuring to accuracy of about 0.25 ,m is described; unit is intended for incorporation in measuring machine of type used to measure screw plug gages of sizes above about 12 in. diam; it enables operator to watch movement of indicator pointer and micrometer simultaneously; unit described is equally suitable for measuring diameter of sizes down to about 4 in.

Combined Micrometer and Sensitive Indicator Unit, W. F. ATKINS. Machy (Lond) v105 n2697 July 22 1964 p 271–2. To overcome difficulty when measuring work pieces of large diameter, design was produced at National Physical Laboratory in which micrometer and fiducial indicator are combined in single unit that can be mounted on machine; external and sectional views of unit are described; unit was fitted to diameter measuring machine used at NPL for checking API screw plug gages.

9.2. Lead Measurements

Note on an Instrument for Measuring Screw Threads, H. J. C., Standards Dep, Board of Trade, Westminster, Oct 1 1901. A design of a measuring instrument, the Visometer, for measuring the angle and pitch of a screw thread.

Determining the Errors in Screws, R. A. BRUCE. Am Mach v27 Apr 7 1904 p 454–5 5 figs. Miscroscope and scale arrangement for determining lead errors of lead screws, with a micrometer for measuring the magnitudes of the errors, a contact point being inserted in the thread space, and a cross hair of the miscroscope being set on the scale divisions.

Measuring the Pitch of Nuts. GB NPL Rep 1906 p 43. A carriage actuated by an accurate guide screw can slide along a bed A, and on the carriage is a second slide B making an angle 62½° with the slide A. On slide B is a pivoted lever arrangement. The nut is set up with its axis parallel to slide A, and the arrangement is such that when the lever point on slide B is brought into contact with the side of the thread any movement of the point in the direction of the slide B causes no displacement of the lever, the angle being 55°. This acts as an indicator of contact between the point and the side of the thread, and by means of the guide screw the pitch may be measured.

Testing the Lead of Taps and Screws, E. OBERG. Machy (NY) v14 Jan 1908 p 317–8, 4 figs. Describes testing the lead by gages and comparators for the lead of taps and screws.

Testing the Lead Screw of a Lathe, E. R. CONNERS. Am Mach v31 Nov 19 1908 p 751. Uses micrometer to measure motion of carriage.

Testing Pitch of Micrometer Screws, H. L. WHITTEMORE. Am Mach v34 Mar 9 1911 p 437–8 3 figs. Optical lever device for testing uniformity of pitch and diameter.

Calibration of New Screw-Measuring Machine, A. J. LEE, H. B. STEELE. Astron J v30 May 5 1917 p 128–9. Description of tests of a new measuring machine designed by F. Schlesinger and made by Gaertner of Chicago. The screw is 18 mm. in diameter and has 249 threads of 1 mm. pitch. The periodic error was found to have a max. value of 0.00013 mm., which is negligible in all work with stellar images. The progressive errors were determined for every cm. of the screw, with a temperature range, during the measurement, of 1.3° C. They are small and negligible for the work in view.

Screw Thread-Lead-Testing Machine, West & Dodge Co., Am Mach v48 May 30 1918 p 931–2. Machy(NY) June 1918 p 949–50. To test the lead of threads the contact point is placed in position in one of the threads and the micrometer spindle adjusted so that the dial indicator points to zero. The point is then moved along a number of threads and micrometer readings taken. Drunken threads are detected by turning the gage partway around and again measuring. The dial indicator is not used for obtaining the actual measurements, but only to show the correct amount of pressure to apply on the micrometer spindle. The large graduated wheel gives readings to

0.0001 in. if desired and a solid plug can be used in place of the indicator spindle and Johansson blocks used between contact points on the base.

Sheffield Thread-Lead Testing Machine for Screw Gages. Am Mach v49 n4 July 25 1918 p 180 incl 1 half-tone. Description of a testing machine for the lead of screw-thread gages. The machine has been placed on the market by the Sheffield Machine and Tool Co., Springfield, O.

Coats Lead Testing Machine. Machy (N.Y.) v24 Aug 1918 p 1150 2 figs. A lead measuring machine in which a fluid gage is used as indicator and measurements of lead are made by means of precision gage blocks.

Thread-Lead Testing Device. Arrow Tool Co., Am Mach v50 Mar 13 1919 p 517–8. To use the device the gage to be tested is placed on the centers and tightened. One of the gaging points is then brought into contact with the gage, observation being made against a piece of white paper or other reflecting material laid on the base. After this adjustment is made the slide is clamped, and the measuring spindle of the micrometer head, which has been brought to some predetermined reading is brought into contact with the raised hub, and slide is then clamped. The micrometer spindle is then turned back, the first gaging point is withdrawn and the second one advanced to contact with the thread. The gage under test must not be allowed to rotate on the centers. If any error exists it must be met moving the slide along the slideway until the second gaging point is in contact. When this is done the variation from true lead is measured directly plus or minus with the micrometer.

Checking the Accuracy of Lead Screws. Machy (N.Y.) v28 July 22 1922 p 903–4 3 figs. Lead screws are checked by determining the distance that the nut moves for a given rotation of the screw. Measurements are made by means of a micrometer and end standards, using P. & W. measuring machine.

The Mechanical Measurement of Pitch, H. T. WRIGHT. Machy (London) v23 Nov 22 1923 p 236–9 8 figs. Method of recording and analysis of test results; describes pitch-measuring machines.

John-Sons Screw Thread Lead Tester and Comparator. Am Mach v61 July 10 1924 p 79. Made in two sizes, No. 0 to ½″ and ¼″ to 1¾″. The cradle of the screw is composed of annular gaging elements which are free to rotate on their holding stud and, with the exception of one fixed roll, can also move laterally to adapt themselves to the lead variations of the screws to be measured. A wedge-shaped plunger which runs in a groove in the "indicator roll" is elevated against the spindle of the indicator, when the screw is placed in the cradle, and provides the means by which the lead errors are recorded on the indicator. The indicator is set to zero by masters.

Steigungsprüfer für Leitspindeln (Pitch Testers for Lead Screws), H. WILDE. Zeit für Feinmech und Präzision Dec 15 1926 p 265–8 6 figs. Describes Zeiss optical instrument and gives examples of measurements.

Screw Thread Pitch Measuring Machine. Machy (N.Y.) v33 May 1927 p 710–1 2 figs. Am Mach v66 May 5 1927 p 752–3, 2 figs. Apparatus brought out by Société Genevoise d'Instruments de Physique, Geneva, Switzerland, embodying a micrometer having a range of 4 in. and a knife-edge multiplying lever system sensitive to 0.00001 in. as the indicator. Machine is adapted to the measurement of both internal and external threads. It will hold plug gages up to 6 in. in diameter and 8 in. in length, and has a travel of its micrometer screw of 4 in.

Michigan Spiral Gear Lead Checking Fixture. Am Mach v75 Sept 3 1931 p 395. This spiral-lead checking fixture will handle spiral gears up to 16 in. in diameter and with

any lead of 10 in. or over, either right or left-hand. The gear is mounted on a stub arbor or between centers up to 12 in. in length. The fixture is of the sine bar type. Mounted on top and towards the sides of the gear carriage are two lapped surfaces which drive the work spindle by contacting two friction rolls. These rolls cause the spindle to rotate in timed relation with the movement of the carriage on which the indicator is mounted.

National-Cleveland Helical-Gear Checking Device. Am Mach v75 Nov 26 1931 p 830. This device is shown attached to the Model "B" gear checking machine, and may also be attached to the Model "C" machine. In addition, it is furnished as a bench type, or mounted upon a pedestal stand. The helical gear is mounted upon a stub shaft carried by a slide, which is moved so that the teeth of the gear engage the teeth of the rack. The reading of the angle thus established is taken direct from the large drum. The device will check right or left hand helical gears. When mounted on a pedestal the device may be placed in the production line to permit 100 per cent inspection.

"Detroit" Lead Testing Instrument. Am Mach v75 Dec 17 1931 p 939–40. Measurement is made by means of a spiral micrometer and microscope, supported on a carriage and focussed on an optical scale. The carriage is fitted with a spring-loaded plunger, carrying at its extremity a removable ball point, which engages two adjacent threads of the piece. This plunger mechanically locates the carriage. Maximum error does not exceed a total of 0.00018 in. for the 8-in. length.

Develops Machine for Testing Lead of Helical Gears. Iron Age v133 n13 Mar 29 1934 p 35; Machy (N.Y.) v41 n3 Nov 1934 p 150–1; Automobile Engr v24 n319 May 1934 p 187. Details of machine introduced by Lees-Bradner Co., Cleveland, Ohio, which accurately measures helix angles or lead of helical gears, and also calibrates machine settings.

New Helical Lead Checking Machine. Machy (N.Y.) v41 Nov 1934 p 150 2 p 3 illus. Details of machine introduced by Illinois Tool Works, Chicago, Ill. for determining the accuracy of helices.

New Helical Lead Checking Machine. Machy (London) v46 n1195 Sept 5 1935 p 690–1. Machine, marketed by Illinois Tool Works, Chicago, for determining accuracy of helixes, has capacity for gears up to 12 in. in diam and will take work up to 15 in. between centers; checks helix angles from 0 to 90°.

Measurement of Drunkenness of Screw Threads, F. H. ROLT, A. TURNER. Machy (London) v52 n1345 July 21 1938 p 489–91. Method devised by authors, which can be applied to testing of machine tool; based on fact that if screw has true helix, then threads or grooves on one side of it are always exactly midway between those on opposite side in same axial plane; machine for testing screw threads for drunkenness illustrated and described.

Messen des Zahnschraegewinkels an Stirnraedern mit Schraegverzahnung (Measurement of Helix Angle and Pitch of Teeth on Helical Gears). F. LAESSKER. VDI Zeit v83 n5 Feb 4 1939 p 133–5. Outline of measuring method and detailed description of testing equipment and its operation, characteristics, and results attainable.

"Sine Line" Machine for Checking Spiral-Gear Leads. Machy (N.Y.) v48 March 1942 p 162 1 illus. Machine of the adjustable sinebar type, is designed to check right-and left-hand spiral gear leads with spiral angles from 0° to 90°.

Method of Screw Pitch Measurement, J. W. DRINKWATER, Machy (London) v60 n1541, 1542 Apr 23 1942 p 341–5 and Apr 30 p 372–3. Outline of necessary measurements to be checked in screw threads if accuracy is desired; description of screw pitching machine; details

of how machine can be used to determine certain defects in screw threads and machine tools.

New Electromagnetic Method of Measuring Screw Thread Leads to Few Millionths of Inch, H. T. RIGHTS. Instrum v17 n3 Mar 1944 p 134–5. Method has been embodied in instrument of comparator type, which can be read directly to within 0.00001 in. and readings can be estimated to within 0.000001 in.; method being electrical rather than mechanical, gaging point functions with pressure of only three ounces; it has no time lag and is rapid in operation; anyone experienced in checking thread lead can set up instrument quickly and operate it successfully.

Fellows Introduces New Lead Measuring Instrument, A. JANSSON. Tool Engr v17 n3 Oct 1946 p 53. Features and operation of new instrument developed by Fellows Gear Shaper Co; instrument incorporates arrangement whereby lead of helix is checked by continuous motion of measuring pointer in conjunction with desired rotation of work; principle embodies two tangent bars and pins, both of which operate slides, one effecting traverse movement of member carrying measuring pointer and other, rotation of work.

Autographic Method of Checking Accuracy of Micrometer Screws, F. H. ROLT. Machy (London) v78 n1993 Jan 25 1951 p 165–7; Engr v191 n4957 Jan 26 1951 p 117–9. Conventional method necessitates recording of numerous readings; new method of obtaining autographic records compares travel of micrometer spindle continuously with that of master screw, differences being recorded as trace on moving strip of paper; design and general arrangement of micrometer head testing apparatus; illustrations.

Measuring Gear Components, F. M. BUTRICK, JR. Tool Engr v26 n2 Feb 1951 p 44–5. Lengthy but simple method for measuring helix angle of helical, herringbone, or screw gear when regular gear checking machine is not available; equipment required and steps to follow; inaccuracies are small; illustrations.

Homemade Checker Bridges Gap, F. M. BUTRICK, JR. Steel v133 n26 Dec 28 1953 p91. Lead comparator for helical gears fabricated in tool room is designed to serve until commercially made comparator arrives; drawing shows how this simple device compares gear with master.

Automatic Measurement of Small Deviations in Periodic Structures, H. T. CLOSSON, W. E. DANIELSON, R. J. NIELSEN. Rev. Sci Instrum v29 n10 Oct 1958 p 855–9. Description of accurate microdeviometer, originally developed for measurement and recording of pitch uniformity of helices in traveling wave tubes; instrument combines optical, mechanical, and electronic techniques; electronic circuitry automatically stores and processes position information and feeds processed information, in form of deviations from corresponding ideal structure, to pen recorder.

At Last a "Drunkometer" for Threads, W. M. STOCKER, JR. Am Mach v102 n26 Dec 15 1958 p 87–9. "Drunken helix" being deviation of helix from theoretical or true helical path can now be measured by new electronic thread comparator developed by Greenfield Tap and Die Division; new instrument compares two points, separated by predetermined angle such as 90 or 180°, on single thread and measures deviation from true helix; typical recorded patterns showing rejected, acceptable and master thread for 8–32 thread plug gages are presented.

Contribution to Testing of Precision Lead Screws, J. SIMONET. Microtecnic v13 n1 Feb 1959 p 15–11; Inspection Engr v23 n6 Nov–Dec 1959 p 134–9. Details of design, construction, and operation of special precision measuring instrument developed at Metrological Laboratory, University of Liege for checking pitch of lead screws. Presents a critical study of a new lead measuring instrument and a statistical examination of results of measurements.

Neues vereinfachtes Messverfahren fuer die Bestimmung des Steigungsfehlers innerhalb eines oder mehrerer Gewindegaenge (New simplified measuring method for determination of errors in pitch within one or several screw threads), H. GIESLER. Werkstattstechnik v49 n4 Apr 1959 p 192–5. Review of existing methods; new method described is more accurate, permits simpler handling and saves time.

New Method of Measuring Pitch Errors of Screws to Very High Accuracy, L. W. NICKOLS. Machy (London) v96 n2480 May 25 1960 p 1171–6. Method developed at National Physical Laboratory employs autocollimator technique to compare pitch of screw with end-standards of length; apparatus was designed to measure pitch errors of V-threaded precision lead-screws, within certain limitations of size, and is also suitable for measuring pitch errors of reference screw plug standards used to calibrate pitch measuring machines; apparatus and measuring procedure described; effect of errors on accuracy of pitch measurement.

New Method of Measuring Pitch Errors of Screws to Very High Accuracy, L. W. NICKOLS. Quality Engr v24 n4 July–Aug 1960 p 107–11. Method developed at National Physical Laboratory for measuring pitch errors of screws having vee-thread form to considerably higher accuracy than formerly; method employs autocollimator technique to compare pitch of screw with end-standards of length; results indicate that, provided no temperature variations occur, pitch may be measured in terms of measured sizes of end-standards to accuracy better than ± 5 μ in.

Controlling the Curvature of Thread Gauges, N. M. ZHURAVLEV. Meas Techns 1959 n12 Sept 1960 p 940–3 6 figs. Translated from Izmer Tekh n12 Dec 1959 p 14. Proposes a new instrument combining high productivity with great precision for measuring helix variation of screw thread gages. Checking of gages showed that such variation sometimes exceeded the pitch tolerance. Can be used for automatic thread testing in conjunction with electric induction or pneumatic recorders.

Checking the Curvature of Thread Gauges, F. P. FROLOV. Meas Techns 1960 n7 Feb 1961 p 583–4 2 figs 1 ref. Translated from Izmer Tekh n7 p 24–5 July 1960. Describes instrument for checking helix variation at 180°.

Method for Determining Comparator Screw Errors with Precision, J. M. BENNETT. J Opt. Soc Am v51 n10 Oct 1961 p 1133–8. Precise determination of relative cumulative error and periodic error of comparator screw; measured curves for Mann comparator and Gaertner comparator; method gives relative lengths of intervals on scales used.

Mitsui Leadscrew Measuring Machine with Automatic Recording Equipment, R. E. GREEN. Machy (London) v100 n2564 Jan 3 1962 p 37–41. Machine built by Japanese company will detect inaccuracies as small as plus or minus (2 plus or minus 3L/1000)μ, where L is length to be measured in millimeters; for such measurements, temperature difference between workpiece and master leadscrew built into machine, must be less than 0.05 C; new measuring principle employed is based on use of 2 electrical measuring contacts, average of two readings being provided electronically; errors due to distortion or eccentricity of screw are automatically canceled out.

Teilungsmessungen an Verzahnungen in der Praxis (Pitch Measurements on Gear Teeth in Practice), H. A. KOOP. Werkstattstechnik v52 n12 Dec 1962 p 646–52. Installations and devices employed are described; interpretation of measuring results with regard to various types of errors is explained.

Interferometric Device for the Calibration of the Micrometer Screw of a Microscope, J. MONTILLA. Anales de la Real Sociedad Española de Fisica y Quimica v59A n1–2 Jan–Feb 1963 p 19–20 in Spanish. The device is based on the relation between the displacement of interference fringes of Fizeau type and the displacement of the microscope tube. An accuracy of λ/200 or better is obtained.

The Error in Measuring Periodic Faults in Guide Screw Pitches, T. S. KIRILLOVA, E. A. SHILOVA. Meas Techns 1962 n7 Feb 1963 p 543–4. Translated from Izmer Tekh n7 July 1962 p 8–10. Compares accuracy of measurements obtained by the use of recorders with those obtained with universal microscopes.

Podatnose statyczna ukladu "O–P–N" i jejwykorzystanie do korekcji bledow skoku przy obrobce srub pociagowych (Static Flexibility of Machine Tool-Workpiece-Tool System and Its Use for Pitch Error Correction in Lead-Screw Machining, H. KALUZKA. Prezglad Mechaniczny v22 n6 Mar 25 1963 p 163–6. Sources of pitch errors in machining high-precision lead screws are analyzed and error formula derived; simple method is suggested for eliminating pitch error by applying to workpiece axial force determined from expression derived and acting from back center towards chuck plate.

Error in Measuring Pitch of Screw Propellers by Means of Goniometers, F. M. KATSMAN, S. V. YAKONOVSKII. Meas Techns 1962 n12 July 1963 p 992–5 3 figs. Translated from Izmer Tekh n12 Dec 1962 p 8–11. Analyzes the precision with which it is possible to measure this element by means of goniometers, in view of the stringent tolerances specified in GOST (All-Union State Standard)

8054–59 for the local pitch of screw propellers which must not exceed ±2% for propellers of the higher and ±3.5% for those of the lower grade.

Investigation and Trial Manufacture of Leadscrew Measuring Machine with Automatic Recording Equipment, A. YAMAMOTO, S. YAMATO, S. ISA, C. KAWAMURA, I. KUMAGAI. Bul Japan Soc Prec Eng v1 n1 Oct 1963 p 13–6 9 figs. Contents: Machine construction; measuring principles; specification; examples of lead measurement; conclusion.

On a Screw Thread Lead Measuring Machine with Automatic Recording Equipment, A. YAMAMOTO, M. ICHIKAWA. Bul of the Tokyo Inst Technol n58 1964 p 37–47 11 figs 3 refs. A SIP model 4 type screw thread cutting lathe which had been used in a machine shop for many years, was repaired and adapted to serve as a screw thread lead measuring machine with automatic recording equipment. From this investigation the following results were obtained. (1) An electric micro-comparator with automatic recording equipment was made by utilizing wire strain gauges, and it was ascertained that it had the satisfactory accuracy and linearity for the lead measuring machine. (2) Periodic error of measurement which was caused by the eccentric rotation of the lead screw was fully eliminated by using a suspension type lead nut instead of the original one. (3) The screw thread lead measuring machine could measure to an accuracy of $\pm 1\mu$ within the measuring range of 100 mm, by giving a correction curve to the plate cam and repairing several parts of the machine. (4) Lead error of an internal thread could be measured without taking into account the influence of eccentric chucking.

9.3.   Wire and Ball Measurements of Screw Threads and Other Helicoidal Features

NOTE: Measurements described in this section relate to evaluation of thread groove diameter (or pitch diameter) of screw threads. As related to gearing where the pitch diameter is an exact theoretical value, not subject to any deviation from the ideal, such measurements are commonly designated as the measurement of tooth thickness or checking of backlash.

Measuring External Screw Thread Diameters, W. CANTELO. Am Mach v26 n26 June 25 1903 p 904–6 7 figs 2 tables. Describes three wire method and wire method for Acme threads. Furnishes formulas and tables of constants applicable to measurements of standard threads by means of a micrometer caliper.

Measuring External Thread Diameters, J. M. STABEL. Machy (N.Y. Eng Ed) v2 n5 Jan 1904 p 248–50 3 figs 3 tables. Describes method of thread measurement by means of wires and micrometers.

Measuring External Screw-Thread Diameters. Am Mach v30 Mar 7 1907 p 356–7. The application of micrometers and wires in the measurement of USS, V, and Whitworth threads.

Measuring Screw Thread Diameters, W. CANTELO. Machy (N.Y.) v14 Sept 1907 p 33–4. Gives formulas for the limiting sizes of wires for 60°, 55°, and 29° threads.

Notes on Screw Threads, H. H. JEFFCOTT, NPL. Proc Inst Mech Engrs Dec 1907 p 1067–1108 17 figs.; Collected Researches NPL v5 1909 p 215–50 17 figs. Contain an account of some theoretical aspects of screw threads, partly from the stand-point of accuracy in the interpretation of results of measurement. Equations of the surface

of the screw thread were obtained in two different ways: One by a consideration of the method of generation and the other by the use of Fourier series. Approximate formulas for the measurement of effective diameter of a screw are derived on the basis that measurements are taken over cylinders, which being free, set themselves nearly along the rake of the thread. A similar case in which the cylinders are fixed perpendicular to the axial plane of measurement of the screw is also considered. The effect of small errors in the various elements of a screw on the interpretation of the results of measurement of effective diameter is exhibited as a formula. Compiler's comment: JEFFCOTT's (approximate) Three-Wire Method has been internationally used for almost 60 years in the measurement of standard screw threads, particularly for single-start screws.

Making Thread Gages, A. L. MONRAD. Machy (N.Y.) v14 Feb 1908 p 387–90 10 figs. Illustrates thread grinding attachment for lathe, fixture for charging diamond lap, thread tool setting gage, lap for plug gages, simple diagrams for determining wire sizes, lead tester, gage for testing angle of thread, holder for micrometer stop. Gives tables of wire diameters for measuring thread angle.

Measuring Metric Screw Threads. Am Mach v33 pt2 Dec 1 1910 p 1028. Includes tables of constants for

measuring the pitch diameter of metric threads by the three-wire system.

Wires for Measuring Threads, J. J. STEWART. Am Mach v36 May 23 1912 p 842. Illustrated discussion of use of wires.

Measuring Screw Threads by Means of Micrometers. Machy (N.Y.) v19 n5 Jan 1913 p 384, 1 fig 1 table. Includes a table of sizes of two types of micrometer ball points applicable to various threads per inch.

One Wire System for Measuring Threads, I. BANWELL. Machy (N.Y.) v20 July 1914 p 978. Gives a formula for measuring pitch diameter with one wire.

Notes on Screw Gages. NPL (Teddington) Feb 1916 28 p. Includes discussion of measurements of effective diameter and angle by cylinders of other than best diameters. Use of a reference groove and cylinder for effective and core diameter measurements.

Measuring B and S or Acme 29 deg. Threads, K. FENNELL. Am Mach v45 Nov 16 1916 p 846. Gives formulas for any size of wire that will touch the sides and project above the top of the thread, not taking the lead angle into account.

Master Whitworth Thread Gages, W. T. ILER, Jr. Machy (N.Y.) v24 Sept 1917 p 51–2. Formulas for measuring the pitch diameter and checking the flank angle by means of two wires.

Measuring Screw Threads by the Three-Wire System. Machy (London) v11 Nov 15 1917 p 181. Formulas proving that the effect of lead angle readings is negligible with standard threads.

Errors in Measuring Thread Pitch Diameters With Wire, J. H. BILLINGS. Am Mach v47 n25 Dec 20 1917 p 1007–8 1 fig ; Mech Wld v63 May 3 1918 p 207. Discusses discrepancy in measurements of pitch diameter obtained by means of wires and by thread micrometers.

Measurement of Internal Threads, W. S. ROWELL. Machy (N.Y.) v24 Jan 1918 p 429. Uses inside micrometer with ball points. Gives formulas for computing pitch diameter from measurements.

Error in Wire Method of Measuring Worm Threads, H. H. WRIGHT. Machy (N.Y.) v24 n5 Jan 1918 p 439–40 1 fig. Points out the necessity of taking the lead angle into account.

Simple Method of Measuring Pitch Diameter of Screw Threads. Machy (London) v12 May 2 1918 p 128. Sketch and formulas are given, using three wires and measuring from crest of thread to over wires.

The Measurement of Internal Threads, W. RICHARDS. Machy (London) v12 July 18 1918 p 425–7. Diagrams. Internal ball point micrometer, with calculations for its use, and table of diameters for ball points.

Fortney Measuring Wires. Machy (N.Y.) v25 Nov 1918 p 269. Four styles of wires are shown designed for use with special machines for measuring pitch diameter.

Thread Measuring Formulas, H. M. FUNNELL. Am Mach v49 n19 Nov 7 1918 p 839 1 fig. States that when using the three-wire system of measuring threads the usual formulas given in various popular handbooks are correct only when the thread is standard. Gives formula based on "angle root diameter" for threads which depart from standard form.

Use of Measuring Wires, H. L. VAN KEUREN. Automotive Industries v39 Dec 19 1918 p 1056. Choice and standardization of wires, Computations.

Determining Error in Thread Angle by Three Wire Method. Machy (N.Y.) v25 Feb 1919 p 552.

Measuring Acme Threads Without Special Wires, H. W. MILLER. Am Mach v50 May 15 1919 p 932. Gives formulas for wires or balls.

Gewindemessen mit Drähten (Screw Thread Measurements with Wires), J. REINDL. Betrieb v1 n14 Aug 1919 p 361–5 11 figs. Discusses manufacture of wires, use for pitch diameter and thread angle measurements, and gives tables for Whitworth, International, and Löwenherz threads.

Gaging Acme Threads Without Special Wires, H. A. PEARSON. Am Mach v51 Nov 6 1919 p 830 1 fig ; Mech Wld v68 July 23 1920 p 60. Equations are given which, it is said, can be applied to any wire which may be available.

Three-Wire System for Measuring Standard Worm Threads, H. A. PEARSON. Machy (N.Y.) v26 Aug 1920 p 1131. Gives formulas and tabular data, when using wires of any suitable diameter. Discussion by T. A. Reilly, Machy (N.Y.) v27 Nov 1920 p 238.

Screw Thread Measurement. Eng Prod v1 Nov 1920 p 440–4 8 figs. Determination of effective diameters by three wire system.

Measuring Screw Threads by the Three-Wire Method, V. E. AYRE, NBS. Machy (N.Y.) v27 Nov 1921 p 281. Gives formulas.

Die Optische Messung des Flankendurchmessers von Gewinden (Optical Measurement of Flank Diameter of Threads), O. EPPENSTEIN. Präzision n22 1922 4 p 8 figs 2 refs. Describes measurement of pitch diameter using a projector and contacting the thread by means of knife edges.

Measuring Thread Plug Gages, J. M. HENRY. Machy (N.Y.) v28 Mar 1922 p 545–6. Shows various set-ups in the Pratt and Whitney measuring machine.

Van Keuren Thread-Measuring Wires. Am Mach v56 June 1 1922 p 833. Machine lapped wires, accurate as to roundness, uniformity, and size, furnished packed in glass bottles to protect against rust, loss, or breakage.

Measurement of Worm Threads, A. FISHER. Machy (London) v20 Aug 10 1922 p 591–2 3 figs. Reply to an inquiry as to formulas for measuring the addendum and thickness of multiple-threaded worms with gear tooth calipers. Discussion by E. A. Limming, Machy (London) v22 Sept 20 1923 p 794–5 1 fig as to the different chords involved.

The Normal Thickness of a Worm Thread, E. A. LIMMING. Machy (London) v20 Sept 7 1922 p 707–8 1 fig. Develops a more nearly correct mathematical formula for the normal thickness of a worm thread at a particular radius R, defined as the thickness in the plane normal to the lead helix of that particular radius.

The Normal Chordal Thickness of a Worm Thread, A. FISHER. Machy (London) v21 Oct 26 1922 p 118–9 4 figs. A further discussion of preceding articles by Limming and Fisher in which it is concluded that very accurate measurements with gear tooth calipers are obtained with difficulty. The dimension usually taken is the minimum thickness obtained when the calipers are allowed to choose their own angle.

Notes on Worm-Thread Formulas, P. A. FREDERICKS. Am Mach v55 Dec 1922 p 1043. Discusses three-wire measurements.

The Exact Calculation of Worm-Thread Dimensions, H. E. MERRITT. Machy (London) v21 Dec 14 1922 p 330–1 2 figs. Discusses preceding articles by Fisher and Limming. Proposes an exact calculaion of worm-thread dimensions.

Normal Thickness of a Worm Thread, E. A. LIMMING. Machy (N.Y.) v21 Dec 21 1922 p 360–2 4 figs ; Machy (London) v22 Apr 1923 p 114–5 1 fig. Derives equation for the calipered chord of a screw thread which is identical with the contact chord of the best-size ball of its contact nut. (They are identical with Vogel's [see below] corresponding equations for the best-size ball measurement of internal threads.) Discussion by A. FISHER. Machy (London) v21 Mar 15 1923 p 759. States basis of definitions in Fisher's preceding articles.

The Gauging of Involute Threads, H. E. MERRITT. Machy (London) Apr 5, 19 July 26, Aug 2 1923 p 11–3 79–81 525 569 13 figs. Deals with : gaging straight-spur teeth by tooth caliper, rack-generated gears corrected for undercut, gaging straight-spur teeth by the plug or wire method, applications of the plug method, zone and line contact between spiral gear and rack, application of the plug method to spiral gears, helical gears. Discussion : E. A. LIMMING Apr 26, May 10 p 114, 191 ; C. PETTIT May 17 p 210 ; H. E. MERRITT May 24, 31 p 251, 275 ; E. A. LIMMING June 7 p 307 ; H. E. MERRITT June 21 p 376 ; A. FISHER July 5 p 442 ; E. A. LIMMING July 12 p 475 ; H. E. MERRITT July 26, Aug 2 p 525, 569.

Measurement of Pitch Diameter of Screw Thread Gages. NBS Letter Cir n23 July 14 1923 60 p 16 figs. Discusses measurement of pitch diameter of straight and taper threads by means of wires, measurement of thread angle by wires, and gives derivations of various wire formulas in the appendix.

Cylinders and Spheres for Gauging Worm or Screw Threads, E. A. LIMMING. Machy (London) v23 Jan 3 1924 p 466–7 2 figs. Derives formula for angle between axis of wire and axis of screw. Also diameter of wire which will touch at a given radius of thread.

The Gauging of Finish-Ground Worms by Cylinders, H. E. MERRITT. Engr v138 Aug 8 1924 p 162–3 3 figs. Shows that from certain fundamental worm dimensions size and position of a cylinder to gage any point on thread contour may be calculated, and in spite of apparent difficulty of problem, solution is very simple and easy of application.

Correction for Elastic Compression in the Measurement of Screws with Small Cylinders, G. A. TOMLINSON, NPL. Machy (London) v28 Aug 26 1926 p 616–8 2 figs. Points out that in accurate measurements of small screw, correction should be applied on account of compression that ordinarily occurs ; nomogram for computing compression correction in effective diameter measurement. See also "Notes on Screw Threads". The National Physical Laboratory, 1930 ; Proc Inst Engrs n4 p 1031–6.

Correction for Rake in Screw-Thread Measurement, G. A. TOMLINSON, NPL. Inst Mech Engrs Proc n4 1927 p 1031–6 4 figs. Simple method of computing necessary rake correction based on exact geometrical considerations and equations, which is now being used at National Physical Laboratory for threaded work of large lead angle, measured by means of wires.

Die Abplattung von Stahlkugeln und Zylindern durch den Messdruck (The Oblateness of Steel Balls and Cylinders due to Measuring Force), H. BOCHMANN, Zeit für Feinmechanik and Präzision v35 Apr 1927 p 95 14 figs. English translation available. Contents : The Hertz theory ; re-

view of literature ; experimental arrangements ; experiments on steel balls between planes ; experiments on steel wires between planes ; experiments on gages between planes ; general evaluation of the several cylinder tests ; experiments on crossed cylinders ; groove tests on steel wires ; summary.

L'emploi des "Piges" pour la Détermination Rationelle des Éléments d'un Filetage (Use of Wires for Proper Determination of the Elements of a Screw Thread), L. FRAICHET. Genie Civ v92 Feb 11 1928 p 138–40 2 figs. Use of wires for measuring pitch diameter is described ; errors of measurement ; measuring thread angle.

Measurement of the Thickness of Involute Gear Teeth, A. H. CANDEE. Am Mach v68 n9, 11, and 14 Mar 1, 15 and Apr 5 1928 p 365–8, 463–7, and 573–6 12 figs. Mar 1 : Formulas for pin measurement developed ; measuring distance across round pins or plugs placed between teeth on opposite sides of gear to determine tooth thickness ; tables from which dimension across pins for standard involute spur gears can be obtained very easily ; direct methods of calculation given for special cases of spur gears and for helical gears. Mar 15 : Calculations for pin measurement with standard pin sizes ; simplification of calculations by means of standard tables for both external and internal gears ; center of pin generally will not come on pitch circle ; for given pitch and number of teeth dimensions between centers of diametrically opposite pins will vary with tooth thickness and pressure angle. Apr 5 : Development of formulas for measuring thickness of helical gear teeth by standard pin method and their application to typical case ; in case of odd number of teeth certain advantage is lost because two pins cannot be placed symmetrically opposite each other ; importance of correct tooth form.

Détermination Rationelle des Éléments d'un Filetage à l'Aide de "Piges" (Rational Measurement of Elements of a Screw-Thread with Wires), L. FRAICHET. Genie Civ v93 Sept 8 1928 p 238–40 3 figs ; Bul Technique, Service Technique et Industriel de L'Aeronautique, n51 Oct 1928. Principles of thread pitch and diameter measurements of screw threads by means of wires and micrometers, and formulas used are described.

Measuring Acme Screw and Worm Threads by Means of Wires or Cylinders. W. RICHARDS. Machy (London) v32 Sept 13 1928 p 787–90 5 figs and discussion v33 Dec 6 1928 p 302–4 4 figs. Fundamental factors involved in measurement of Acme and worm threads by means of wires or cylinders are given with formulas which take into account variation due to inclination of thread with axis of screw or lead angle. Further discussion by F. W. SHAW, Oct 18 1928 p 80 ; E. A. LIMMING Dec 27 p 405 ; W. RICHARDS Feb 14 1929 p 637.

Measuring Worm Threads by Means of Cylinders, E. A. LIMMING. Machy (London) v33 n846 Dec 27 1928 p 405–10 9 figs. Discussion of formulas developed by W. Richards in v32 p 787 of this magazine ; method said to be theoretically incorrect because geometrical principles underlying conditions of contact between sides of threads and cylinders have not been completely taken into account ; other formulas are developed.

Measuring Acme Screw and Worm Threads by Means of Wires or Cylinders, W. RICHARDS, E. A. LIMMING. Machy London) v33 n853 Feb 14 1929 p 637–40, 4 figs and discussion v34 n862 Apr 18 1929 p 82–5 5 figs. Answer to comments made by E. A. LIMMING appearing in Dec 27 issue of magazine upon author's articles which were published in Dec 6 and Sept 13 issues ; criticism of data for design of worm tools and production of worm thread refuted.

La Mesure des Filetages des Vis a Filet Triangulaire (M e a s u r i n g Triangular Screw Threads), P. A.

LAURENT. Genie Civ v94 n14 Apr 6 1929 p 333–6 9 figs. Precision method of French Navy described; it is combination of wire measurements of angles, diameters and pitch and mathematical derivations therefrom; precautions to be taken and errors resulting (±1 micron).

Messfehler durch Abplattung beim Gewindemessen (Errors Through Flattening in Measuring Screw Threads), H. BOCHMANN. Zeit InstrumKde v49 n4 Apr 1929 p 188–203 4 figs. Errors in measuring screw threads by ball or wire method due to flattening of measuring wires or balls. English translation available.

The Measurement of Screw Elements. Machy (London) v34 n884 Sept 19 1929 p 789–93 7 figs. Description of methods employed in measuring pitch diameter of screw threads with wires and verifying thread angle by two different diameter wires; charts are given for use in checking thread angle of U.S. Standard, Whitworth, S.I., and British Association threads by using set (of three) of each of two different diameter wires.

Measuring Pitch Diameters of Taper Threads, C. KUGLER. Am Mach v74 May 7 1931 p 730. Gives a practical procedure for measuring pitch diameter at a definite point with three-wire system. Includes formulas.

Measuring Cycle Engineer's Institute Standard Screw Thread by the Three-Wire Method. Machy (London) v38 May 14 1931 p 212–3. Derivation of formulas for measurement over wires and the best size of wire. Table of wire sizes.

Flankenmessungen an Schnecken und Trapezegewinden, (Measurement of Pitch Diameter of Worms and Trapezoidal Threads). A. RICKENMANN. Maschinenbau/Betrieb v 10 Oct 1 1931 p 619 4 figs. A cone and vee micrometer is used. Discusses corrections to measurements and gives curve for lead angle corrections.

Determination of Thread Diameters by the 3-Wire Method, G. BERNDT. Zeit InstrumKde Nov 1931 p 560–74. Describes method, derives equations for pitch diameter. Corrections are also obtained for the flattening of the wires and for the case of oblique threads, and tabulated.

Three-Wire Measurement of Screw Threads, J. R. CORNELIUS. Am Mach v74 May 21 1932 p 805; discussion by W. S. ROWELL v75 Sept 10 1932 p 416. Gives tables.

Helical Gear Tooth Measurement, S. TRIMBATH, Am Mach v76 Aug 31 1932 p 966–7. Advantages of sizing helical gear teeth by measuring across pins; standard form.

Die Bestimmung des Flankendurchmessers nach der Dreidrahtmethode (The determination of pitch diameter by the three wire method), G. BERNDT, Zeit InstrumKde v51 Nov 1932 p 560–74; Maschinenbau/Betrieb v11 Apr 1932 p 133. Advantages, methods of making measurement, calculations, and discussion of errors.

Korrektionen bei der Messung von Innengewinden (Corrections for the measurement of internal threads), J. WILHELM. Feinmechanik und Präzision v41 Oct 1933 p 147–52. Derivation of factors for correcting the measurement of internal threads by means of balls, V-blocks, and size blocks taking into consideration the deformation of the balls and the errors relating the helix.

Analytisches Verfahren zur Ermittlung der Günstigsten Messdrähte für die Sogenannte "Dreidrahtmethode" (Analytical method for determining the most suitable measuring wires for the so-called "three-wire method"), N. GUENTHER. Zeit InstrumKde v53 Sept 1934 p 373.

Das Messen von Saegegewinden (The Measurement of Buttress Threads.), W. KNEDEL. Werkstatttechnik

v29 Feb 1935 p 50–2. The method of measuring Buttress threads by the three-wire method. Explanation of calculations involved.

Bestimmung des Flankendurchmessers von Gewinden nach der Dreidrahtmethode bei unsymmetrischem Profil (Determination of pitch diameter of screw threads of unsymmetrical profiles by the three-wire method), G. BERNDT. Werkstatttechnik v29 June 1935 p. 237–9.

Die Messung Konischer Gewinde (The measurement of tapered threads), G. BERNDT. Bauer and Schaurte Neuss 1937 81 p. Various calculations.

Size Measurement of Gears, W. L. CHESLEY, Tool Engr v5 n9 Jan 1937 p 14–5. Easily understood method presented of calculating sizes over pins or balls for spur or helical gears.

Neuartige kopfkreisfreie Zahndicken-Messungen für Schrägzahnräder und Evolventen-Schnecken (Novel Method of measuring tooth thickness for involute helical gears and involute worms without use of addendum circle), W. F. VOGEL. Werkzeugmaschine v41 n11 June 15, 1937 p 253–61. Mathematical analysis of span measurements and its application to both spur- and helical involute-shaped tooth forms. A section "Tauchkörper-Messungen" (Dive-Body Measurements) deals first with pin- and ball-measurements of involute spur teeth. Extension of the analysis to ball-measurements of helical involute gears and involute worms leads to the introduction of the author's "Substitute- (thin) Disk Method", which reduces the measurement simply to that of involute spur gears. The same simplified method and equations have later been applied to pin-measurements of all involute screws. (VOGEL 1945 see subsections 10.1.2 and 10.1.3 and ZAHORSKI in Van Keuren Handbook 33 1945.) Bibliography.

Errors in Wire Measurement, O. E. KOEHLER. Am Mach v82 n9 May 1938 p 367. When lead is great, as with Acme or multiple V threads, consideration of lead angle should be included when measuring by wire method.

Pin Method of Measuring Worms and Helical Gears, E. BUCKINGHAM. Machy (N.Y.) v45 n1 Sept 1938 p 1–7 2 figs. Gives general formulas for pin diameter and measurement over pins; general formulas for screw threads and helical gears; application to screw threads and to a helical gear; compensation for possible deflection of pins or wires; errors in tooth thickness resulting from pin deflection; relation between a formula for screw threads and the simplified general formula. Compiler's comment: Formulas take lead angle into account but are not exact, as stated. They are approximations similar to those of Jeffcott. (See reference above.) NBS formula (10) quoted on p 5 is likewise not exact as here stated. In the original B523 reference it was stated to be a close approximation for screw threads. (See BUCKINGHAM below.)

Gauging Screw Threads by Wire Method. Machy (London) v53 n1359 and 1360 Oct 20 1938 p 71–4 and Nov 3 p 133–8. Screw threads can be measured with precision by making use of calibrated wires; direct reading charts and tables prepared by Société Genevoise d'Instruments de Physique, Geneva, for use in conjunction with standard calibrated wires and measuring instruments, are given. Includes formula for computing values, correction factor for obliquity, method of computing best diameter, corrections for elastic deformation of wires.

Gaging Multi-Start Threads by the Wire Method. Machy (London) v53 Nov 17 1938 p 200. Formulas for determination of best wire diameter in measuring multi-start threads and threads with very large lead angles.

Checking Screw Threads and Vehicle Gears by Measurement over Pins. E. BUCKINGHAM. Machy (N.Y.) v45 n4 Dec 1938 p 273. Compiler's comment: This article was

obviously in answer to reader objections to the author's preceding September article. Particularly, the author's allegedly exact theory was incompatible with the exact contact conditions of pins and balls used in the measurement of involute screws, as analyzed and published by A. H. Candee 1928. In this article the author tries to explain these contradictions by his obviously honest belief and statement that the behavior and contact geometry of a pin in the thread groove of an involute screw are basically different from those in other types of screws. More recent developments disprove this concept as well as the author's theory of bending deformations of the pins and their needed compensations. See TOMLINSON 1927, VOGEL 1947, and MARRINER and WOOD 1958, this subsection.

Die Messung der Flankendurchmesser mehrgängiger Gewinde mit drei Drähten (Measurement of Flank Diameter of Multiple Threads with Three Wires), N. GÜNTHER, H. ZÖLLNER. Feinmechanik und Präzision v47 n9 1939 p 129–31 2 figs. Contents: The three-wire method; the theory of screw surfaces; contact conditions with derivation of exact transcendental equation; the approximation process; summary, and buttress threads.

Ball Measurement of Helical Gears, A. ZAHORSKI. Am Mach v83 n14 July 12 1939 p 520–2. Method developed consisting of substituting real ball by imaginary roll, which will permit carrying out computation of measurement of tooth thickness of helical gears in same manner as done for spur gears; formulas and examples illustrated and described. Same as the Vogel "substitute disk" method" 1937.

Die Bestimmung des Flankendurchmessers von Gewinden mit symmetrischem Profil nach der Dreidrahtmethode (The Determination of Flank Diameter of Threads with Symmetrical Profile by the Three-Wire Method), G. BERNDT. Zeit InstrumKde v59 n11 Nov 1939 p 439–48. Determination of flank diameter of screw threads with symmetric profile according to three-wire method; mathematical and geometrical considerations and applications. The algebraic and geometrical considerations of the method and the influence of various sources of error are considered.

Die Bestimmung des Flankendurchmessers von Gewinden mit Unsymmetrischem Profil nach der Dreidrahtmethode (Determination of Pitch Diameter of Threads with Unsymmetrical Profile by Means of the Three-Wire Method), G. BERNDT. Zeit InstrumKde v60 Jan 1940 p 14-22. Theoretical principles and application of method, influence of errors, smallest and greatest possible wire diameters, numerical examples, detailed explanation of calculations involved.

Die Anlagekorrekturen bei der Bestimmung des Flankendurchmessers von symmetrischen und unsymmetrischen Aussen und Innengewinden (Corrections of Position in Determination of Flank Diameter of Symmetric and Asymmetric External and Internal Threads According to Three-Wire Method or By Means of Two Spheres), G. BERNDT. Zeit InstrumKde v60 n5, 6, 7, 8 and 9 May 1940 p 141–54, June p 177–86, July p 209–20, Aug p 237–48 and Sept p 272–8; Werkstattstechnik und Werksleiter v34 n17 Sept 1 1940 p 277–82. Detailed theoretical mathematical study; approximate formulas for corrections of position presented. Bibliography.

Durchmesser der Draehte fuer das Dreidrahtverfahren (Diameter of Wires for the Three-Wire Method), etc. G. BERNDT. Werkstattstechnik und Werksleiter v36 n23, 24 Dec 1942 p 507–19. Diameter of wires for three-wire method of determination of flank diameter of single threads with symmetrical profile; determination of flank diameter without regard to non-perpendicular position of wires to thread axis; influence of position of measuring wires inclined toward thread axis.

Calculating Screw Thread P. D., W. T. TAYLOR. Tool Engr v12 n8, 9, Aug 1943 p 87–9; Oct p 99, 101, 103, 105. Purpose is to simplify general formulas for overwire (3-wire) dimension, to present formulas in terms of basic pitch diameter and basic major diameter, to show best wire sizes which may be used for any particular number of threads per inch and to show permissible plus-minus limits on wire diameter for Whitworth 55° thread so that American wire sizes can be used to practical advantage; method of calculating and measuring even and odd fluted taps.

Involutometry and Trigonometry, W. F. VOGEL. Michigan Tool Co., Detroit 1945 325p 28 figs 33 refs. Contains simple exact equations, with derivations, for pin and ball measurements of involute-shaped spur gears and splines, also of involute screws (e.g. helical gears, helical involute splines and involute worms). Forms with step by step calculations are provided for various purpose measurements of spur toothed products. All measurements are explained as applications of a complete geometrical system of involutometry (see abstract in Sub-Section 10.1.2) and are tailored to be used with the large Main Table and a great variety of other numerical tables (see abstracts in Sub-Section 10.1.3).

Larmar Three-wire Measuring Instrument for Screw Threads. Machy (London) v66 n1684 Jan 18 1945 p 75–6. Illustrated description of apparatus manufactured by Larmar Eng Co; to obviate difficulty in positioning three wires prior to measuring over them with micrometer, wires are held to micrometer anvil and spindle faces by clamps.

Checking Pitch Diameters of Precision Screw Threads, E. BUCKINGHAM. Machy (N.Y.) v52 n1 Sept 1945 p 162–4. Consideration of three classes of screw thread profiles affecting measurement in checking pitch diameter of screw thread by measuring over pins or wires; involute-helical gear formula provides theoretically correct results when applied to screw thread of involute helicoidal form and very close approximations for threads having intermediate profiles; applicable formulas given.

Compiler's comment: This is a new idea for attacking the intricate problem of measuring screw threads over pins or wires. The author is to be commended for his proposal to utilize the simpler expressions of the corresponding measurement of involute screws (e.g. helical involute gears and involute worms) for this purpose. Simple exact equations for pin- and ball-measurement of involute screws have been known before (e.g. Candee 1928, Vogel 1937 and 1945 etc., in this subsection). They offer the great advantage of free pin selection and also yield the exact contact points between pins (or balls) and the helical tooth surfaces. Any attempt, however, to prescribe the size of the contact radius of the involute screw not only kills the free selection of the wire size but also leads to strictly *transcendent* exact equations of the whole measurement. The same is true for the exact measurement-equations with best-size wires of *all screw types*, since such wires are meant to contact the screw exactly at the pitch cyclinder. (See Vogel 1947 and 1955 in this subsection.)

Buckingham's equations of the pin measurement of helical involute gears in his Manual of Gear Design, vol. 3, 1937, p. 150 were given without derivation and explanation except the statement that they were meant for contact at a given cylinder of the gear. Referring to those (nontranscendent) expressions the author now admits in this article that those two formulas for both the pin-size and the over-pin dimension were only approximations. Simultaneously claiming very small errors of those approximations, he proposes to utilize the pin-size formula as best-size wire formula for screw threads. This claim was not borne out in later comparative error investiga-

tions of various best-size pin formulas (see Vogel 1947, in this subsection).

In his new Thread Measuring Method, Buckingham established a best-size wire by an approximate formula, but abandons completely his previous approximate formula for the over-wire dimension of an involute screw. Working with the thus established best-size wire, he uses it like a freely selected pin dropped into an involute screw and instead, applies an exact equation for establishing its over-pin dimension. The method would be strictly exact, if the best-size wire had exactly the theoretically needed diameter, but as this was not the case, the whole method is only an approximation, whose accuracy obviously is influenced by the error of the used best-pin size formula. The author himself was aware of this. In his first "numerical example" he utilized the approximate best-pin size formula from his manual of Gear Design, 1937, as initially recommended. In his second numerical example he silently discarded his own recommendation and specified (without calculation) a wire size, which happens to correspond to that of a formula proposed in another of his previous publications, namely 1938. His preferred latter approximation is also used exclusively in his representation of his new method in Machinery's Handbook, 17th ed. 1964 on p. 1217–20. According to Vogel (1947 of this subsection) the latter best-size pin is always undersize, while the best-size pin formula used in the first example always leads to an oversize for the wire. The quoted references and Van Keuren Handbook 36 (1955) also contain newer developments of simple exact best-pin measurement equations, numerical tables, and more precise approximations. The compiler hopes his cross-references will result in a more nearly up-to-date presentation in the next edition of Machinery's Handbook.

Three-Wire Thread Gaging Simplified, J. J. MEADOWS. Iron Age v157 n16 Apr 18 1946 p 51–7. Formula for checking thread size using three-wire method, based on major thread diameter; charts and tables commonly involved and cover National Fine and National Coarse series, Whitworth standard, British Assn, British Standard Fine, and French standard thread forms.

Effect of Elastic Modulus on Measurement of Thread Wires. D. E. WILLIAMSON. Prod Eng & Mgmt v18 n2 Aug 1946 4 p 5 figs. Analyses the various factors relating to the use of Carboloy wires.

Wire Dimensions for Screw Threads, J. W. LEE. Tool Engr v18 n1 Feb 1947 p 36–8. Develops formulas for calculating wire measurements of pitch diameter, taking the lead angle into account. These are based on the assumption that the contact points of the wire with the thread are located on the normal to the central pitch helix of the thread (which assumption gives more accurate results than assuming contact in an axial plane but still is not exactly true). Presents relations between screw dimensions and measurement data.

The Best Wire for Over Wire Measurement of General Screws, W. F. VOGEL. The Van Keuren Co. Watertown, Mass. Sept 9 1947 56 p. Develops universal theory of screw measurements over pins. including prerequisites for a general screw measurement, significance of the involute screw, the exact equations for general screw measurement (i.e. for cylindrical screws of any symmetrical thread profile), number of pins and balls to be used, and formulas for routine calculations. Monograph copies deposited at Library of Congress, National Bureau of Standards, Detroit Public Library, and Wayne State University.

Thread Grinding and Measurement, A. C. PARKINSON, W. H. DAWNEY. Sir Isaac Pitman & Sons, London, and Pitman Publ Corp, New York, 1949 227 p illus diagrs charts tables. Thread terms and definitions are classified and explained; limit systems and their special applications to screw threads, worms, and hobs; in regard to thread measurement, considerable amount of space devoted to wire methods. Eng Soc Lib, N.Y.

Determination of the Thickness of the Teeth of Worms and Spiral-Toothed Wheels with the Help of Rollers and Balls, F. L. LITVIN. Acad Sci (Russia) v10 n39 July 6 1950 p 22–7 18 figs 4 refs. English translation available at NBS and Van Keuren Co. A distinction is made between convoluted, Archimedean, and evoluted helical surfaces. Develops exact relationship between position of the roll in the thread space of the worm, the lateral surfaces of the teeth, and the thickness of the teeth. Develops relationships connecting variation in the position of the roll and variation in thickness of teeth.

Position of Contacting Sphere Between Teeth of Helical Gear, N. J. C. PERES, Machy (London) v77 n1977 Sept 21 1950 p 324 1 fig. Derives equation for angle between center of pin and point of contact of pin and tooth. (Obviously the author was unaware of the existence of much simpler exact equations offered in the "Substitute Disk Method", see Vogel 1937 and 1945.)

On Precision Screw Threads, M. OGAWA. Rep Inst Indus Sci Univ of Tokyo v2 n1 ser 10 Apr 1951. Translation of Chapter 1 on Theory on the Three-Wire Method is available from Eng. Metrology Section, NBS. Chapter has 11 figs 10 refs. Contents of chapter: General theory; states of contact between measuring wires and a helicoidal surface; conditions for the stable contact; general solutions; the most accurate ordinary solution; the best wires; errors in the three wire method.

Prüfen und Messen von Gewinden (Testing and Measurement of Screw Threads) F. WOLF, Munich 1952.

Analysis of Screw Thread Measurement, W. H. HARRISON. Mach v96 Apr 2 1952 p 602–4 2 figs. Gives analysis intended to make clear the exact conditions of contact of measuring cylinders to thread flanks, without taking account of deformation of work or measuring cylinders. Solve example by iteration.

New Thread Measuring Formulas, W. F. VOGEL. Catalog and Handb n36 Appendix D The Van Keuren Co 1955. Exact equations of the trigonometric solution of the Best-Pin method are provided with numerical tables (by the Van Keuren Co) based on it.

Die Berechnung der Gewinde-Anlagekorrekturen, M. GARY, PTB. Forschung auf dem Gebiete des Ingenieurwesens v21 n4 1955 p 107–17 5 figs 7 refs. Calculation of rake corrections in screw thread measurements; conditions governing contact of spheres and cylinders in helical grooves of thread; resulting transcendental equations solved by iteration for all threads with straight flanks in axial sections; formula established for best pilot wire diameter for asymmetrical thread profiles.

Geometrische Probleme bei der Vermessung von zylindrischen Evolventen-Schnecken und Evolventen-Schrägstirnrädern (Geometric Problems in the Measurement of Cylindrical Involute Worms and Involute Helical Gears), M. GARY, PTB. Konstruktion v8 n10 1956 p 412–8 2 figs 4 refs. Methods are outlined for measurements of the standard gage with balls or measuring wires of cylindrical involute worms and involute helical gears. For symmetrical involute worms a method is given for determination of the base cylinder radius and the tooth thickness. Contents: Equations for the position of a cylinder in an involute worm (1) cylinder with predetermined inclination to the worm axis; (2) cylinder at minimum distance from the worm axis. Equations for the position of a ball in an involute worm. Computation of the base cylinder radius and tooth thickness from the results of two diameter determinations over cylinders or balls. Three numerical examples.

Screw Thread Standards for Federal Services. NBS Handb H28 (1957) Parts I and III and 1963 Supplement. Supt. of Docs, Government Printing Office, Washington 25, D.C. Appendix 4, Wire Methods of Measurement of Pitch Diameter of 60° Threads. Appendix 13, Three-Wire Method of Measurement of Pitch Diameter of 29° Acme, 29° Stub Acme, and Buttress Threads.

Effect of Differences between U.S. and British Practices in Measuring Screw Gages for Unified Threads, L. W. NICKOLS. Machy (London) v90 n2315 Mar 29 1957 p 723–5; Metalworking Prod Mar 29 1957 p 539–41 2 figs. American and British methods of measuring effective diameters of screw plug gages and setting plugs; effective diameter measurements made at single specified position on each of five screw plug gages having Unified threads in order to determine experimentally effect of differences between two methods.

Precise Formulas for Over-Pin Measurements of Helical Forms, E. C. VARNUM, S. J. JOHNSON. Tool Engr v38 n6 June 1957 p 116–20; Also Letter to the Editor of the Tool Engr v39 n2 Aug 1957 p 183 by W. F. VOGEL; also AGMA Paper 239.03 June 1957. (The print is an authorized AGMA paper only if it carries a sticker giving credit to preceding exact solutions by W. F. Vogel in Van Keuren publications.) Gives a desk calculator routine for computing over pin measurements by iteration.

Discussion des méthodes de mesure du diamètre sur flanes des filetages coniques males (Discussion of methods of measuring diameter of conical screw threads on their flanks). J. SIMONET. Revue Universelle des Mines v14 n3 Mar 1958 p 73–9. Five methods of measurement are examined; in each case there is serious difficulty in calibration of measuring instrument; advantages and disadvantages of each method, and domains of their application.

Over-Pin Measurements of Worms, L. D. MARTIN. Tool Engr v41 n1 July 1958 p 50–4. Simple approximate formula for over-pin measurement of worms presented which yields results within practical limits affected by workpiece elasticity, measuring pressure, profile deviations and observational error. Criticism by J. SILVAGI, Nov 1958 p 195–6.

Rake Correction in the Measurement of Parallel External and Internal Screw Threads, R. S. MARRINER, MRS. J. G. WOOD. Inst Mech Engrs (London) July 1958 9 p 6 figs 2 refs. Formulas are derived for calculating the rake correction for a ball seated in the helical groove of an internal screw thread and a ball or cylinder in an external thread. The equivalence of a ball and cylinder in an external thread is discussed. A simple approximation formula, and an exact equation are derived for determining occurrence of double contact between the cylinder and thread flank.

Determination of Helical Gear Sizes by the Two-Roller Method, I. P. NEZHURIN. Russian Eng J v39 n8 1961 p 11–3 3 figs. English translation by PERA. Describes a method of calculation of the size over rolls which ensures an easy criterion of their displacement in the tooth groove of helical gears with an odd number of teeth. Demonstrates the existence of the "oddness effect", that is: In contrast to even-numbered helical gears, the axis of the micrometer when measuring over two rolls is askew to the axis of the odd-numbered helical gear; it neither intersects the axis nor is its location in a plane of rotation of the gear. The correctly recognized geometry of the problem was evaluated in exact equations for the measurement. For one of them an approximate simplification is offered. (Unfortunately, one of the exact equations was found to be erroneous. See correction by KHALEBSKII, 1963, and acknowledgment by NEZHURIN, 1963, in this subsection, p. 212.

New Equations Simplify Pin Measurement of Gears, J. H. GLOVER. Prod Eng v32 n11 Mar 13 1961 p 80–4 4 figs 3 refs. Gives equations for calculating over-pin and between-pin measurements of ideal involute tooth forms of external and internal spur gears. The equations also establish measurements for desired variations in tooth thickness and pin size. This will be very valuable if the calculations are made with the assistance of numerical tables giving over- or between-dimensions only for a specified thickness (usually: standard thickness) and for a specified theoretical value of the pin size, which may not be available at the needed accuracy. The same equations can be used for external helical gears only if they have an even number of teeth. Internal helical teeth cannot be measured by pins. If balls are used for their measurement then the mentioned equations can be applied to both even and odd numbered internal helical gears. (The author claims that his way of formulating the known basic exact equations simplify the measurement, but the simple basic geometry of the measurement can no more be recognized in this presentation.)

Further Report on the Effect of Differences between U.S. and British Practice in the Measurement of Screw Gauges for Unified Threads, P. W. HARRISON, NPL, Machine Shop Mag v22 n4 Apr 1961 p 207–9. The application of rake correction to measurements made by American methods improves their agreement with the British values in seven out of eight cases and reduces the mean difference to one quarter of its previous value.

Getting Bugs Out of 3-Wire Measurement, R. T. PARSONS. Am Mach/Metalworking Mfg v105 n14 July 10 1961 p 86–8. Three sources of error in 3-wire method of measuring thread gages and threaded parts are discussed including lead angle effect, calibration and accuracy of measuring wires and computation of correct constants, and measuring instruments and pressures; 60° single-start threads with lead angles of less than 5° are considered only.

Study on a Ball Screw (Part 3), Z. MURASE, J Japan Soc Prec Eng v28 n6 1962 in Japanese. There are many reports on the measuring method about the triangular helicoidal surface, but rather few about generalized helicoidal surface. In the Part 3, the mechanical measuring method of the radius from the screw axis to any point on the race-way surface (generalized helicoidal surface) of the nut or the threaded shaft of the ball screw, using the balls or the cylinders as the measuring feelers, is studied. And the exact equations, by which the correction value of the measuring results will be calculated, are deduced. These corrections are necessary, because the elastic deformation at the contact point of the race-way with the measuring feelers and the diametral error of the feelers are always existent more or less. New mathematical method of determining the race-way surfaces, the exact equation of the principal direction and principal curvature on the contact point of the ball-race with the ball, and the theoretical calculation of the elastic approach between the ball-race and the balls of the ball screw are the fundamentals of the studies on this part 3, and they are reported in the previous two parts of this series.

Sonderfragen zur Geometrie der Gewindeflanken (Special Problems in the Geometry of Screw Thread Flanks), H. HAAKE. Werkstattstechnik v52 n4, 7 Apr 1962 p 180–6, July p 339–43. Special problems concerning geometry of flanks of threads; it is shown how diagrams can be drawn which make possible general view of entire thread series and facilitate calculation in measuring flank diameter with three wires. Apr. Thread with unsymmetrical profile considered. July. Taper threads discussed.

Measurements of Helical Gears with Pins or Balls, Analysis of Pitfalls and their Elimination, A. S. BEAM, C. E.

HALL. AGMA 129.15 June 1962 7 figs 1 ref. Clarification of the geometry of measurements from center of gear over one pin. Useful mathematical formulations are presented as a new tool in the art of gear inspection. It is shown that when pins are used on helical gears with even numbers of teeth, the prevalent belief that the distance between the axes of the two pins assumes an extreme value which can be found as a low or high point of the measurement is an oversimplification. The discussion covers: (1) Measurement over one pin or ball; (a) measurement from the center over one pin and (b) measurement from the outside surface over a pin or ball placed in an opposite tooth space. (2) Measurement over two pins or balls when (a) gears have even numbers of teeth and (b) gears have odd numbers of teeth. (3) Measurement over three pins of spur and helical gears.

Neues Verfahren zum Messen von engtolerierten Innengewinden (New Method for Measuring Close-Tolerance Internal Threads), G. VOENEKY. Werkstratt u Betrieb v95 n11 Nov 1962 p 755–8. Explanation of 2-ball method used in measuring effective diameter of internal threads is followed by comparison with method using contact arms and with that of caliper microscope; application of internal thread measuring device in connection with shop microscope and universal comparator is described.

Determining the Size of Helical Gears by Rollers, N. T. KHALEBSKII. Russian Eng J v42 n10 1963 p 10–1. English translation by PERA. Alleges an error in one of Nezhurin's (1961) exact equations and presents simpler approximations.

Measuring Helical Gears with an Odd Number of Teeth by Rollers, I. P. NEZHURIN. Russian Eng J. v42 n10 1963 p 11–3 2 figs 2 refs. English translation by PERA. Calculations as given in previous articles have been simplified by means of a nomogram which yields highly accurate values fully consistent with those derived by KHALEBSKII.

Specification for Screw Thread Measuring Cylinders. Brit Standards Instn—Brit Standard 3777 1964 17 p. Standard relates to two grades of screw thread measuring cylinders intended for use in checking external screw threads by means of pitch diameter measuring machines; first part gives bases for diametral tolerances of Grade A and Grade B screw thread measuring cylinders and relative merits of these grades; second part gives complete specification for both grades of cylinders suitable for forms and pitches of screw threads shown.

9.4. Tables for Ball, Pin, or Wire Measurements

See also subsection 10.1.3 for similar tables for gears.

NOTE. The following references are either completely tables or contain tables along with other material.

Gewindemessen mit Drähten (screw thread measurements with wires), J. REINDL. Betrieb v1 n14 Aug 1919 p 361–5 11 figs. Gives tables for Whitworth, International Metric, and Löwenherz threads for pitch diameter and angle measurements with wires.

Correction for Elastic Compression in the Measurement of Screws with Small Cylinders, G. A. TOMLINSON, NPL. Machy (London) v28 Aug 26 1926 p 616–8 2 figs. Contains nomogram for computing compression in "effective diameter" measurement.

Checking Gear Size by Measurement Over Pins, K. E. BAUERLE. Machy (N.Y.) v44 n6 Feb 1938 p 353–7. Tables simplifying application of this precise and generally available method to external and internal spur and helical gears.

Tables for Precise Measurement of Screws, H. L. VAN KEUREN. Catalog and Handb n34 1948 The Van Keuren Co., Watertown, Mass. See also Handbs n35 1952 and n36 1955. The tables, meant for wire contact exactly at the pitch cylinder of the screw, were computed with the Vogel

(1948) approximate formulas Nos. 662 and 710 and spot-checked and (where necessary) corrected by applying the exact equations of Vogel's Best-Wire Method, 1947 and 1955, referred to in subsection 9.3, p 210. The tables cover a wide range of standardized and non-standardized screws, including single-start and multiple-start threads and worms.

Gauging and Measuring Screws. National Physical Laboratory, Teddington, 1951. Section VII, Formulae and Corrections for Use in the Measurement of the Effective Diameter of Parallel Screw Plug Gauges by Means of Small Cylinders, p 23–32 5 figs. Includes charts for lead angle correction and compression correction.

Screw Thread Standards for Federal Services. NBS Handb H28 (1957) Parts I and III and 1963 Supplement. Supt. of Docs. Government Printing Office, Washington, D.C. Appendixes 4 and 13 contain tables for wire measurements for 60°, 29° and Buttress threads.

Machinery's Handbook 17th ed 1964 2104 p. The Industrial Press, N.Y. A section on measuring screw threads p 1208–25, contains tables of wire sizes and constants for wire measurements of Unified, Whitworth, and Acme Screw threads.

Addendum to Section 9

9.3. Wire and Ball Measurements of Screw Threads and Other Helicoidal Features

Compiler's comment: TOMLINSON (see p 207) deserves credit for apparently having derived the first exact solution for the over-wire measurement of "Archimedean Screws" by means of freely selected wires. The solution is applicable to all screws, helical splines, and worms having symmetrical straight flanked axial profiles.

General Equations for the Conditions for Single Contact between a Measuring Pin and a Screw, R. A. MacDONALD. A thesis submitted to the College of Engineering of Wayne State University, Detroit, Michigan in partial

fulfillment of the requirements for the degree MS in Engineering Mechanics. Approved Nov 1 1965 33p 9 figs 12 refs. The author first offers a general procedure, including new exact equations, for location of a freely selected ball or measuring wire in a thread groove of a cylindrical "general screw" having any contour which is a continuous function of y that has at least a first derivative. The second part of his procedure established the necessary criteria for examining multiple contact in any plane of those screws and changing the wire size, if necessary, to obtain single contact.

Section 10. Measurement of Gears

CONTENTS

10.1. Gear Metrology, General

10.1.1. Standards and Nomenclature

NOTE: Most of the references in this subsection do not deal with measurement, but they provide geometrical information which is essential to the measurement of gears. Standards are revised so frequently that readers should consult the latest edition of the reference listed.

Proposed Standard Practice for the Inspection of Gears. Am Mach v70 n17 Apr 25 1929 p 657–60 10 figs; Power Transmission v34 n5 May 1929 p 37–40 10 figs. Proposed American recommended practice for inspection of gears, including worms hobs, and other cutters, compiled by Sub-committee No. 9 of Committee on Standardization of Gears; gear inspection of cylindrical and tapered holes; keyways for Woodruff keys, shafts, shifter grooves, small size spur, helical, internal and bevel gears, backlash, involute curves, angular velocity, thread inspection, external threads, internal threads and worm inspection; hob inspection, inspection of gear cutters (shaper and disc).

Machine cut gears, C. Worm gearing, BS 721 : 1937. Brit Stand Inst. Available from ASA.

Machine cut gears. A. Helical and straight spur. BS 436 : 1940, with amendments. Brit Stand Inst. Available from ASA.

Fine Pitch Gears. Product Eng v16 n9, 10, 11, Sept 1945 p 598–601, Oct p 710–13, Nov p 758–60. AGMA Standard 234.01 May 1945 for inspection and tolerances of gears of 20 diametral pitch and finer. Sept: Scope of standard, general specifications and classifications and spur and helical gears covered. Oct: Details pertaining to worms, worm gears, bevel gears and backlash in gears. Nov: Inspection and tolerance.

Gear Tolerances and Inspection (AGMA 231.01, 232.01, and 233.01). ASA B6.6–1946, out of print.

New High-Speed Helical and Herringbone Gear Standard. Machine Design v19 n12 Dec 1947 p 157–8. Standard practice set forth by AGMA for use primarily in design of self contained speed reducer units, but equally valuable in design of other types of high speed helical gear drives falling within this classification.

British Standard Specifications for Gearing, W. A. TUPLIN. Engr v185 n4819 June 4 1948 p 549. Discussion of Specifications 436, 545 and 721.

Bevel Gears (Machine Cut). BS 545 : 1949 36 p. Brit Stand Inst. Available from ASA. Applies to machine-cut, conical gears connecting intersecting shafts, the teeth being either straight or curved, pressure angle 20°. Three classes of accuracy are covered and tolerances are given.

Ein System fuer Verzahnpassungen (A System for Tooth Fits), O KIENZLE. Werkstattstechnik und Maschinenbau v39 n5 1949 p 129–39. DIN tolerance system for spur gears with involute teeth; report of work carried out at end of war under auspices of German Standards Committee; general principles of fit system; errors in gear teeth tolerances; system developed, known as "unit distance between axes"; tolerances given in 12 degrees of accuracy; tables, diagrams. Bibliography.

Fine-Pitch Straight Bevel Gears (AGMA 206.03)—American Standard B6.8–1950. Publ ASME, New York 1950 9 p out of print. Standard covering generated straight bevel gears of 20 diametral pitch and finer, for all shaft angles, with numbers of teeth equal to or greater than $^{16}\!/_{16}$, $^{15}\!/_{17}$, $^{13}\!/_{20}$ for 90° shaft angle; standard is identical in technical content with AGMA standard on Fine Pitch Straight Bevel Gears.

Gears for Traction. BS 235: 1951. Brit Stand Inst. Available from ASA. For drives of vehicles running on rails.

Gears For Instruments and Clockwork Mechanisms: BS 978: Part 1: 1952, Involute, spur, helical, and crossed helical gears. BS 978: Part 2: 1952, Cycloidal type gears with Addendum 1, Double circular arc types. BS 978: Part 3: 1952, Bevel gears, Brit Stand Inst. Available from ASA.

Gears for Turbines and Similar Drives. BS 1807: Part I: 1952 Accuracy. BS 1807: Part 2: 1958 Tooth form and pitches. Brit Stand Inst. Available from ASA.

Simplified Standards for Gears, W. A. TUPLIN. Engr v193 n5017 Mar 21 1952 p 394–7. Standard gear defined as one that may be generated by standard cutter; it is desirable to use simple system of gear design that permits full use to be made of versatility of standard involute generating tools; any calculation procedure that demands accuracy beyond that offered by 10-inch slide rule is (according to the author) not well conceived; diagrams.

Worm Gear Design, H. WALKER. Engr v194 n5035 July 25 1952 p 110–14. B S Specification 721 gives recommendations satisfactory for worm gears having involute helicoid thread form, but there is range of multi-thread worms of high lead angle not adequately covered by specification; experience has shown desirability of defining more clearly method of spacing gear designs so as to reduce total number of new hobs and tools without over-restricting choice of available designs; proposals provide means for overcoming difficulties.

Development of Gearing Standards, W. A. TUPLIN. Machy (London) v81 n2090 Dec 5 1952 p 1173–7; see also Engr v194 n5048 Oct 24 1952 p 538–42. Author's proposal that blank diameter of gear should be one essential in manufacture is now being considered by British Standards Instn for spur, helical and worm gears; procedure for designing pair of helical gears to work at specified center distance and to have specified velocity ratio; present standards for worm gears critically examined; features of proposed new standards. Before Brit Gear Mfr's Assn.

Straight-Sided Splines (for Cylindrical Shafts), Nominal Dimensions in Millimeters. ISO Recommendation R14–1953. Available from ASA, $0.60.

Proposed Standard Design for General Industrial Coarse Pitch Cylindrical Worm Gearing, F. G. EAST. ASME Trans v76 n2 Feb 1954 p 163–72. Suggested method of standardizing general industrial coarse pitch cylindrical worm gear drives, particularly worm diameter and tooth proportions, to eliminate present difficulties where no recognized standard exists; proposals do not insist on single worm diameter for each pitch or center distance but rather, limited group of worms that will cover range of good design.

Letter Symbols for Gear Engineering. ASA B6.5–1954. Available from ASA, $1.50. Identical with AGMA 111.02.

Gear Nomenclature, Terms, Definitions, and Illustrations ASA B6.10–1954. Available from ASA, $1.50. Identical with AGMA 112.03.

System for Straight Bevel Gears (AGMA 208.01) ASA Am Stand B6.13–1955. Publ ASME, New York, 1955 9p $1.50. Standard covering recommended tooth proportions and dimensions of blanks for generated straight bevel gears of tooth ratios in general industrial use; data given is development from system originated by Gleason Works and adopted by AGMA in 1922, revised in 1940, and with further changes in 1955 revision.

Stand der Verzahnungsnormung (Status of Gear Standardization), A. BUDNICK. VDI Zeit v97 n11–12 April 15 1955 339–43. Status of gear standardization and its further development; standardization of spur gears according to DIN 3960; tolerances for spur gear based on DIN 867; DIN 3974 standard for worm gears; status of international standardization.

20 Degree Involute Fine-Pitch System for Spur and Helical Gears. ASA Am Stand B6.7–1956. Publ ASME, 1950 16 p, (AGMA 207.04) out of print. Standard fine pitch series includes gears of 20 diametral pitch and finer having 20° pressure angle; data concerning pinion enlargements.

Design for Fine-Pitch Worm Gearing. (AGMA 374.03) ASA AM Stand B6.9–1956. Publ ASME, 1950 18 p, $1.50. Standards covering worms and worm gears with axes at right angles, comprising cylindrical worms with helical threads, worm gear being hobbed for fully conjugate tooth surfaces; it does not include helical gears used as worm gears; data for standard axial pitch range of 0.030, 0.040, 0.050, 0.065, 0.080, 0.100, 0.130 and 0.160.

Inspection of Fine-Pitch Gears ASA B6.11–1956, out of print. AGMA Stand 236.05 June 1956 41 p 27 figs. Available from AGMA, $2.50. Includes a section on pin measurements of fine-pitch involute spur gears.

Inspection of Coarse-Pitch Spur and Helical Gears. AGMA Stand 231.02 July 1956 18 p. Available from AGMA, $1.50.

Inspection of Coarse-Pitch Bevel and Hypoid Gears, AGMA Stand 232.02 Aug 1956 11p. Available from AGMA, $1.50.

Inspection of Coarse-Pitch Cylindrical Worms and Worm-gears. Tentative AGMA Stand 234.01 Aug 1956 12 p. Available from AGMA, $1.50.

Whither British Standards for Gears? H. E. MERRITT. Engr v202 n5256 Oct 19 1956 p 547–9. Attention directed to difficulties encountered in attempting to revise certain standards for toothed gears, and to prompt wide based discussion which may help to stimulate action in revision of standards.

Normung, Tolerierung und Messen von Verzahnungen (Standards, Tolerances, and Measurement of Gear Teeth), R. NOCH. Konstruktion v8 n10 Oct 1956 p 406–12, Reference to German DIN standards; tooth defects and their measurement.

Basic Rack of Cylindrical Gears for General Engineering. ISO Recommendation R53–1957. Available from ASA, $0.60. See also ASA B6.1–1932, out of print.

Modules and Diametral Pitches of Cylindrical Gears for General Engineering. ISO Recommendation R54–1957 Available from the ASA, $0.60.

American Standard Drafting Manual—Gears, Splines, and Serrations (Section 7) ASA Y14. 7–1958. Available from ASA, $2.00.

Gears for Turbines and Similar Drives. Brit Stand Inst BS n1807 pt 2 1958 7 p. Pt 2: Tooth form and pitches; standard specifies basic tooth forms and standard pitches of helical gears for high speeds, but should not be taken to suggest that they are unsuitable for other speeds; diagrams.

Fine-Pitch On-Center Face Gears for 20-Degree Involute Spur Pinions. AGMA Stand n203.01 Feb 1958 20 p, Design of face gear and its pinion; recommended method of delineation of face gear on detail drawings; two information

sheets show tooth proportions for pinions with less than 12 teeth, and one covering alternate method of calculating outside diameter of face gear.

Tooth Proportions for Coarse-Pitch Involute Spur Gears. AGMA Stand System 201.02 Mar 1958 21 p. Available from AGMA. $1.50. Standard provides tooth proportion information required in designing spur gearing with 20° and 25° pressure angle full depth tooth forms; two information sheets on tooth proportions for 14½° full depth and 20° stub involute, and 14½° composite coarse pitch spur gears, and formulas and limitations for coarse pitch spur gear tooth proportions.

Zerol Bevel Gear System. AGMA Stand System 202.02 July 1958 19 p. Available from AGMA, $1.00.

New Standards for Gears Span Wide Range of Quality, L. D. MARTIN, Prod Eng v29 n52 Dec 22 1958 p 46–9. All-inclusive standard presented that can be applied to spur and helical gear specifications without conflicting with present AGMA standards; 15 classes established with logarithmic sequence resulting from detailed examination of thousands of gears.

System for Spiral Bevel Gears. AGMA Stand 209.02 June 1959 11 p. Available from AGMA, $1.00.

Involute Splines, Serrations and Inspection. ASA B5.15–1960. Available from ASA, $5.00.

New Formula Simplifies Worm-Gear Ratings, J. E. GUTZWILLER. Iron Age v186 n13 Sept 29 1960 p 116–17. AGMA 440.03 is designation for new worm gear rating standard to replace separate standards AGMA 213.02 and AGMA 440.02; new standard includes formula for rating worm gearing which is complete departure from previously used ratios; standard also provides specifications for design of worm driven speed reducers.

Straight-Sided Splines and Gauges, Dimensions in Inches, ISO Recommendation R232–1961. Available from ASA, $7.50.

Design for Fine-Pitch Worm Gearings. (AGMA 374.03). ASA B6.9–1956 (R 1962). Available from ASA $1.50.

Nomenclature of Gear Tooth Wear and Failure. (AGMA 110.03) Jan 1962 15 p 31 figs. Available from AGMA $1.50.

Specification for Master Gears. Brit Stand Instn—Brit Stand 3696 1963 8 p. Standard relates to 2 classes of spur master gears for use as reference and inspection standards with pitches in range 2 to 64 normal diametral pitch inclusive; class A master gears are intended to test precision class product gears and Class B to test gears for general purposes; specification may also be applied to helical master gears so far as tolerances are concerned, but tolerances given have been chiefly derived from information from spur master gears.

Specification for Worm Gearing. Brit Standards Instn—Brit Stand 721 1963 34 p. Standard applies to worm gearing and comprises cylindrical involute helicoid worms and worm-wheels conjugate thereto, dimensions of which are expressed in inches; 4 classes of gears are provided which are related to function and precision; range of modules is given in convenient steps from 0.052 to 1; it does not refer to pairs of cylindrical gears connecting nonparallel axes known as crossed helical gears.

10.1.2. Textbooks and Handbooks Dealing Partially with Measuring Methods

NOTE: For further abstracts of most of these books see subsection 10.1.3, Numerical Tables.

Zahnräder (Gears). A. SCHIEBEL. Julius Springer Verlag, Berlin, 1913, 1922, 1930. Authoritative German presentation of theory and principles. See also 4th ed. by Lindner, 1954, abstracted in subsection 12.1.

Spur Gears. E. BUCKINGHAM. McGraw-Hill Book Co. Inc., 370 7th Ave., New York, N.Y., 1928. Chapter 9 on measuring gear teeth includes descriptions of gear-tooth vernier, gear-tooth micrometer, roll measurement, tooth thickness and root diameter by vernier caliper, methods of measuring tooth spacing and involute contour, the odontometer, projection methods, composite tests, rack type tester.

Schraubgetriebe, ihre mögliche und ihre zweckmässigste Ausbildung (Screw Drives, Their Possibilities and Their Most Suitable Development). F. G. ALTMANN. VDI-Verlag GMBH Berlin NW7 1932 30 p 73 figs 36 refs. Contents: Introduction; fundamentals of toothing of screw drives; the screw surfaces of cylinder screws; the investigation of different cylindrical screws as to suitability for forming lubrication film; the production of involute screws and the corresponding worm wheels; operation results of drives with involute screws; summary.

Analytische Untersunchung des zylindrischen Schneckentriebes mit gerader, die Achse schneidender Erzeugender (Analytical Investigation of Cylindrical Worm Drive with Straight, Axial Worm Profile), W. F. VOGEL. Omnitypie-Gesellschaft, Stuttgart, 1933. Doctoral Dissertation submitted to the Technische Hochschule Berlin on July 3, 1931 and endorsed Nov. 2, 1932, 62 p 52 figs bibliography. (Exactly the same text published on the book market by the author (in 1933) under the industrial title: "Eingriffsgesetze und analytische Berechnungsgrundlagen des zylindrischen Schneckentriebes mit geradflankigem Schnecken-Achsenschnitt" is now out of print.) Analytical computation methods are developed for cylindrical worm-wheel mechanisms with straight-lined axial worm profile (Archimedean worms). All such mechanisms are reduced to dimensionless Unit-Worm-Drives having unit pitch-radius "one" of the pitch cylinder. The equations of the helicoidal surfaces of the worm are developed in rectangular as well as cylinder-coordinates. From them equations of the imaginary "Surface of Contact" were derived, yielding a complete analysis of the laws of contact between worm and wheel, including exact expressions for the (utilized) "Field of Contact," undercut limitations, the contact ratio, the surfaces of the wheel-teeth, and frictional velocities. Several particularly simple graphical constructions, especially for the paths of contact in longitudinal planes of the mechanism also are revealed for the first time. The equations of the worm's thread surfaces are also those of the customary cylindrical fastening and power screws and were later used by the author for the establishment of exact equations and the analysis of several tool profiles for all of these products. (See 6 abstracts: Vogel 1933, 1934, and 1935 in subsection 12.6.3, p 272.)

Manual of Gear Design, E. BUCKINGHAM. 3 vols Machy (N.Y.) 1935. In vol 2, p. 26–9, are given equations relating measurements over rolls and diameter of rolls to arc tooth thickness, and pressure angle at a given radius for involute spur gears. *Compiler's comment:* In vol 3, p 150, are given formulas, (which are not exact equations), relating diameters of rolls and measurement over the rolls to diameter, tooth thickness and pressure angle at the given diameter of a helical gear. (For errors of these approximations, which are not negligible for small numbers of teeth, see abstract of Buckingham, 1945, in subsection 9.3, p 209.)

Grundlagen fuer die Messung von Stirnraedern (Funda-

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mentals of the Measurement of Spur Gears, G. BERNDT. Berlin, Julius Springer, 1938 155 p diagrs charts tables. Measurement of involute toothed gears discussed; following determination of ideal gear wheels, methods for measuring contact angles and tooth flanks are given; determination of flank shape, tooth slope and circular division of gear wheels covered, and effect of impulse blows of teeth on running of gear considered; testing and inspection methods included.

Involutometry and Trigonometry, W. F. VOGEL. Michigan Tool Co. Detroit 1945 325 p 28 figs 33 refs. Main Table provides columns of the natural trigonometric functions and involute functions conveniently arranged alongside each other. Complete sets of angular conversion tables and involute and cycloid tracing tables followed by other numerical and algebraical tables presenting geometric relations of gear dimensions and gear tooth profiles. Exact step-by-step calculations for measurements of external and internal spur and helical teeth over freely selected balls and pins. Appendix gives a complete system of involutometry, classified as: (1) Geometry and calculations of involutes of base circles and related curves; (2) involutoids, namely surfaces containing a multitude of such curves; and (3) solids bordered fully or partially by involutoids.

Gears, Gear Production and Measurement, A. C. PARKINSON, W. H. DAWNEY, Pitman Publ Corp, New York and Chicago 1948 260 p. Book intended for those in trade who have gear problems, but who have little or no background of basic knowledge of gear forms, and of range of manufacturing and measuring methods; special attention paid to inspection procedure. Eng Soc Lib, NY.

Analytical Mechanics of Gears, E. BUCKINGHAM. McGraw-Hill Book Co. Inc. 1949 546 p. The first chapters give an analysis of conjugate gear-tooth action, nature of the contact, and resulting gear-tooth profiles of the several types of gears. These include spur, internal, helical, spiral, worm, bevel, and hypoid gears. The last chapters give analyses of gear teeth in action including frictional heat of operation and its dissipation, friction losses and efficiencies, dynamic loads in operation, beam strength or resistance of the teeth to breakage and fatigue, surface-endurance limits of materials, and the limiting wear loads or the potential resistance to surface disintegration and excessive wear.

Zahnradgetriebe (Gear Drives), R. RITTER. Verlag Leeman, Zurich, 1950 184 p 49 figs 34 tables 250 refs. Developed in three parts: (1) Assembly of the standard drive with special consideration of the combined drive; (2) tooth forms and tooth corrections,—the 20° standard system, null, V₀, and V (variable center) drives; (3) calculation of gear wheels as to strength and wear life. Devoted to the concepts of the interchangeable manufacture of gear wheels, and tested specifications for the shop drawings and the manufacturing tolerances, in order to meet the requirements of the technical bureaus and the workshops.

Practical Gear Design, D. W. DUDLEY. McGraw-Hill Book Co., Inc. New York 1954 335 p 158 figs. Contents: Gear design trends; preliminary design considerations; design formulas; gear materials; gear-manufacturing methods; design of tools to make gear teeth; the kinds and causes of gear failure; special design formulas.

Métrologie D'Atelier (Workshop Metrology), L. COMPAIN. Editions Eyrolles, Paris 1952 261 p 91 figs bibliography. Chapter 6, Verification of Gears, p 144–92, treats the following subjects: Verification of tooth profile, spacing, tooth thickness and tooth span, eccentricity, distortion; geometrical tolerances of cylindrical gears.

The Barber-Colman Hob Handbook. Barber-Colman Co., Rockford, Ill., 1954 388 p 25 refs. Contains general engineering data, trigonometric and involute relationships, plotting involute tooth profiles and engineering data for fine-pitch gear hobs, spline and serration hobs and cutters, worm and worm gear hobs and cutters, and sprocket hobs and cutters.

Gears, H. E. MERRITT, 3d Ed. 1955 527 p 29 tables 30 charts 32 refs. Sir Isaac Pitman and Sons, Ltd. London. Includes chapters on the geometry of involute spur, helical, spiral, conical involute, bevel and worm gears. Derives formulas for roll diameters and measurements over or between rolls for involute spur gears on p 114–6; also for helical gears on p 149–50.

The Involute Curve and Involute Gearing. The Fellows Gear Shaper Co. 1957. Covers the application of the involute curve to gear teeth; design, cutting and checking of involute gears; definitions of gear-tooth elements, etc.

A Treatise on Gear Wheels, G. B. GRANT. Philadelphia Gear Works, Inc., 20th ed 1958 (copyright 1899) 105 p 169 figs. Subject headings are (1) Theory of tooth action. (2) The spur gear in general. (3) The involute system. (4) The cycloidal system. (5) The pin tooth system. (6) Twisted, spiral, and worm gears. (7) Irregular and elliptic gears. (8) The bevel gear. (9) The skew bevel gear. Presents condensation of geometry which is basic to measurement of gears.

Basic Gear Geometry—Reference Information, ALLAN H. CANDEE, AGMA 115.01 July 1959 25 p 37 figs. Available from AGMA, $1.50. The information presented has been collected and arranged to make the important geometrical relationships as easy to see as possible to provide a sound basis for a thoroughly logical and comprehensive system of gear geometry. A clear and accurate understanding of the elements involved is indispensable to all who deal with the design, dimensioning, cutting, and measurement of gear teeth.

Introduction to the Kinematic Geometry of Gear Teeth, ALLAN H. CANDEE. Chilton Company, Book Division, Philadelphia and New York, 1961 204 p figs refs. Contents: Introduction and general principles; general ideas of tooth design; cutting and generating spur gears; involute teeth and the involute curve; fillet curves; layout and construction of involute profiles, rectangular coordinates; involute racks and involute tooth thickness; changes in center distance in involute gears; geometrical strength factor for spur gear tooth; profile errors, modifications, variations; involute approximations; six tables of involute coordinates, rectilinear and circular with derivations of equations.

Gear Handbook, D. W. DUDLEY. 1962. McGraw-Hill Book Co., Inc. 24 chapters. Presents key information to solve the design of a gear, plan tooling for a gear job, analyze a gear failure, or select an appropriate manufacturing process. Chapter 23 deals with inspection or measurement of the various standard types of gears.

Maag Gear Book. Maag Gear-Wheel Company Ltd. Zurich. Dec 1963 576 p charts figs tables 168 refs. Deals with gear geometry and load capacity, gear drives, gear cutting, gear grinding, inspection of gears, gear materials and their heat treatment, gear dictionary, and bibliography.

Modern Methods of Gear Manufacture. National Broach and Machine Co., Detroit. 3rd ed 1950 revised 1964 164 p 170 figs. See abstract under 12.1.

10.1.3. Numerical Tables

Index of Mathematical Tables, A. FLETCHER, J. C. P. MILLER, L. ROSENHEAD, L. J. COMRIE. 2d ed, 1962. Addison-Wesley Publishing Co., Inc. Reading, Mass. The most complete worldwide bibliography of important mathematical tableworks, systematically referenced, cross-referenced, and abstracted. NOTE: Its standard indication for range and table progress of the entering column, for instance: 0° (0.01°) 60°, was adopted in some descriptions of our lists of numerical tables.

10.1.3.1. Tables for Involute Calculations and Plotting

NOTE: Involute functions are needed for the calculation of the involute (of a base circle), which is the principal part of transverse tooth profiles of most spur gears, helical gears, and other involute screws (including involute worms). Outside of these fields of application the involute functions are still almost unknown, although they had been tabulated in large numerical table works for more than three decades. This justifies a short introductory description (see fig. 1).
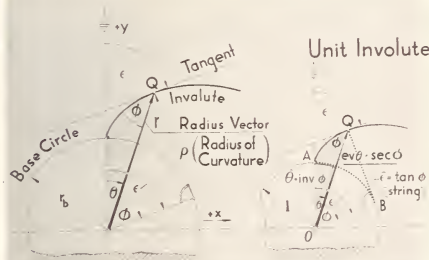
FIG. 1.—INVOLUTE AND UNIT INVOLUTE

θ Polar Angle, ϕ Pressure Angle, ϵ Roll Angle

Line sections, and curve sections of any involute are r_b times their corresponding values of the unit involute.

Authorized reproduction from W. F. VOGEL. "Involutometry and Trigonometry" 1945. Courtesy Michigan Tool Co., Detroit, Mich.

Any single dimension of the unit involute (of base radius "one") determines all of its shown dimensions. For instance:

$$\hat{\theta} = \text{inv } \phi = \tan \phi - \phi = \hat{\epsilon} - \arctan \epsilon$$
$$\text{ev } \theta = \sec \phi = \sqrt{1 + \epsilon^2}$$

Any one of these can be and has been used by different authors as the entering column of numerical tables for the Unit-Involute.

For any other involute (of base radius r_b) Vogel's polar equation of the involute reads simply: $r = r_b \times \text{ev } \theta$

Spur Gears, E. BUCKINGHAM. McGraw-Hill Book Co., New York, 1928. An extensive presentation of theory,

problems, and solutions, particularly about involute gears. Contains probably first extensive table of the involute function: invϕ, namely the polar angle in radians to 6 significant figures (without differences) plotted against the pressure angle 0°0′ (1′) 60°0′.

Laying Out and Checking Involute Tooth Forms, F. W. SHAW. Machy (London) v 35 Jan 2 1930 p. 441–446 and Jan 16 p 513–9 11 figs. For an abstract of the first article see subsection 10.2.6. The second article is also on involute spur gears and gives numerical tables as follows:

Table 1 lists tooth thickness-semiangles of gears (for standard thickness). For details see subsection 10.1.3.3.

Table 2 gives 8-decimal values of the involute's polar angle $\theta = \text{inv } \phi$ [in radians], tabulated against the pressure angle in degrees, namely $\phi = 0°$ (0°.5) 45°. Other columns tabulated alongside list 8-decimal values for arc ϕ, cos ϕ, log cos ϕ, tan ϕ, and log tan ϕ. No differences are given in the table.

Table 3 contains functions for the lay-out of involute teeth using their axis of symmetry as one axis of the rectangular coordinate system, while the other axis passes through the center of the base circle. The table refers to Unit-Involutes of base radius "one" and is immediately usable only for standard-thickness gears (without backlash). The following functions; arc, sin, arc-sin; vers=1—cos and log vers are tabulated at seven decimals (without differences) against their *variable* profile-thickness semi-angle in the range 0°5′ (5′) 15°0′.

Examples for the utilization of the 3 tables for lay-outs and even for calculation of span-measurements are given. The publication is chronologically remarkable for that early date, but the calculations are too cumbersome in the light of more recent and much more convenient numerical tables.

Manual of Gear Design, 3 vols, E. BUCKINGHAM. Publ., by Machy (N.Y.) 1935 v1, Mathematical Tables, contains the following tables: Gear ratios, factors of numbers to 6000; 8-place trigonometric functions: sin, cos, tan, cotan, with differences, plotted against $\phi = 0°.00$ (0°.01) 90°.00; 8-decimal radian table: arc ϕ plotted against $\phi = 0°.00$ (0°.01) 45°; 8-decimal values of inv ϕ, with differences, plotted against $\phi = 0°.00(0°.01)37°.00$, and 7-decimal values of inv ϕ, with differences plotted against $\phi = 37°.00(0°.01)$ 60°.00.

Neue Grandlagen der Evolventenberechnung für die Zahnradtechnik (New Foundations for the Calculation of the Involute in Gear Metrology), W. F. VOGEL. Werkzeugmaschine v40 1936 p 225–31 4 figs 5 refs. Mutual fertilization between theory and practice. Review of previous equations for computation. Additional new equations for establishment of direct relations between the polar coordinates. Introduction of the author's radius vector function, ev θ, leads to his simple polar equation: $r = r_b$ ev θ, (see Fig. 1 at left). Simultaneous representation of the involute functions and trigonometric functions on the unit circle of trigonometry and involutometry. Introduction and significance of the "Compressed Involute." Rectangular coordinates of the involute and of the compressed involute. Applications of the new equations: The base-tooth thickness semi-angle. The addendum of "pointed" teeth. The law of profile thickness variation of involute teeth. Pin-measurement laws for spur gears. Significance of the "involute screw," surprisingly simple equations for its axial section. Summary of existing numerical tables. The article culminates in the demand for the creation of special numerical tables for involutometry and gear metrology. A sample of such a table was shown in the form of a "frame table," and support by the German gear industry for a pertinent project was solicited. (The support materialized immediately and lead to the creation of the Peters Table, 1937, see abstract on next page.)

Neue Zahlentafelwerke zur Evolventenberechnung (New Numerical Tableworks for the Calculation of the Involute), W. F. VOGEL. Werkzeugmaschine v40 1936 p 436. Short supplement to the survey of existing and planned numerical tables, listed in the preceding publication.

Sechsstellige Werte der Kreis- und Evolventen Funktionen (6-place values of circular and involute functions), J. PETERS. Publ. Dümmlers Verlag Berlin and Bonn. First edition 1937, second edition 1951. The Main-Table, planned together by Profs. Peters and Vogel, has the same arrangement as described in Vogel's book (see next description). All columns except those for the polar angle have one decimal less than the Vogel Table; those for the polar angle have even 2 decimals less. Some other tables of PETERS' book are abstracted in subsections 10.1.3.3 and 10.1.3.6.

Involutometry and Trigonometry, W. F. VOGEL. Michigan Tool Co., Detroit 1945 321 p 38 figs 33 refs. Main table provides a conveniently arranged table for trigonometry as well as involutometry. Also presents tables and geometrical relations of gear tooth profiles and gears. Various other tables. Bibliography. The Main Table is a seven-place table, with differences of all six trigonometric functions: sin, cos, tan, cotan, sec, and cosec tabulated for $\phi = 0°.00(0°.01)90°$. The fact that the radians, arc ϕ, are also tabulated alongside, actually provides also the six reversed functions arcsin ϕ, arccos ϕ, arctan ϕ, etc. The addition of (alongside tabulated) columns of the polar angle θ of the involute in degrees and in radians (including difference columns) provides a complete table of the polar angle of the unit involute in the whole possible range. Since all of the mentioned functions (with their differences) are throughout tabulated on two opposite pages of the Main Table, one single opening of this table provides also the roll-angle and the radius of curvature of the unit involute at the selected point and thus all data essential for the calculation of involutes.

Another set of tables, designated as Involute Tracing Tables, provides seven-place polar coordinates and rectangular coordinates of the unit involute, this time tabulated against the polar angle θ as entering column, namely: $\theta = 0°(0°.1)1°$; $1°(0°.25)3°$; $3°(0°.5)20°$; $20°(1°)70°$; $70°(5°)90°$. All other essential values of the unit-involute are again tabulated alongside, while the radians and the six trigonometric functions of the polar angle are listed (alongside) on the corresponding opposite pages. (For abstracts of some additional tables of this book see subsections 10.1.3.3 and 10.1.3.6.)

Gears, H. E. MERRITT. Pittman Publ. Corp., New York. Appendix of second edition, 1946, and third edition 1954 give 7 decimal table, without differences of the polar coordinates of the Unit Involute, tabulating its polar angle in radians against its radius vector: 1.0000 (0.0001) 2.0000. This corresponds to a range of pressure angle from 0° to 60°. The first edition, 1942, gave the same table at only 6 decimals and for a smaller table progress, namely table 1.000 (0.001) 2.000 in the entering column.

The Construction of Large Accurate Involute Curves, C. ATTWOOD. Machy (London) v70 Apr 10 1947 p 374–8, May 29 p 561–4 8 figs. In a coordinate system, having its origin at the initial point of the involute (rather than at the center of its base circle), rectangular coordinates x and y of the Unit Involute are tabulated with differences at seven decimals for $x = 0$ (0.001) 0.500. The tabulated values correspond to a range from 0° up to approx. 20° polar angle or approx. 71° roll angle of the involute. An auxiliary table lists the roll angles in degrees and 2 decimals of the degree tabulated with differences against x, but only in the small range: $x = 0$ (0.001) 0.075.

Involute Rectangular Coordinates, Hogland Eng and Mfg Co., Inc. Berkeley Heights, N.J. 1954. Seven decimal rectangular coordinates of the Unit Involute tabulated, with differences, against the Roll Angle: $0°$ $(0°.01)$ $90°$.

Taschenbuch der Längenmesstechnik (Manual of Length Metrology), P. LEINWEBER. Springer-Verlag, Berlin, 1954 806 p 790 figs. P 733 gives a six decimal table of the polar angle of the involute in radians, tabulated with first and second differences against the pressure angle $10°0'$ $(5')$ $35°0'$.

Introduction to the Kinematic Geometry of Gear Teeth, ALLAN H. CANDEE. Chilton Company, Book Division, Philadelphia and New York, 1961. The appendix carries five-decimal tables of involute coordinates, all for a table progress of 0.001 of the entering column. Tangent values of certain angles, tabulated alongside, are however listed only at 3 decimals. The tables are not only for different coordinate systems but also for different numerical units. Unfortunately the captions of two out of four explanatory illustrations (p 170) refer to the wrong sets of tables. Tables 1 and 4 are for Unit Involutes ($r_b = 1$), with the origins of their coordinates starting at the base circle and coinciding with the initial point of the involute. Table 1 is for rectangular coordinates; its x and y axes are normal and tangential, respectively, to the base circle. Y-values and the tangent of the roll angle are tabulated, without differences, against $x = 0$ (0.001) 0.470. With respect to arrangement and range the table is comparable to that of Attwood (1947), which however does give differences and 2 more decimals. Table 4, headlined "circular coordinates", lists values which are actually truncated polar coordinates of the Unit-Involute. The value "x" is the polar angle θ (according to AGMA-Standards) in radians, while the "y" value is the part of the radiusvector which protrudes outside of the base circle (namely ev $\theta - 1 = \sec\phi - 1$). The polar angles "x" (in radians) and their differences are tabulated against $y = 0$ (0.001) 0.480; this corresponds to a range of the polar angle from 0° to approx. 15°. Tables 2 and 5 (for $\phi_M = 20°$) and Tables 3 and 6 (for $\phi_M = 14\frac{1}{2}°$) are for involute profiles of Pitch Radius One and the shown Main-Pressure Angles, respectively. Tables 2 and 3 list the rectangular coordinates of those involutes in a system, whose x and y axes are tangential and normal, respectively, to the tooth profile at the pitchpoint. The y-coordinates and the tangents of corresponding roll-angle increments are tabulated against x-coordinates: $x_1 = 0$ down to the base circle (inside the pitch circle) and outer coordinates $x_0 = 0$ (0.001) 0.450 [or 0.358] for $\phi_M = 20°$ or $= 14\frac{1}{2}°$, systems, respectively. Tables 5 and 6 list the circular coordinates of the described Pitch Circle One—Involute Profiles for $\phi_M = 20°$ and $14\frac{1}{2}°$, respectively. Their circular coordinates are actually increments of the polar angle "x" (measured in radians from the pitch point) and of the radius vector "y", protruding inside [subscript "i"] or outside [subscript "o"] from the pitch circle. x_1 values are tabulated against y_1 values down to the base circle, and x_o values are tabulated (with their differences) at 6 decimals against their "y_1" or "y_o" values, the latter covering: $y_o = 0$ (0.001) 0.400.

Gear Handbook, D. W. DUDLEY. 1962, McGraw-Hill Book Co., 24 chapters. More than 3 dozen specialists contributed various sections. Names of authors responsible for the numerical tables are indicated below.

Table 7–7 p 7.10 and 7.11, Polar Angle of the involute, M. F. SPOTTS. The polar angle $\theta = $ inv ϕ is tabulated in radians without differences, against the pressure angle: 6 decimals for $\phi = 0°$ (0°.1) 75°; 5 decimals for $\phi = 76°$ (0°.1.82°; 4 decimals for $\phi = 83°$ (0°.1) 87°; 3 decimals for 87° (0°.1) 89°; 2 decimals for 89° (0°.1) 89°.9. (For ϕ greater than 29°, linear interpolation of the table leads to uncertainties larger than 0.5 unit of the last decimal and can lead to intolerable errors in some part of the range.)

Table 24–14, p 24.24 and 24.25, Polar Angle of the Involute, R. T. PARSONS. Seven-decimal table, with differences. $\theta=$inv ϕ (in radians) is tabulated against the pressure angle $\phi=0°$ ($0°.01$) ($40°$). Most of the table is unusable for ordinary (linear) interpolation. (The error caused by such interpolation starts [with more than 0.5 unit of the last decimal] at ϕ larger than 4.8° and grows with increasing values of ϕ.

Table 8–2, p 8.9 and 8.10. Tangent and Normal Coordinates of Involute Curve, E. C. VARNUM. The heading above is misleading, because *only the axes* of each selected coordinate system are tangential and normal, respectively, to the involute of that system. The principle of the axes selection is admittedly the same as that in Candee's, 1961, Tables Nos. 2 and 3 (see above). The x and y axes of the coordinate system are tangential and normal, respectively, to the involute profile at its pitch point, which is determined by its unit pitch radius (one) and by the pressure angle of the selected system (3 systems namely $\phi=14°.5$, 20° and 30°). The y-coordinates of each system are tabulated, at 7 decimals, alongside each other against selected values of x, namely: x=0.500 (−0.01) 0.100; x=10.00 (−0.100) 0.000; x=0 (−0.001) −0.014; and x=0.000 (−0.01) −0.140. (Neither differences nor any of the involute angles belonging to these coordinates are tabulated.)

Table 8–3, p 8.10, Tangent and Normal Coordinates of Circle of Curvature at Pitch Point, E. C. VARNUM. The same type of coordinates as described in Table 8.2 above for the involutes of the 3 systems is now tabulated for their 3 special circles of curvature. Their y-values are tabulated at 7 decimals, without differences, for x=0.200 (−0.01) 0.0120 and for x=0.010 (−0.001) 0.000. Comparison of Tables 8–3 and 8–2 gives a precise picture of the deviation in 3 systems of this special circle of curvature from the corresponding involute shape.

Table 8–4, p 8.12 and 8.13, Tangent and Normal Coordinates of the Involute at Convenient Radii (20° Pressure Angle) E. C. VARNUM. A rectangular coordinate system with the x and y axes tangential and normal, respectively, to the involute profile at the pitch point is also used in Table 8–4, but exclusively for an involute profile of the 20° Mainpressure Angle system. The addition of 2 other columns, also makes this Table 8–4 different from Table 8–2. The entering column is not x but the ratio R/r, in which R is a freely selected radius and r, the radius of the given pitch circle. The coordinate-ratios x/r and y/r are tabulated at seven decimals against the radii ratios, namely: R/r=1.200 (−0.01) 0.940 and R/r=1.020 (−0.001) 0.951. A fourth column lists the polar angle increments (in degrees) to seven decimals, counted from an axis connecting the pitch point of the profile with the center of the base circle. Thus, this column together with the entering column may be considered as a table of "truncated" polar coordinates of the involute. No differences are listed.

Table 8–5, p. 8.14, Involute Polar Coordinates m, D. W. DUDLEY. This table should also be named: "Truncated Polar Coordinates of the Involute". Here, however, the entering column is the polar angle increment, labelled "μ" and counted from the axis connecting the pitch point of the selected involute profile with the center of its base circle. The radii ratios R/r (as explained for Table 8–4) is labelled here "m" and is listed for 3 different involute-profile systems of 14°.5, 20°, and 30° pressure angles. Seven decimal m values, without differences, are tabulated in adjacent columns for the 14°.5, 20°, and 30° systems against the polar-angle increments, in radians, in the range: $\mu=+0.0015$ (−0.0001) −0.0015.

Table 23–1, p 23.3–23.5, Involute Roll Angles, A. S. BEAM. The roll angles, labelled "ϵ_z" of any involute are tabulated against their diameter ratio D_z/D_b, in which the subscripts "z" and "b" refer to any selected involute profile diameter and base circle diameter, respectively. Actually $D_z/D_b=$sec ϕ and ϵ_z (in radians) = tan ϕ mean the radius vector and the roll angle functions of a unit-involute. The roll angles ϵ_z (in degrees to 2 decimals) are tabulated, with differences, against D_z/D_b in the following range: $D_z/D_b=1.0001$ (0.0001) 1.0100; 1.0100 (0.0005) 1.0500; 1.0500 (0.0010) 1.4500. (It appears strange that the ϵ_z-column shows throughout one or two less significant figures than the entering column, but it is even stranger that the difference column, $\triangle\epsilon_z$, shows one more decimal than the ϵ_z column. This means that the printed difference values are not the real differences of the ϵ_z values and therefore worthless for interpolation. Since the late author was known as a perfectionist, his manuscript would not be expected to have contained such discrepancies. Someone else must have cancelled the third decimal of the ϵ_z column and neglected to adapt the difference column to this change.)

Maag, Gear Book, Zurich 1963 by Maag Gear Wheel Company, Ltd. (English language edition of the German issue: MAAG, TASCHENBUCH). Contains an elaborate and complete collection of information on gears, including tables and a gear dictionary. On p 514–6 the polar angle in radians, at 6 decimals is tabulated against the pressure angle: $10°0'(3')34°0'$. For some additional tables see subsection 10.1.3.5.

Machinery's Handbook (USA) 1964 p 270–4 carries a table of the polar angle of the involute [in radians] at 5 significant figures, without differences, namely inv ϕ for: $\phi=14°0'(1')58°0'$.

10.1.3.2. Tables for Uniform Angular Indexing

(See also subsection 10.2.5)

Cumulative errors in precision indexing and its inspection are avoided by starting all angular measurements from one single selected space, (the zero space of reference). Consequently, angular spacing or indexing tables offer precalculated angular values of the form $360°\times n/N$. Herein "N" is the total number of uniform divisions of the circle (i.e. the total number of teeth or the total number of spacings), while "n" (frequently designated as indexing number), is every integer number smaller than "N".

Angular Spacing Tables, W. F. VOGEL. Vinco Corp. Detroit, 1943 233 p. Contains table of the included angle between any point of beginning and any one or more uniform divisions of a circle up to and including 200 divisions. Values of the Main Table are listed in degrees, minutes, and seconds up to the thousandth of the second. Appendix contains tables of fundamental dividing angles 90°/N, 180°/N, and 360°/N, each tabulated in degrees, minutes, and seconds up to 0.0001 units of the second; in degrees and decimals of the degree up to 7 decimals of the degree; and in radians up to 10 decimals of the radian; conversion tables of minutes, seconds, and decimals of a second to 8 decimals of a degree. A collection of important constants gives π and $1/\pi$ to 70 decimals; also, some integer multiples of divisions of π and $1/\pi$ to 35 decimals; also, 35-decimal radian-equivalents of some integer angular degree values and vice versa.

Angular Spacing Tables, W. F. VOGEL. Vols 2 and 3, 1945. Vol. 2: continuation of the Main Table for 201 to 300 divisions. Vol 3: continuation of the Main Table for 301 to 360 divisions. Complete manuscripts of these unprinted volumes are in the hands of the Vinco Corporation, Detroit.

Teiltabellen (Division Tables), CARL ZEISS, Oberkochen. T60–410, 1957. Divisions of circles from 2 to 200 in degrees and minutes and 2 decimals of minutes.

Angular Indexing Tables; numerical tables for dividing circles and establishing rectangular coordinates, J. J. JAEGER, E. E. KIRKHAM, 1959. Publ. by Pratt & Whitney Co., Inc. Provides for dividing a circle into any number of equal divisions from 2 to 210, inclusive. For each division, the necessary angle is tabulated in degrees up to 4 decimals of the degree and alongside in degrees, minutes, and seconds. Also the sine and cosine of each angle are given, which establish 8-decimal rectangular coordinates of the corresponding points on the unit-circle of radius "one."

10.1.3.3. Other Tables for Uniform Subdivision of the Circle

If N is any integral number, the angles 360°/N, 180°/N and 90°/N occur in regular polygons and, therefore, in gears and splines. They are sometimes designated as "Fundamental Dividing Angles". The values 360°/N and 180°/N are also denoted as "Angular Pitch" and "Angular Semi-Pitch", respectively, while 90°/N denotes the tooth thickness semi-angle for such gears whose circular thickness of the teeth is equal to that of tooth grooves at the pitch circle. Numerical tables of these angles and some of their trigonometric functions are listed below:

Angles 360°/N: in degrees, minutes, and seconds:
To 4 decimals of the second: Vogel 1943 p 212–3 for N=1 to 200.
To 1 decimal of the second: Vogel 1945 p 244–5 for N=1 to 300.
Without decimals of the second: Jaeger & Kirkham 1959 for N=2 to 210.

Angles 360°/N: in degrees and decimals of the degree:
To 7 decimals of the degree: Vogel 1943 p 214–5 for N=1 to 200.
To 5 decimals of the degree: Vogel 1945 p 244–5 for N=2 to 300.
To 4 decimals of the degree: Jaeger & Kirkham 1959 for N=2 to 210.

Angles 360°/N: in radians (i.e. 2π/N)
To 35 decimals: Vogel 1943 p 233 for N=1 to 19.
To 10 decimals: Vogel 1943 p 216–7 for N=1 to 200.
To 7 decimals: Vogel 1945 p 244–5 for N=2 to 300.

Angles 180°/N: in degrees, minutes and seconds:
To 4 decimals of the second: Vogel 1943 p 212–3 for N=1 to 200.
To 2 decimals of the second: General Electric Co. Standard Tables Div., Schenectady, Sect. G 902.4 1954 for N=3 to 500.

Angles 180°/N: in degrees and decimals of the degree:
To 7 decimals of the degree: Vogel 1943 p 214–5 for N=1 to 200.
To 4 decimals of the degree: Peters 1937 and 1951 p 186–90 for N=1 to 500.
To 5 decimals of the degree: Vogel 1945 p 217–9 for N=3 to 500.

Angles 180°/N: in radians:
To 35 decimals: Vogel 1943 p 233 for N=1 to 19.
To 10 decimals: Vogel 1943 p 216–7 for N=1 to 200.
To 7 decimals: Vogel 1945 p 217–9 for N=3 to 300.
To 6 decimals: Peters 1937 & 1951 p 186–90 for N=1 to 500.

Angles 90°/N: in degrees, minutes and seconds:
To 4 decimals of the second: Vogel 1943 p 212–3 for N=1 to 200.

Angles 90°/N: in degrees and decimals of the degree:
To 7 decimals of the degree: Vogel 1943 p 214–5 for N=1 to 200.
To 5 decimals of the degree: Vogel 1945 p 250–2 for N=2 to 300.

To 4 decimals of the degree: Peters 1937 & 1951 p 186 for N=1 to 250.

Angles 90°/N: in radians:
To 10 decimals: Vogel 1943 p 216–7 for N=1 to 200.
To 8 decimals: Shaw Machy (London) 1930 p 514 for N=1 to 120.
To 7 decimals: Vogel 1945 p 250–2 for N=2 to 300.
To 6 decimals: Peters 1937 & 1951 p. 186–90 for N=1 to 250.

Trigonometric Functions of 180°/N:
Sin, cos, 1–cos to 7 decimals: Vogel 1945 p 217–9 for N=3 to 300.
Sin, cos, tan & sec to 7 decimals: General Elec. Co. Sect G. 902.4 1954 for N=3 to 500.
Sin and cos to 6 decimals: Peters 1937 & 1951 p 186–90 for N=1 to 500.

Trigonometric Functions of 90°/N:
Sin, cos, 1–cos to 7 decimals: Vogel 1945 p 250–2 for N=2 to 300.
Sin and cos to 6 decimals: Peters 1937 & 1951 p 186–90 for N=1 to 500.

Function N sin 180°/N: Tabulates the "Chordal Pitch" for gears of diam. pitch one:
To 7 decimals: Vogel 1945 p 246 for N=2 to 300.

Odd Numeral Factor: cos 90°/N for odd and integer values of N:
These factors and their reciprocals are needed in pin and ball measurements of gears having an odd number of teeth.

Cos 90°/N to 8 decimals: Van Keuren Handbook, No. 36, 1955 p 130 for N=5(2)201; also for single values N=301; 401, and 501.
Cos 90°/N and sec 90°/N to 7 decimals: Vogel 1945 p 286 for N=3(2)299.
Cos 90°/N to 5 decimals: Buckingham 1928 p 332 for N=1(2)99, and Buckingham 1944 v2 for N=1(2)99.

10.1.3.4. Tables for Pin and Ball Measurements of Involute Spur Gears and Spur Splines

Pin Measurements of Spur Gears, R. TRAUTSCHOLD. Machy (N.Y.) v24 Jan 1918 p 406–9 5 figs. Gives table of sizes of pins used in the measurement of 1 D.P. gears.

Measurement of Gear Wheels with Ball Micrometer, W. H. COWLIN. Machy (London) v15 n389 Mar 11 1920 p 762–3 3 figs. Gives table intended to simplify calculations of distance between centers of balls.

Measurement of Thickness of Involute Gear Teeth, ALLAN H. CANDEE Am Mach v68 n9, 11, and 14 Mar 1, 15 and Apr 5 1928 p 365–8, 463–7, and 573–6 12 figs. Contains tables from which dimension across pins for standard involute spur gears can be obtained easily.

Checking Gear Size by Measurement Over Pins, K. E. BAUERLE. Machy (N.Y.) v44 n6 Feb 1938 p 353–7. Tables simplifying application of this precise and generally available method to external and internal spur and helical gears.

Gauging Involute Teeth or Splines Over Rolls, F. W. HALIS. Machy (London) v78 n2012 June 7 1951 p 952–3. Contains graph and table for selection of roll diameter.

Pin Measurement Tables for Involute Gears (based on 1.728 series of pins), R. E. RAWLING. Am Mach v96 June 23 July 7, 21 Aug 4 1952 10 p. Available from Rawling Gear Works, Inc., Shrewsbury, Mass. For convenience in measuring without calcualtion of dimension over pins, tables cover spur gears with pitches from 3 to 32 DP and ¼ to 1 in. CP, 10 to 120 teeth, 14½ and 20° PA.

Precision Measuring Tools, Catalog and Handbook No. 36. The Van Keuren Co., Watertown, Mass. 1955 258 p. Contains the following tables pertaining to gear measurements: Table 7, p92, gear wire sizes of 1.728, 1.68, and 1.44 diametral pitch for selected pitches from 1 to 200: Table 8, p 95 is a guide to wire selection; Tables 9–18, p 98–115 give measurements over wires and change factors for 1 diametral pitch, standard pressure angles of 14.5, 17.5, 20, 25, and 30°, standard addendum external and internal spur gears, and 2 or 3 wire diameters, 5 to 101 or more teeth. Table 20, p 117 gives wire sizes for circular pitch gears. Tables 23–24 p 125–6 give pin measurements for 20° and 14.5° pressure angle long addendum involute spur gears. Table 26, p 134–5 gives change factors (K) for 1.728 wires used on external helical gears. Table 28. p 143 gives basic pin measurements and change factors for 30° involute splines from 6 to 50 teeth. Table 30, p 146 gives basic pin measurements for serrated shafts (ASA B5.26), 6 to 100 teeth.

Inspection of Fine-Pitch Gears. American Standard ASA B6.11–1956 41 p 27 figs. Publ by ASME, New York. Section 8, Pin measurements of fine-pitch involute spur gears contains 4 tables for external and internal 20° involute spur gears.

American Standard Involute Splines, Serrations and Inspection. ASA B5.15–1960 108 p. Contains extensive data and tabulations relative to measurements over or between pins for space width and tooth thickness for involute serrations and splines and straight-sided serrations.

Vereinfachte Berechnung der Masse fuer die Messung ueber Rollen bei Aussen- oder Innenverzahnungen mit Eingriffswinkel 20° (Simplified calculation of dimensions for measurements over rolls of external or internal gears with 20° angles of pressure), H. BERGMANN. Werkstatt und Betrieb v94 n6 June 1961 p 341–9. Methods are described and their application explained by diagrams, numerical tables, and examples.

Gear Handbook: the Design, Manufacture, and Application of Gears, D. W. DUDLEY. McGraw-Hill Book Co., Inc., N.Y. 1962. Section 24 gives numerical data tables. Table 1 is a guide to wire selection. Table 2 gives gear wire sizes for selected diametral pitches from 1 to 120. Table 3 for external gears 20° pressure angle, and 1 diametral pitch gives measurements over wires and change

factors with 1.728, 1.92, and 1.68 diameter wires, and numbers of teeth from 5 to 201 and 6 finer gears. Table 4 is the same for 14.5° pressure angle. Tables 5 and 6 are similar tables for internal gears. Table 7 is for external gears, 25° pressure angle. Tables 8–12 are auxiliary tables.

AGMA Standard Inspection Pin Measurement Tables for Involute Spur Gears. AGMA Standard 231.52 Dec 1962 18 p. Available from AGMA. Contains 8 tables of pin measurements of 20 and 14½ deg external and internal involute spur gears and long-addendum pinions. The tables and formulas given, as well as the standardization of pin diameters, are for the purpose of simplifying and facilitating the use of pins for measuring the tooth thickness of spur gear teeth. The scope is limited to spur gears coarser than 20 DP.

Machinery's Handbook, 17th ed. 1964 2104 p. The Industrial Press, N.Y. Contains section on checking gear size by measurement over wires or pins, p 845–64. Tables 1–4 give over-wire and between-wire dimensions, respectively, for 1 diametral pitch and 5 standard pressure angles. Table 1 gives over-wire dimensions for 1.728/diametral-pitch wire sizes covering external gears for even numbers of teeth from 6 to 170 and 6 finer gears. Table 2 is the same for odd numbers of teeth from 7 to 171 and 6 finer gears. Table 3 gives between-wire dimensions for 1.44/diametral-pitch wire sizes covering internal gears for even numbers of teeth from 10 to 170 and 6 finer gears. Table 4 is the same for odd numbers of teeth from 7 to 171 and 6 finer gears. Tables 7 and 8 are similar tables for external gears and over-wire dimensions using 1.68/ diametral-pitch wire sizes.

10.1.3.5. Tables for Span Measurements

Tables for Span Measurement of Spur Teeth

All tabulated values are for spur teeth of standard thickness at the pitch circle. All span-dimensions are in inches for diametral pitch one or in mm, respectively, for metric module one. The "selector column" is for measurement closest to the pitch circle. Peters and Vogel tables give additional tables for "more convenient measurement" prepared for "safer feeling" in the measurement of pinions, having small N-values.

Author	Year	Gage system (Pressure angle)	N Total number of teeth	Selector column for number of teeth within the caliper [2]	Span dimension [2]	Span decimals
Taylor Am Mach	1913, v36 p 1071–3	14°.5 18° 20° 22° 30°	10 to 50	X X X X X	X X X X X	5 5 5 5 5
Wildhaber Am Mach	1923, p 552	14.5° 20°	12 to 100 12 to ?	X X		
Buckingham Spur Gears	1928, p 333	14.5° 17°	12 to 100 12 to 96	X X		
Buckingham Manual	1935, v2 p 29	20 22.5 25	12 to 81 12 to 72 12 to 65	X X X		
Peters Sechsstellige	1937 and 1951, p 204–6	14.5° 15° 20°	8 to 250 11 to 250 8 to 250	X X X	X X X	4 4 4
Parkes Machy (London)	1939, p 326–7	14.5° 20°	12 to 110 12 to 81	X X	X X	3 3
Vogel Involutometry and Trigono	1945, p 265	14.5° 20°	13 to 310 9 to 297	X X		
Van Acker AGMA 239.01	1954	14.5° 20°	9 to 134 7 to 133	X X	X X	4 4
Maag Gear Book	1963, p 438–41	15° 20°	5 to 300 4 to 300	X X	X X	5 5
Machinery's Handbook [1]	1964, p 862–3	14.5° 30°	12 to 110 12 to 81	X X	X X	4 4

[1] NOTE: This book also has such a set of tables for enlarged pinions on p. 864.
[2] X means that the table exists.

WILDHABER, Am Mach 1923 v59 p 587 gives a selector table for the 14°.5 (normal press angle) involute system, exclusively, covering N-values and helix angles of 10°; 15°; 20°; 22.5°; 25°; 30°; 45°. (The selector-values are based on the assumption of standard thickness at the pitch cylinder.)

VAN ACKER, AGMA 239.01, 1954 gives a selector nomogram for the 14.5° and 20° (ϕ_n) involute systems, covering N-values and any helix angle between 0° and 45°. The selector values are based on the assumption of standard thickness at the pitch cylinder. He also gives tables of some auxiliary functions for facilitating the final calculation of the helical span-dimension.

MAAG Gear Book 1963 p 442–3 gives 2 selector-nomograms, one for 15° and the other for 20° normal pressure angle system, respectively; both covering N-values and any helix angle between 0° and 45°. By contrast to the two preceding tables, this selector-graph also covers a range of varying modification coefficients featuring deliberately and considerably modified tooth thicknesses. An elaborate system of numerical tables p 444–507 provides auxiliary values facilitating the final calculation of the helical span dimension.

10.1.3.6. Tables Of Base Tooth Dimensions referring to the base cylinder of involute shaped teeth

Base Thickness Semi-Angles and Base Space Semi-Angles. Tables are valid only for gears having standard thickness at the pitch circle. For angles in radians their equations read, respectively:

$$\tau_b = \frac{\pi}{2N} + \text{inv } \phi_M \text{ and } \sigma_b = \frac{\pi}{2N} - \text{inv } \phi_M$$

where ϕ_M is the Main Press Angle (in the plane of rotation) at the pitch circle.

Tables for angles in radians:

To 6 decimals : PETERS 1937 & 1951 p 195–202 for ϕ_M= 14.5°; 15°; 20° and N=1 to 250.

To 7 decimals : VOGEL 1945 p 273–85 ϕ_M=14.5° and 20°; and N=1 to 300.

Tables for angles in degrees; To 5 decimals of the degree :

VOGEL 1945 p 273 to 85 ϕ_M= for ϕ_M=14.5° and 20°, and N=1 to 300.

Tables for Linear Base Tooth Dimensions : in inches for diametral pitch or in millimeters for module one.

To 4 decimals : PETERS 1937 and 1951, p. 191–3, base circle diameters for ϕ_M=14.5°, 15°, and 20° and N=1 to 250.

To 7 decimals : VOGEL 1945 p 273–85. Base radii, base diameters, base tooth thickness and base space. (The latter two dimensions are meant only for gears having standard thickness at the pitch radius.) All dimensions for ϕ_M=14.5° and 20° and N=1 to 300.

Table of Base Helix Angles, MAAG Gear Book 1963 p 444–507. The base helix angles of the 15° and 20° (ϕ_M involute systems) are tabulated in degrees, minutes, and seconds against the pitch helix angles: 0°0′(1′)45°0′.

10.1.3.7. Miscellaneous Gear Tables

Analysis of Stresses, New Departure Engineering Data, General Motors Corporation, 2 volumes, Bristol, Conn., 1946. The second volume gives extensive curves for numerical evaluation of the pertinent Hertz equations for the contact of two solid elastic bodies under compressive force. See also KOZMA etc., 1962, on this page.

The Sevolute, A New Function for Use in Involute Gear Calculations, J. J. WILLIAMSON. The Fellows Gear Shaper Co., Springfield, Vt. 1949. Also Supplements n1

and n2. Tabulates the function sev ϕ=sec ϕ−inv ϕ= evθ−θ at 5 decimals to simplify the problem of calculating 'full-radius' fillets or tips. Geometrical significance is given to the function in the first supplement. The second supplement discusses the sevolute and the "extended sevolute" in connection with pin measurements of gears and splines.

Calculation of Testing Center Distance, J. L. WILLIAMSON. Pub Fellows Gear Shaper Co., Springfield, Vt., 1957. Six decimal values of polar-angle deviations $\triangle$(invϕ), (differences $\triangle$invϕ=invϕ_{nom}−invϕ_{actual}) are tabulated for varying ratios $\cos\phi_{actual}/\cos\phi_{nominal}$; also printed with six decimals in small tables headlined each by a constant nominal pressure angle. From table to table the headlined (nominal) pressure angle changes: $\phi_{nominal}$=13° .0-(0.1) 24°.1. The tables are valuable for fixture-setup and/or for numerical evaluations of gear testing by rolling fixtures employing master gears.

Tables for Calculating the Compressive Surface Stresses and Deflections in the Contact of Two Solid Elastic Bodies Whose Principal Planes of Curvature do not Coincide, A. KOZMA, H. CUNNINGHAM. Industrial Mathematics, Detroit v12 1962 p 31–40. The tables, based on the pertaining theory by Heinrich Hertz, are intended to facilitate the use of his equations. In that respect they may be particularly valuable for numerical computation of the influence of surface deformations on the results of pin and ball measurements of precision-screws, gears, and worms. Simultaneous stress analysis could benefit from the establishing and/or standardization of load limits for these measurements.

Table of Diametral Pitches and Modules with the Corresponding Pitches and Base Pitches, Maag Gear Book 1963 p 39–41. The circular pitch and the circular base pitch are tabulated each in inches and in mm against two entering columns, giving in "bold face" standardized values of the diametral pitch or the metric module, respectively. The values for the base pitches are printed for the 15° as well as for the 20° involute spur gear system. All dimensions are given to 5 or 6 decimals.

10.1.4. Technical Papers on Gear Measurement, General

A Spur-Gear Anglemeter, W. M. WILSON. Am Mach v28 Apr 13 1905 p 479–82 3 figs. An illustrated description of an instrument designed for determining the variation in the angular velocity ratio of gears, explaining its use.

Gaging and Inspecting Gears, D. T. HAMILTON, Machy (N.Y.) v23 Apr 1917 p 679–88 25 figs. Good discussion of fixtures for testing pitch, pitch diameter, tooth shape, tooth thickness and concentricity with photographs and illustrations. Subjects taken up in detail are : Inspecting gear blanks; templets for gear blanks, bevel protractor for testing bevel gear blanks, gear tooth templets and calipers; tolerances for bevel and spur gears; testing center distances, pitch diameter and concentricity of spur gears; fixtures for testing pitch diameter, concentricity, thickness of spur gears, transmission gears and pinion shafts; testing bevel drive gears and spur gears for noise under load; testing bevel drive ring gears; fixture for testing involute curve of spur gear teeth; testing ground faces of bevel ring gears, testing fixtures for steering worm sectors.

Backlash in Gearing and Methods of Its Measurement. Automotive Indus v42 May 6 1920 p 1058–60. Shows that some backlash is necessary to provide free action between teeth. Describes and illustrates methods of measurement.

Inspection of Involute Spur and Helical Gear Hobs, C. G. OLSON. Machy (N.Y.) v20 Sept 1921 p 11–13, Oct 1921 p 138–40; Machy (London) v19 p 90. Testing the accuracy

of hob and tooth parts, hobbing test, involute test, jump test, roll test, and three tables of base circle disk diameters.

Inspection of Mill Reduction Units, R. H. RAUSCH. Iron Age May 25 1922 p 1440–2. Testing of tooth shape, checking helix angles, shaft alinement and other points.

Testing Gear and Gear-Cutter Teeth, R. E. FLANDERS. Machy (N.Y.) v28 June 1922 p 817–9 6 figs. Description of screw-thread comparator for quickly detecting imperfections. (Abstract.) Paper read before AGMA convention. Adaption of Hartness comparator for inspection of gear cutters, testing uniformity of form cutter teeth, testing accuracy of a hob, method of projecting and testing gear shaper cutters, method of testing spur gears.

Some Causes of Gear-Tooth Errors and Their Detection, K. L. HERRMANN. SAE J v11 Nov 1922 p 391–7 14 figs. Discusses different gear noises, gives examples of defects that cause noise, and describes device for checking tooth spacing; also instrument for analyzing tooth forms that produce noises.

Quality Control in Gear Manufacture, S. O. BJORNBERG. Machy (N.Y.) v29 Apr 1923 p 623–6 7 figs. Equipment employed for inspecting hob, hobbing machine, and finished gear. Fig 1, machine for testing the profile of hob teeth. Fig. 3, machine for testing the correctness of lead, by comparison with a master screw, and concentricity of cutting edges. Fig. 6, fixture for checking the radial height and the face of teeth on resharpened hobs.

Zahnräderprüfung (Gear Testing), M. KURREIN. Werkstattstechnik v17 Apr 15 1923 p 225–32 29 figs. Describes various types of testing apparatus.

The Gaging of Involute Threads, H. E. MERRITT. Machy (London) v22 Apr 5 and 19 and July 26 1923 p 11–13, 79–81 and 525–8 13 figs. Apr 5 and 15: Gaging straight-spur teeth by tooth caliper, and by plug or wire method. July 26: Geometry of finished-ground worm thread; fundamental dimensions; application of some of the properties of thread surface to gaging problems. See also p 191, 210, 251, 275, 307, 376, 475, and 569.

Gear-Measuring Machine. Eng v116 July 27 1923 p 104–9 28 figs. Gear-measuring machine designed and constructed at Nat. Physical Laboratory, for measuring individual specimens, such as spur and helical, plain and spiral bevel and worm wheels, and for recording errors in running of combined gears.

Gear-testing Machine at the National Physical Laboratory. Machy (London) v22 Aug 2 1923 p 579–83 8 figs. Elements in gear teeth; wheel clamps; use of machine for straight spur gears; helical and bevel gears.

Zahnräderprüfung und Sonderherstellung (Gear Testing and Special Production), A. STEINLE. Werkstattstechnik v18 Mar 15 1924 p 169–73 22 figs. Optical testing methods and instruments.

Wickman Gear Measuring Machine. Engr v138 Sept 5 1924 p 272–3 4 figs; Automobile Engr v15 Jan 1925 p 25–6 3 figs. Designed to differentiate between errors of spacing and errors of concentricity and parallelism.

Société Genevoise Gear Testing Machine. Am Mach v61 Oct 16 1924 p 635 2 figs.; Machy (London) v24 1924 p 831; Eng Production v7 Nov 1924, p 317–8 4 figs. For testing pitch, eccentricity, and tooth profiles of gear wheels. May be used on bevel and helicoidal gears, and spur gears with straight or helical teeth.

Universal Gear Testing Machine, F. JOHNSTONE-TAYLOR. Machy (N.Y.) v31 Dec 1924 p 289–91 7 figs. Machine developed under the direction of G. A. Tomlinson

by NPL of Great Britain which may be used for any kind of gear and for recording errors in running of meshed gears.

Steel Tapes for Measuring Large Diameters, G. C. REILLEY. Am Mach v62 Jan 1 1925 p 26. Used for testing outside diameter of gears for turbine reduction-gear sets. Machine for measuring tapes also described.

Measuring Gear Teeth, J. L. WILLIAMSON. Am Mach v63 Oct 15 1925 p 609–12 7 figs. Points out that to check eccentricity, points of contact should be as near as possible to ends of teeth; to check spacing, points of contact should be near pitch circle; comparative readings cannot be obtained on different testing fixtures unless diameter of ball and pressure angle of rack tooth is same on both machines.

Testing Spur and Helical Gears or Cutters. Machy (N.Y.) v32 Jan 1926 p 382–3 4 figs. Describes two machines used in tool room of Maxwell Motor Corp., Detroit, Mich., for determining accuracy of spur and helical gears and gear-shaped cutters; how test is made; using machine as comparator; checking spacing and concentricity of teeth; using optical micrometer.

Measuring Inaccuracy in Gear Teeth, J. L. WILLIAMSON. Can Machy v36 July 29 1926 p 15–7 7 figs. Discusses common errors in checking inaccuracies in gear tooth form and spacing and describes simple methods of determining errors. Paper read before Am. Gear Mfrs. Assn.

Machining and Measuring Gear Teeth, E. BUCKINGHAM. Am Mach v66–67 May 26 June 9, 23, July 7, 14, Aug 11, 18, 25, Sept 15, 29, Oct 20, 27 and Nov 10 1927 p 879–82 969–72, 1051–4, 7–10, 49–52, 233–7, 265–9, 313–6, 419–22, 497–8, 617–20, 657–9, and 733–6 83 figs.

Accuracy in Gear Teeth. Automobile Engr v18 Apr 1928 p 136–8 8 figs. Maag method of measuring along common normal between successive tooth faces; routine testing of pitch and profile; instrument gives direct indication and record of departure of actual tooth profile from true theoretical involute; checking backlash between pair of gears; testing gears for concentricity.

Illinois Universal Hob and Worm Testing Machine. Am Mach v68 June 28 1928 p 1068–9. Head arranged to test the lead, the pressure angle, and the contour of the teeth in both straight and helically fluted hobs, and of corresponding parts of worm threads. Will also test the concentricity of the relief clearance of hob teeth, and the spacing of threads or starts in multiple threaded hobs and worms.

Société Genevoise Gear-Testing Machine. Machy (N.Y.) v35 Oct 1928 p 147–8 3 figs.; Automotive Indus v59 Dec 8 1928 p 842 1 fig. Am Mach v69 1928 p 558. Gear-testing machine designed for quick inspection of gears for errors in pitch, concentricity, and tooth profiles, developed by Soc Genevoise Instrum Phys Geneva, Switzerland, is described.

A Gear Cutter Comparator, S. TRIMBATH. Am Mach v75 p 296 Aug 20 1931 2 p 2 illus. An arrangement whereby the rack angle can be determined from a given pitch circle and the involute. Discussion by F. W. SHAW. Am Mach v75 p 803 Nov 26 1931 1 p 1 illus. Cutter rolls in relation to steel tapes upon its base circle instead of upon its pitch circle; pressure angle is zero and angle of testing rack tooth zero; device utilized also for testing accuracy of tooth spacing. Further discussion by S. TRIMBATH. Am Mach v76 p 229 Feb 18 1932 1 p 2 illus. Author further describes and defends his design.

Zeiss Gear Testing Machine, Geo. Scherr Co. Inc. N.Y. Am Mach v76 Feb 11 1932 p 218. Measuring precision to 0.0001 in. combined with rapid operation are features of this instrument. The gear tester will take spur, bevel,

helical and worm gears and test the following elements: circular pitch, eccentricity, uniformity of tooth spaces, and uniformity of tooth thickness. The gear is placed between centers, where it can be revolved to bring successive teeth into position.

New Methods of Inspecting Gears for High-Speed Transmission, D. T. HAMILTON. Machy (N.Y.) v38 Aug 1932 p 932–8. Procedure followed in checking spur, helical, and herringbone gears for shape, spacing, pitch diameter, and eccentricity on machine designed by Fellows Gear Shaper Co., Springfield, Vt.

Fellows Gear Measuring Machine, Am Mach v76 Aug 3 1932 p 920. Various elements of a gear tooth that can be checked on this machine are: involute profile or shape, circular pitch, pitch diameter and eccentricity; also the lead or corresponding helix angle on helical gears, guides, and the helically splined members. The column is positioned by gage blocks. Work is held on a vertical arbor. The fixture, which carries the dial indicator and the various inspection units, can be moved about on the table. This machine has a capacity for measuring gears from 2 to 7 in. pitch diameter.

Pruefen von Zahnraedern (Testing of Gears). Maschinenbau v12 n1¾4 July 1933 p 361–2 4 figs. Testing of gears; outline of test with regard to division, thickness of tooth, true running, engagement axle distance, involute curve.

Gear Shaper As Inspection Tool, S. TRIMBATH. Am Mach v77 n17 Aug 16 1933 p 517–21. No. 6 Fellows gear shaper can be used in checking accuracy of spur and helical gears and also spur and helical cutters; machine had been replaced by No. 7 high-speed gear shaper for cutting purposes and then converted into measuring machine at nominal cost.

New Lees-Bradner Gear Tester. Iron Age v133 p 33 Feb 1 1934 1 p 2 illus. Gear tester will check tooth contour, arc of action, length of line of action, tooth to tooth spacing, cumulative error and eccentricity of both spur and helical gears.

Methods for Checking Gears, D. T. HAMILTON, R. BEARDSLEY. Iron Age v136 n3, 5 July 18 1935 p 14–7, 92 and 94 and Aug 1 p 20–2 and 94; Steel v97 n3 July 15 1935 p 32–5 and 67. Principal requirements to be considered in production of accurate gears; devices for checking individual gear-tool elements illustrated and described; automatic inspection of all errors in combination, by means of recording machine. Before Am Gear Mfrs Assn.

Messverfahren und Messgeraete der Zahnradfertigung (Measuring Methods and Equipment of Gear Finishing), H. GREGOR. Maschinenbau v15 n½ Jan 1936 p 17–21. Measuring methods and equipment in manufacture of gears; reference to paper by A. SODEN indexed in Engineering Index 1933 p 532 from VDI Zeit Mar 4 1933 on noise in gears; measuring equipment used for this purpose is described by present author.

Zahnradpruefung (Gear Testing), G. ZIEHER. Werkstattstechnik und Werksleiter v31 n3 Feb 1937 p 49–53. Practical article on various methods of testing of gears with respect to isolated flaws, impact failures, thickness and width of teeth; testing of pins; overall tests.

Fehlerpruefung bei Zahnraedern (Error Testing of Gears), R. BOCK. VDI Zeit v81 Feb 27 1937 p 267–72. Testing methods and equipment are described and analyzed.

Testing of Gears for Errors, R. BOCK. Eng Progr v18 n9 Sept 1937 p 197–202. Notes on design and preliminary operations, machine and tools, hardening, drawings, bores

and splineways, number of testing instruments required, checking for centricity, pitch and tooth thickness, tooth form; axle spacing and engagement conditions of meshing gears.

Grundlagen der Pruefverfahren fuer gerade Zahnraeder mit Evolventenverzahnung (Testing Method for Involute Spur Gears), G. BERNDT. Werkstattstechnik und Werksleiter v31 n23 Dec 1 1937 p 522–34. Extensive treatise on principles of various measuring methods and equipment and their application; methods developed may be applied to other forms of gears.

Quiet Gears, S. O. BJORNBERG. Steel v102 Feb 7 1938 p 46–50. Accuracy in gear teeth is real answer to quietness, and correct inspection methods are means of obtaining such accuracy; describes inspection methods of testing machines manufactured by Illinois Tool Works for involute profile, tooth spacing, composite errors, and lead of spur or helical gears.

Slide Rule for Variable-Center Distance System Gears and Measurement of Amount of Profile Shift, T. NAKATA. Soc Mech Engrs Japan Trans v5 n21 Nov 1939 p IV–41–9. Slide rule devised for computing center distance and other dimensions of pair of involute spur or helical gears; giving number of teeth and amount of profile shift; using such method, further generalization of variable center distance system is developed; amount of profile shift in such gear, of which tooth proportion is unknown, can be estimated by roller method. (In Japanese.)

Pruefen von Innenverzahnungen auf der Bearbeitungsmaschine (Testing of Involute Internal Gears on Production Machine During Manufacture), P. KLUWE. Maschinenbau v19 n11 Nov 1940 p 477–9. Illustrated description of special measuring methods and gages employed for this purpose; determination of nominal and actual dimensions.

Adaptable Gear-Testing Machine. Machy (London) v57 Feb 27 1941 p 599 3 p 3 illus. Description of machine manufactured by Monarch Tool Co., Huddersfield, designed for testing spur, helical, bevel, spiral and worm gearing; suitable for either laboratory or shop use; gears tested by rolling together thereby eliminating many individual measurements; simple and easily mounted attachments enable whole range of gearing specified to be tested.

Instrumentation at Nuttall Gear Works. Instrum v14 n5 May 1941 p 117–20. Pictorial presentation of instruments ranging from simple gages to control systems and uses from intermittent single measurements to continuous autographic tests and automatic control.

Gear Inspection Methods, D. T. HAMILTON, Iron Age v148 n16 17 Oct 16 1941 p 29–34 and Oct 23 p 38–44. Methods of measuring individual tooth elements, like tooth shape, tooth spacing, tooth thickness and eccentricity, are discussed; how gear errors may be checked in combination; factors causing gear noise analyzed; use of helical gears is solution to noise problem and calls for special checking apparatus; importance of tooth bearing is emphasized.

Measurements of External and Internal Helical Involute Gears, H. PELPHREY. Tool Engr v11 n4 Apr 1942 p. 64. Simplified method for calculating proper dimensions where accuracy is vital. Compiler's comment : The method is based on strict geometry and on exact equations for the ball measurement of involute screws which are, however, not simpler than Vogel's (1937) in subsection 9.3. It permits free ball selection and most of its equations could be applied unchanged to more easily executed pin measurements of these products. [e.g., Candee (1928) and Vogel (1945) in subsection 9.3].

Why Does a Gear Sing? How Can Singing be Avoided? A. MEHDAHL. Brown Boveri Rev v29 n9/10 Oct/Sept 1942 p 284–9. Results of measurement on large helical gears; pitch of note; shadow lines; table drive measurement.

Measuring Errors in Involute Spur Gears, S. CORNELL. Iron Age v153 n12 Mar 23 1944 p 68–73, 144. In order to set up measuring standards for spur gears, author presents picture of ideal gear which has no errors and using this imaginary gear as reference point, presents general classification of spur gear errors and outlines method of recording and evaluating deviations.

Improved Gear Tooth Vernier. Passenger Transport J v91 n2305 Sept 8 1944 p 129–30; Transport Wld v96 n3073 Sept 14 1944 p 226. Illustrated description of simplified type developed by David Brown & Sons (Huddersfield) Ltd; instrument has advantage of only requiring setting to linear dimension between fixed and moving anvils; measurements are over number of teeth and, as anvils are tangent to tooth flanks definite "feel" is obtained as in using micrometer on cyclindrical object, no height measurement being involved.

How to Improve Accuracy and Efficiency in Measurement and Testing of Gears, K. BUERGER. Engrs' Digest (Brit Ed) v5 n9 Sept 1944 p 275–9; Engrs' Digest (Am Ed) v1 n11 Oct 1944 p 637–41. Illustrated description of methods and equipment for testing form of teeth; testing surface of flanks; testing circular pitch and chordal pitch; thickness and width of teeth, and width of space; parallelism of teeth; testing with regard to collective defects. English abstract from Maschinenbau (Betrieb) v22 n3 Mar 1943 p 101–7.

Recent Developments in Gear Inspection Methods, D. MONCRIEFF. Instrum v19 n 10 Oct 1946 p 586–8. Methods of producing accurate gears that are quiet and smooth running; problem of heat treatment distortions, checking tooth profile, hob contour checking; tooth spacing tests; helical gear lead and spur gear tooth alignment check; hob lead checking; size and concentricity; speeder test.

Profile and Surface Analysis. Aircraft Prod v8 n97, 98 Nov 1946 p 509–12, Dec p 557–60. Nov: Napier technique of checking gear teeth by combination of mechanical and optical magnification described. Dec: Some variants of method as applied to surfaces of certain other components, including valve sleeves, are dealt with.

Measurement of Errors in Gears for Turbine Reduction Drives, C. TIMMS, Instn Mech Engrs Proc v157 (War Emergency Issue n35) 1947 p 418–32 (discussion) 432–51, 2 supp. plates. Review of work carried out at National Physical Laboratory in development of methods for measuring errors of large gears for turbine reduction drives by means of series of portable instruments; relationship between errors and inaccuracies of gear hobbing machines and gears cutting holes; methods of determining inaccuracies.

Practical Design of Gears and Gear Cutting Tools, H. PELPHREY. Michigan Tool Co., Detroit, Michigan 1947 31 p 50 figs. Gives analyses of gear design based on both the involute system and straight-sided spline section. Includes a set of exact equations for measuring involute spur and helical gears using balls or pins.

Contrôle des Engrenages à Denture en Développante (Gaging of Involute Gear Teeth), C. MACABREY. Pratique Indus Mecaniques v30 n1 Jan 1947 p 3–11. Method based on characteristics of development of circle and simple formulas; derivation of formulas applicable to any arc.

Inspection of Helical Involute Gear, W. H. WITTRICK. Instn Engrs Austral J v19 n2 Feb 1947 p 43–4. Inspection

of gear for aircraft supercharger drive; data on inspection device used for determination of distance from axis where ball should seat and of tolerance on dial gage reading for any given tolerance in tooth thickness.

Some Gear Cutting Inaccuracies and Their Effect on Gear Loads and Gear Noises, S. F. DOREY, G. H. FORSYTH. North East Coast Instn Engrs & Shipblds Trans v63 pt6 Apr 1947 p 267–330, (discussion) pt 8 July p D183–D208. Study of causes underlying gear failures; measurement of magnitude of errors in gear hobbing machines; gaging of errors in finished gears; measurement of undulations along tooth flanks; equipment and apparatus used; tooth form errors.

Equations for the Normal Profile of Helical Gears, A.F. ZAMIS. Am Mach v91 Sept 25 1947 p 82–4 4 figs. Derives equations for the normal section of an involute helicoid for application in checking the profiles of large heavy gears and in verifying the operation of standard involute machines on smaller machines. From the equations rectangular coordinates of the normal section may be calculated. See also PERES (1959) and WATERS (1961), both on p. 227 in this subsection.

Gear Tooth Inspection Method As Index of Performance, L. D. MARTIN. Prod Eng v19 n2 Feb 1948 p 87–9. Elements that constitute good spur gear and fundamental principles of involute curve outlined; analysis and interpretation of inspection data obtained by pin measurement method and master gear or rack method of checking accuracy of gear tooth elements.

Le Contrôle des Engrenages (Gear Measurements), M. WOLPER. Rev Universelle des Mines v91 n2 Feb 1948 p 196–205. Testing methods and apparatus described and illustrated; results tabulated.

Comparator Chart Layout Checks Involute Gears, F. E. BROWNING. Am Mach v92 n11 May 20 1948 p 89–92. Quick, accurate checking of involute gears is done on comparator with master chart laid out by calculating points outlining tooth profile; advantages of optical projection; method is illustrated by calculation worked out for gear having following specifications: 20° full depth spur gear, 30 teeth, 8 diametral pitch, 3.750 in. pitch diam and 4.000 in. basic outside diam.

Measurement of Periodic Errors in Gear-Hobbing Machines, C. TIMMS, A. A. KING, L. E. JEANS. Eng v166 n4315 Oct 8 1948 p 337–40. Record of latest form of G. A. Tomlinson's instrument and method for measuring errors of controlling movement of hobbing machines while in motion; equipment consists of notched disk which actuates microswitch and impulses from "make and break" are recorded by piezoelectric record cutter on smoked plate carried slowly round on machine table.

Helical Gear Nomograph, W. A. RING. Prod Eng v20 n11 Nov 1949 p 159. Chart giving center distance and normal pitch from helix angle and number of gear and pinion teeth.

Autographic Recording of Errors in Gear Hobbing Machine Tables, C. TIMMS. Machy (London) v76 n1947 Feb 16 1950 p 237–41; Engr v189 n4909 Feb 24 1950 p 251–3; Eng v169 n4390 Mar 17 1950 p 307–8. In investigation, table movement is linked to rotation of hob spindle by means of friction drive, any variation in relative movement being amplified electrically and recorded autographically on chart paper; results of measurements on commercial gear hobbing machines and on Pfauter gear hobbing machine, type R.S.00, are plotted on charts. Communication from Nat Physical Laboratory.

Hob Flank Angle Measuring Machine. Engr v190 n4932 Aug 4 1950 p 131. Machine developed by Coventry Gauge

and Tool Co for checking by direct measurement form of involute helicoids and other helicoids straight sided in normal or axial planes; indicator is mounted on pillars on which it is adjusted vertically for setting stylus to correct plane by means of standard height block.

Analysis of Gear-Tooth Undulation Records, P. M. GILET. Eng v172 n469 Sept 21 1951 p 373–6. Method used in testing turbine reduction wheel; appendix gives modification of undulation in recording; diagrams.

Pin Measurement of Face Gears, J. SILVAGI, V. FRANCIS. Am Mach v96 May 12 1952 p 183–7 4 figs; Van Keuren Catalog and Handb n36 1955 p 248–50 2 figs. Describes method of measuring the tooth thickness of a face gear by measuring over a single cylindrical pin placed in a tooth space to some locating plane such as the back mounting face of the gear. A pin will rock in the same manner as a pin in the space of a helical gear.

Analytical Gear Checking. Illinois Tool Works 1954. Discusses lead, involute, spacing, and composite checks.

Geometry of Involute Helicoidal Hob and Gear Teeth, N. J. C. PERES. Austral J App Sci v5 n4 1954 p 309–29 1 fig. 9 refs; v10 n1 1959 p 17–24 1 fig 4 refs. In the 1954 paper the geometry of the involute helicoid is treated quite generally in terms of familiar gear parameters. It is shown how the radius of curvature of the axial section becomes very large when the pitch helix angle is large, and in the particular case of hob threads with helix angle approximately 87°, the axial section becomes practically straight sided. The coordinates of any point on the curve of intersection of a plane normal to the pitch helix and the surface have been derived. These enable the theoretical normal section of an involute worm or helical tooth flank to be plotted for comparison with the normal profile as traced out on a smoked glass plate by the pantographic technique of measurement. The equations for various other sections of the surface, often given in texts without adequate proof, follow immediately from the general treatment. In the 1959 paper entitled "Involute Gear Geometry" the vector treatment has been extended from the particular to the general case along similar lines to include every tooth and space in any gear. The general geometry holds for internal as well as external spur and helical gears, and particular properties follow from the general treatment. See also PERES (1959) in subsection 10.1.4, p 227.

A Precise Technique for Accurate Checking of Gear Dimensions, W. S. TANDLER, AGMA 239.02 Oct 1954. Describes Probograph method. The Universal Probograph consists of a base unit, an automatic rotary head, tailstock, a probing head for longitudinal, transversal, and vertical measurements, and additional units including one for automatic stationing and a reciprocating stylus unit especially for gear measurements. May be used for several types of gears for all gear dimensional characteristics.

Measurement of Gears, C. TIMMS. Eng v178 n4638 Dec 17 1954 p 789–92 (Editorial comment) p 779. Instn Prod Engrs J v34 n12 Dec 1955 p 792–801 (discussion) 801–4. Existing methods of gear measurement and various measuring machines in use; recent developments and possible future trends; establishment of unified system of pitch tolerances based on results obtained from comprehensive series of pitch measurements, proposed. From paper before Brit Gear Mfrs Assn.

Checking Accuracy of Gears. Eng v179 n4643 Jan 21 1955 p 85. Machine made by David Brown Tool Co for checking concentricity, tooth contact center distance and tooth thickness of internal and external spur and helical gears; machine will accommodate spur gears up to 24 in. in diam.

Examining Machined Surfaces by Interferometry, J. DYSON. Eng v179 n4696 Mar 4 1955 p 274–6. Interferometer microscope applied to study of experimental double helical pinion to investigate differences in surface finish produced by hobbing and by shaving; overall profile of tooth surface is much improved in smoothness by shaving, but fine surface structure is made considerably worse.

Gear Gaging Goes Automatic, T. S. GATES. Tool Engr v36 n5 May 1955 p 95–9. Application of automatic, in-process inspection to gears; requirements of automatic gear gages and their function; basic factors of gear gages and their application; sound testing of gear; future of automatic gear gages.

Selecting Effective Gear Inspection Methods, F. BOHLE. Tool Engr v34 n6 June 1955 p 111–4. Determination of most economical checking procedure; functional gear checking; values for runout listed, with tolerances grouped according to pitch, pitch diameter and speed range; advantage of analytical comparators; other gear inspection procedures.

Der Einfluss von Werkstoff, Maschine und Werkzeug an die Oberflächenguete der Zahnflanken (Influence of Material, Machines, and Tools on Surface Quality of Gear Teeth), W. HAGEN. VDI Zeit v97 n25 Sept 1 1955 p 849–59, Sept. 21 p 956–62. Test method and surface roughness of tooth surfaces; photomicrographs.

Messen der Verzahnungen an grossen Raedern, E. WAGNER, K. H. WEBER. VDI Zeit v98 n8 Mar 11 1956 p 304–8. Measurement of large gear teeth, survey of development of measuring methods and instruments in Germany and other countries.

Production and Metrology of Gearing, R. L. COWEE. Inspection Engr v20 n5 Sept–Oct 1956 p 98–103. Elementary design principles of involute gearing; production process on shapers and hobbers; preparation of gear blanks and production of gears; errors in machines and tooling and their results on gears produced; hand measuring tools; instruments and machines available for gear metrology.

Methods of Specifying Precision of Spur Gears, G. W. MICHALEC. Prod Eng v27 n12 Nov 1956 p 135–42. Analytical and functional methods of specifying gear size and tolerance, including: over-pins measurements; vernier gear tooth measurements; block gaging methods; Am Gear Mfrs Assn and modified methods; converting from one system to another.

Tooth Gearing and Research, S. A. COULING. Engr v202 n5266 Dec 28 1956 p 915–8. Attempt made to stimulate interest in research, with view to remedying some of present defects; fundamental and applied research; tooth measurement, lubrication and other problems requiring research.

Vereinfachte Berechnung von Messweiten fuer aussenverzahnte Gerad- und Schraegzahnraeder mit Evolentenzaehnen (Simplified Calculation of Measuring Width Standards for Externally Toothed Straight and Helical Gears with Involute Teeth), H. HARTSCHEN. Werksstatt und Betrieb v90 n3 Mar 1957 p 187–90: Methods for determining standard measuring width of O-type and V-type gears with or without flank and radial clearances, formulas and tables.

Surface Roughness of Large Gear Wheels for Ship's Turbines, W. DE BRUIN. Ingenieur v69 n3 Aug 16 1957 p W115–8. Application of interference microscope with immersion cuvette for measuring surface roughness of tooth flanks; study was made in connection with installation of new gear hobbing machines in plant of N. V. Koninklijke Maatschappij "De Schelde" at Flushing; relatively small roughness found which compares very favorably with that shown in previous tests (in English).

Equipment for Testing Involute Gears, E. SCHULTHESS. Microtecnic v12 n1 Feb 1958 p 1–7. High accuracy instruments for measuring distance between centers and for checking true running; single flank rotary type instruments; equipment for pitch measurements; instruments for testing gear flanks; device for measuring angle of tooth; micrometers for chordal measurements; compound and universal types of instruments; testing equipment for bevel gears.

New Hope for Angular Accuracy in Precision Gear Trains, F. FREUDENSTEIN. Prod Eng v29 n23 June 9 1958 p 70–71. Four equations are offered for measuring angular errors in gearing, where suitable inspection methods are lacking; besides predicting magnitude of error, equations indicate corrective measures for eccentricity, wobble, profile errors and thickness and pitch errors.

Measurement of Large Gears, C. TIMMS, Inst Mech Engrs (Advance copy July 28 1958). Discusses surface finish of gear teeth; adjacent, short span, and cumulative pitch errors; tooth lead or helix angle; tooth profile; and gear hobbing machine errors: 29 refs.

Probleme der Grosszahnradmessung (Problems in Measurement of Large Gears), A. BUDNICK. VDI Ber v32 1959 p 57–67. Two most important questions are stated to be those of stability and accuracy of test instruments; survey of English and German measuring methods and devices, accompanied by illustrations. 23 refs.

Die theoretische Grundlage fuer die Pruefung von Kegelraedern (Theoretical Principles for Testing Bevel Gears), G. ZIEHER, VDI Ber v32 1959 p 89–98. Straight bevel gear and its manufacture; measurement of tooth profiles.

On the Difference between the Normal Plane Helical Gear Profile and the Virtual Spur Gear Approximation, N. J. C. PERES. Australian J. App Sci v10 n1 1959 p 17–24 1 fig 4 refs. Helical involute gears are sometimes milled with rotary cutters or ground with formed grinding wheels, whose form corresponds to the tooth space profile of an imaginary "virtual" or "equivalent" involute spur gear in the plane normal to the pitch cylinder helix. The present paper gives equations for the difference between the profile so produced and the correct normal plane profile and shows that in some cases the approximation is not sufficiently accurate. See also PERES paper (1954) p. 226; ZAMIS (1947) p. 225 and WATERS (1961) p. 227 in this subsection.

Messen und Pruefen von Kleinstzahnraedern (Measuring and Testing Miniature Gears), L. MEYDING, VDI Ber v32 1959 p 77–88. Gear errors in watch movements and other small mechanisms; measuring instruments described. 23 refs.

On the Difference between the Normal Plane Helical Gear Profile and the Virtual Spur Gear Approximation, N.J. C. PERES. Australian J. App Sci v10 n1 1959 p 17–24 1 fig 4 refs. Helical involute gears are sometimes milled with rotary cutters or ground with formed grinding wheels, whose form corresponds to the tooth space profile of an imaginary "virtual" or "equivalent" involute spur gear in the plane normal to the pitch cylinder helix. The present paper gives equations for the difference between the profile so produced and the correct normal plane profile and shows that in some cases the approximation is not sufficiently accurate. See also PERES paper (1954) p. 226; ZAMIS (1947) p. 225 and WATERS (1961) p. 227 in this subsection.

Vereinfachte Berechnung der Zahnweiten und der Grundkreisdurchmesser, insbesondere bei korrigierten Schraegverzahnungen und Eingriffswinkeln, die von 20° abweichen (Simplified Calculation of Width of Teeth and Base Circle Diameters, Particularly in Case of Corrected Helical Gears and Pressure Angles Which Deviate from 20°),

H. BERGMANN. Werkstatt und Betrieb v92 n1 Jan 1959 p 10–14, Diagrams and/or numerical tables for pressure angles of 15°, 20°, 22°30′, and 30° in standard and special gears presented.

Der neue GOST-Standard ueber Messmittel fuer Stirnraeder (New GOST (Russian) 5638–58 Standard of Measuring Instruments for Spur Gears), K. BOEHM. Standardisierung v5 n4 Apr 1959 p 1/152–6. Outline of Soviet standards and comparisons with East German standards in this field.

Measuring Gear Teeth Errors Under Load, B. WOOD. Eng v187 n4861 May 8 1959 p 614. Errors measured for pair of spur gears defined as deviation from uniform rotation of one gear when other gear is rotated uniformly; measuring apparatus consisted of two 2⅝ in. diam steel disks and two 1¾-in. diam steel rollers; practical difficulties.

Measuring Kinematic Errors of Gears, M. BARASH, P. OXLEY. Machy (N.Y.) v66 n2 Oct 1959 p 139–40. Of two instruments developed in Soviet Union, one measures relative rotation between standard gear and gear being tested while they are simultaneously run in mesh with third gear, and second instrument is designed for checking fine pitch gears; their design and operation.

Die erweiterte Anwendungsmoeglichkeit des Taylorschen Grundsatzes (Possibility of Extended Application of Taylor's Fundamental Principle), H. WEINHOLD, Magdeburg Hoschschule Schwermaschinenbau Wiss Zeit v4 n2 1960 p 139–45. It is shown that this principle can also be applied to testing of gears, if complex notion of function is defined beforehand.

Vybor tochnosti izmeritel'nykh sredstv dlya kontralya zubchatykh koles, B. A. TAITS, N. N. MARKOV, Stanki i Instrument v31 n1 Jan 1960 p 20–4, see also English translation in Machines & Tooling v31 n1 1960 p 22–6. Development by Interchangeability Bureau of Committee on Standards, Gauges and Measuring Instruments of guide for selection of accuracy of measuring devices used for quality control of spur gears.

Geometricheskii raschet tsilindricheskikh zubchatykh koles s pomosch'yu spetsial'nykh tablits (Geometrical Calculation of Cylindrical Gears Using Special Tables), G. I. KOGAN. Stanki i Instrument v31 n2 Feb 1960 p 24–32; see also English translation in Machines & Tooling v31 n2 1960 p 26–34. Calculation method proposed is universal and simplifies direct calculations; its use eliminates calculations of intermediate values; especially when determining only individual features which characterize pinion or gear; examples of calculation of spur and helical gears given.

Brief Description of New Single-Face Gear Testing Device, F. LOBE. Microtecnic v14 n3 June 1960 p 101–12. Methods of measuring gear teeth accuracy are reviewed; manner in which control is performed on new single face testing device for coping with all types of transmission elements is described; design and construction of prototype for testing worn gears by single face method is discussed; photographs and sketches.

Exact Equations for any Normal Profile of an Involute Helical Gear, W. C. WATERS. Apr 24 1961 63 p 7 figs 6 refs. An essay submitted to the Graduate Council of Wayne State University in partial fulfillment of the requirements for the MS degree in the Dept of Mech Eng. Object is to investigate the errors inherent in the equivalent gear approximation. Subject headings include: Derivation of general equation set; test on equation accuracy; computer program formulation; computer results; section normal to central tooth pitch helix; section normal to lateral pitch helix; discussion of computer results; appendix. See also ZAMIS (1947) p. 225 in this subsection.

Ein Beitrag zur Pruefung der Zahnrichtung an Zahnraedern (Study of Tooth Direction in Gears). W. ROMMERSKIRCH. Werkstattstechnik v51 n10 Oct 1961 p 529–33. Measuring methods and devices for testing straight toothed and helical gears, and internal toothing described; checking of measuring instrument.

Achsabstand und Profilverschiebungen in Evolventen—Stirnradgetrieben (Backlash and Profile Displacement in Involute Spur Gears), R. NOCH. Tech Zeit für prakt. Metallbearbeitung v56 n7 1962 p 365–71 5 figs 7 refs. Diagrams are given from which the corresponding values for the axial clearance and the profile displacement can be read out, in many cases, to a sufficient number of decimal places.

Pribor dlya knotrolya kinematicheskoi tochnosti zubchatykh peredach (Instrument for Testing Kinematic Accuracy of Gears), YU. A. FEDUKIN. Stanki i Instrument n5 May 1962 p 29–30; see also English translation in Machines & Tooling v23 n5 1962 p 32–3. Description of method developed in Saratov Heavy Gear Cutting Machine Works; how continuous record of measurements was obtained by means of standard recorder; method is based on comparison of length of piano wires being wound (or unwound) on drums mounted on gears tested.

Gear Measurement, Inspection Equipment and Practices. AGMA 129.15, June 1962. Seven papers presented at the 46th annual meeting of the AGMA. (See GREEVE and DEVOS references below in this subsection and BEAM in subsection 9.3.)

Die Fertigung von Genauigkeits-Grosszahnraedern (Production of Large Marine Gears of High Precision), W. DREYHAUPT. Werkstatt und Betrieb v95 n11 Nov 1962 p 733–43. Details of gear hobbing machine and operating conditions, manufacturing procedure and measuring and safety devices employed; numerous measurement results presented indicate accuracy of gears.

Pruefung der wichtigsten Verzahnungsgroessen an Stirnraedern (Testing Most Important Sizes of Spur Gear Teeth), A. BANHART. Werkstatt und Betrieb v95 n11 Nov 1962 p 745–54. Whole field of testing spur gears for individual and cumulative errors is discussed in detail, and testing methods and apparatus employed are described.

Teilungsmessungen an Verzahnungen in der Praxis (Pitch Measurements on Gear Teeth in Practice), H. A. KOOP. Werkstattstechnik v52 n12 Dec 1962 p 646–52. Installations and devices employed are described; interpretation of measuring results with regard to various types of errors is explained.

Measuring Method of Gear Accuracy, by Means of Two Feelers, J. ISHIKAWA, H. OHMURA. Japan Soc Mech Engrs Trans v28 n196 Dec 1962 p 1655–69. New method in which 2 feelers contact simultaneously on two adjacent tooth surfaces and draw error curves in same way as with usual tooth profile tester; center distance of 2 feelers is set equal to normal pitch of gear, so that two curves of profile errors are recorded; curves are superposed to give entire error; method is applicable for spur gears; curves for meshing and angle position errors were derived. In Japanese with English abstract.

New Instruments for Measuring Accuracy of Gears and Gear Trains, K. STEPANEK. Czechoslovak Heavy Industry n10 1963 p 34–42. IMO–S equipment developed in Czechoslovakia makes it possible to determine exactly inaccuracies of gear hobbing machines, shapers, and grinders; apparatus is portable and measures gears directly on machine; results obtained are presented graphically and analyzed; accuracy of indexing gears can be assessed with high precision by means of thorough analysis of results or additional tests.

Gear Checking Equipment, E. F. FABISH. ASTME Creative Mfg Seminars—Tech Paper 586 1963–64 9 p. Gears should be checked under conditions simulating actual operation mounting conditions; of two basic types of test equipment, functional and analytical, first is available in all ranges from manual to fully automatic; efficiency of hand and semi- and fully-automatic gear rollers; analytical type equipment is exemplified by helical lead-measuring instrument and tooth-space comparators; sources of gear errors are pointed out.

Equipment for Measuring Driving Gears of Diesel and Electric Locomotives, YU. V. IVANOV. Meas Techns 1962 n8 Feb 1963 p 643–4 2 refs. Translated from Izmer Tekh n8 p 19–20 Aug 1962. Discusses equipment needs for measuring large railway gears.

Determination of Cyclic Errors in Cylindrical Spiral Gears, B. YA. VERKHOTUROV, N. N. MARKOV. Meas Techns 1962 n12 July 1963 p 988–91 4 figs 5 refs. Translated from Izmer Tekh n12 p 5–8 Dec 1962. Discusses the use of waviness meters for checking cyclic errors, which is the basic parameter for smooth operation of spiral gearing in GOST 1643–56.

Goulder Mikron No. 4 Analytical Gear Tester. Machy (London) v104 n2678 Mar 11 1964 p 594–5. Design and operation of apparatus for checking gears for concentricity, involute profile, lead and pitch; it incorporates Taylor-Hobson electronic recording equipment of paper strip type, which gives 6 magnifications from 100x to 5000x; gears up to 48 in. diam by 10 in. wide, and weighing up to 3000 lb can be tested; separate attachment is available for carrying out dual-flank rolling tests.

Improved Gear Measurement Techniques for the Correlation of Gear Error with Noise, C. H. McDOWELL, A. MARK, J. SPENCE. Res and Development Rep nl. Naval Boiler and Turbine Laboratory, Philadelphia, Penna, Apr 1964 19 p plus 26 figs. Reports on project to establish accurate methods and techniques to measure undulation and pitch errors. The laboratory has devised a measuring technique wherein undulations along a gear tooth can be measured and recorded on a continuous strip chart and analyzed with a sensitivity capability of better than 5 μin. Also, the measurement of pitch error by a differential technique may be made to an accuracy equal to that of the divided table used for small diameter gears and superior accuracy with large diameter gears.

10.2. Spur and Helical Gears

10.2.1. Involute Form Measurement

Gear-Testing Machine, G. WIRRER. Machy (N.Y.) v26 Mar 1920 p 633–5 8 figs.; Machy (London) v15 Apr 1 1920 p 862–4 8 figs. Description of a machine designed to test spur gears for accuracy of tooth profile and concentricity by comparing the rolling action of the pair of intermeshing gears with the rolling action of two accurate base circle disks. The result of this comparison is graphically recorded by the machine.

"Kavle" Correct Involute Contour Indicator. Am Mach v52 Mar 25 1920 p 698, 2 figs. Used to test the accuracy of the form of gear teeth. Operation employs the same principle as used in laying out a true involute tooth form. As the straight edge is rolled about the base circle plug, the short arm follows the tooth form while the long arm

remains in contact with the indicator plunger. If the tooth is of true form the pointer will not move. If the tooth is not of true form the indicator will show any deviation from within 0.0002 of an inch.

Gear-Testing Machine. Machy (London) v15 Apr 1 1920 p 862–4 8 figs. Machine designed to test spur gears for accuracy of tooth profile and concentricity. Principle on which machine operates is comparison of rolling action of pair of gears under test with rolling action of two circular disks. result being recorded on chart.

Inspection of Involute Gear Hobs, C. G. OLSON. Machy (N.Y.) v28 Oct 1921 p 138–40 6 figs. Describes involute contour tester for spur and helical gears used by the Illinois Tool Works. Gives three tables of base circle disk diameters.

Lees Bradner Gear-Tooth Testing Machine. Am Mach v58 Apr 26 1923 p 640–1 4 figs ; Machy (N.Y.) v29 Apr 1923 p 649–50 4 figs. Measures the accuracy of that portion of the tooth contour that conforms to an involute curve, and also measures the spacing of the teeth of the gear. A disk on the work arbor is of the same diameter as the base circle of the gear to be inspected. A tangent bar or straightedge is held against the base circle under spring tension by two ball bearings on the slide frame. As the slide frame is rotated upon the work arbor, the tangent bar rolls about the base circle and the point of the contact lever traces the involute of this base circle. The straightedge carries a bracket on which are mounted the contact point, magnifying levers, and a dial indicator. The contact point engages successive teeth of the gear, and if the tooth curve is a perfect involute the hand of the indicator attached to the device will stand at zero while the contact point travels from the base to the point or outside edge of the tooth.

American Grinder Co. Gear Tester. Am Mach v59 Aug 30 1923 p 346–7. For checking and charting involute curves and testing tooth spacing. The machine consists of a base with a longitudinal slide upon which a transverse slide is mounted and constrained by tapes to move a distance equal to the peripheral motion of the base circle disk. Both slides are moved by screws with hand wheels and micrometer heads. On the transverse slide are mounted the contact finger and an indicator.

"National-Cleveland" Tooth Form Tester. Am Mach v64 Mar 25 1926 p 495. For measuring tooth spacing and profile of an involute gear shaper cutter or a gear. The gear or cutter is mounted on a spindle and held by a stop while the contact point on the lower end of a lever touches the tooth to be measured. The indicating lever is mounted on a slide that is moved by steel tapes from a pulley on the back end of the spindle that carries the gear being tested. Moving this slide turns the gear and the contact follows the tooth form as the gear rolls in unison with the movement of the slide. Any inaccuracy in the tooth form is shown by the indicators at the upper end of the pointer.

Gear Measuring Equipment. Machy (London) v28 June 17 1926 p 301–4 9 figs. Gear-measuring instrument made by Maag Co., Zurich, Switzerland ; measurements obtained with this instrument are made with reference to theoretically correct involute curves ; instrument for examining involute tooth profiles and comparing these with correct theoretical shape ; also serves to examine symmetry of two profiles of tooth.

Involute Gear Tester. Machy (London) v29 Mar 31 1927 p 838–9 4 figs. Zeiss tester is designed for accurate testing of involute profile curve of gear teeth ; instrument will accommodate all spur gears with involute teeth up to 16-in. diameter ; it is also possible to determine base diameter of gear if this is not known, it being only necessary to find diameter which gives smallest deviation.

Co-ordinates of Involute Teeth. Machy (London) v34 n860 Apr 4 1929 p 6 2 figs. Method of determining co-ordinates of involute teeth is described with formulas ; in one particular type of gear grinding machine, application of mathematics of tooth curve of setting of machine will greatly facilitate set-up.

National-Cleveland & Gear Checking Machine. Am Mach v72 Mar 6 1930 p 434. Improvements on the Model B gear checking machine permit readings to 0.0001 in. with a one-to-one lever arm mounted on ball bearings. Ball bearings are also used on the work spindle and the base circle disks. In addition to checking involute tooth forms, the machine has been found adaptable to checking the concentricity of the involute curved tooth with the bore of the cutter, by checking through an arc of 180 degrees. The machine is also arranged to check the spacing of the teeth. It is made in 4-, 6-, and 8-inch sizes.

Involute Gear Tooth Testing Instrument. Eng v133 Jan 1 1932 p 22 ; Engr v153 Jan 29 1932 p 138. Instrument produced by D. Brown and Sons, is simple, but accurate and reliable, mechanism for testing involute profile of teeth on spur and helical gears ; capable of accommodating gears up to 12 in. in base circle diam., and records directly on to dial with sensitiveness to one ten-thousandth in. any deviations from correct involute form.

Orcutt Involute Measuring Machine. Engr v155 n4032 Apr 21 1933 p 408. Machine developed by Gear Grinding Co., Birmingham, England, to meet its own requirements ; machine will measure any involute struck from any base circle between 1 and 13 in. in diam.

Die Bestimmung des Evolventenfehlers von Zahnraedern (Determination of I n v o l u t e Error of Gears), E. BOLBRINKER. Maschinenbau v18 n3/4 Feb 1939 p 73–5. Valuation of flank test ; diagrams of involute testing apparatus.

Charted Accuracy Minimizes Errors in Gear Profiles. Elec Mfg. v31 n1 Jan 1943 p 90, 92, and 120. Gen Electric and Fellows Gear Shaper collaboration has lead to automatic electric chart recording of involute gear profiles in Fellows involute measuring machine which is illustrated and described.

Involute Checking Machine for Large Helical Gears, D. W. DUDLEY. Machy (N.Y.) v54 n2 Oct 1947 p 142–5. Details of entirely new machine designed for checking large industrial and marine gears ; gear profiles are checked in normal section by special checking head which is moved across tooth profile and transmits deviation from straight line to recorder ; setup and typical application explained.

Master Gaging for Involute Curve, C. H. BODNER. Tool Engr v19 n5 Dec 1947 p 25–8 ; Am Mach v21 n26 Dec 18 1947 p 87–90. Proposed optical projection method and recommended practice for checking involute profile ; method requires use of master spline chart gage pattern, separate chart for each spline size ; proposal limited to side bearing involute with 30° pressure angle, but can be applied to any involute profile whether straight or helical.

Selection of Measuring Rolls for 30-degree Involute Splines, J. SILVAGI. Tool Engr v22 n2 Feb 1949 p 26–8. Method used to determine correct size of cylindrical measuring rolls for contour gaging involute spur gears and involute spur splines ; graphs simplify roll selection for standard SAE or SAS involute splines ; they are based on standard tooth space widths ; they can also be used to determine location of contact ; table gives general equation for determining roll diameter to contact at given diameter on nonhelical gear.

Epures Mobiles Universalles pour le Trace des Profils en Développante (Universal Movable Calculators for Outline of Involute Tooth Profiles) J. BERGERE. Pratique des Industries Mécaniques v32 n10 Oct 1949 p 311–7. Design and application of calculators and gages which permit rapid and accurate tracing of tooth profile ; illustrations.

Simple Linkage Which Generates Close Approximation to Involute, E. R. WIGAN. Machy (London) v86 n2204 Feb 11 1955 p 321–5. Linkage described provides simple method of gaging profiles of involute spur gears ; geometry and parameters of linkage ; tabulation of involute and mechanism parameters ; sources of error in mechanism designed to conform to geometry of presented view.

Involute and Helix Tester for Large Gears. Engr v202 n5256 Oct 19 1956 p 561. Tester, "Model PGZ," introduced by W. Ferd. Klingelnberg Soehne, Remscheid, Germany, stated to make possible testing of profiles on tooth flanks of gears too large for existing standard equipment.

Ermittlung des zu einer Evolventen-Schrägzahnflanke gehörenden Grundzylinderradius (Investigation of the Base Cylinder Radius Belonging to an Involute Helical Gear Flank), M. GARY. Konstruction v9 n10 1957 p 397–9. Calculation, measuring process, and example.

Measurements of the Form Error of Small Gears Under Working State (Operating Conditions), K. YAMAMOTO. Report of the Central Inspecton Institute of Weights and Measures, Japan, v8 n3 Report 19 1959 in Japanese. There have been many measuring methods of gears, but few of them are applicable for small gears, because their minuteness necessitates an extraordinary accuracy in detecting form error of small gears. For example if the accuracy of measurement of gears with module three is to be required one micron, the equivalent measuring accuracy of small gears with module 0.3 must be 0.1 micron, and the detection of such a small dimension is very difficult. On the other hand the demand for such a high measuring accuracy grows greater and greater as the fine instruments are developed. For the above reasons a method for measuring form errors of spur gears is developed. The principle of the method is based on the fact that the driving torque of a gear train is fluctuated by sliding friction and form errors of gear teeth contacting each other. A gear and a pinion are meshed together and a loading torque is applied on the pinion and then gear is driven so slowly that the angular motion of the gears can be assumed to be in an equilibrium state, and equilibrium can be obtained, one pair of which are equations when the gear is driven clockwise and the other when the gear is driven anti-clockwise. From these equations the reaction forces Q^+ and Q^- acting on the pinion from its bearings can be shown analytically, and Q^+ is the reaction force when the gear is driven clockwise and Q^- is the reaction force when the gear is driven anti-clockwise. The fluctuations of ($Q^+ + Q^-$) are brought about mainly by the form error of the gears but little by the sliding friction, while with the fluctuations ($Q^+ - Q^-$) the reverse happens. And hence the friction and form error can be obtained if Q^+ and Q^- can be obtained. The apparatus to obtain the forces Q^+ and Q^- is shown, and some examples of records of Q^+ and Q^- are also shown. It is proved that the form error, the friction and the actual contact of the gear and the pinion can be analyzed successfully.

Die Ueberpruefung von Evolventenpruefgeraeten und das pruefen von Stirnraedern mit sehr kleinen Zähnezahlen (Examination of Involute Checking Devices and Testing of Spur Gears with very small Numbers of Teeth), W. ROMMERSKIRCH. Werkstattstechnik v49 n11 Nov 1959 p 674–6. Methods for checking accuracy of recording device : nomogram as aid in testing of spur gears.

Pribor dlya kompleksnogo odnoprofil'nogo kontrolya zubchatykh koles, A. T. DRAUDIN. Stanki i Instrument v31 n1 Jan 1960 p 24–6 ; see also English translation in Machines & Tooling v31 n1 1960 p 27–8. Design of single profile testing machine BV–963 with universal setting for center distance from 2.756 in. to 9.843 in. and transmission ratios from 0.33 to 3.0 developed by Bureau of Interchangeability.

Investigating the accuracy of evolventometers, G. S. SIMKIN, G. Y. GAFANOVICH. Meas Techns 1961 n6 Dec 1961 p 435–8 1 fig 4 tables 3 refs. Translated from Izmer Tekh n6 p 8–10 June 1961. · Investigaton of several foreign make involute testers. Conclusion is that it is necessary to produce new instruments for measuring gears of high accuracy by GOST standards. It is also necessary to develop a more reliable method of setting the measuring tip for a given base circle diameter.

Gear Checking Method Eliminates Errors in Setup, J. W. GREEVE. Tool & Mfg Engr v48 n5 May 1962 p 121–4. (See next reference by DeVos.)

Ford Pin Type Master for Involute Gears, L. DeVOS. AGMA 129.15 June 1962 5 p 4 figs. New geometrically constructed masters use highly accurately ground and positioned pins of circular cross section instead of involutetoothed master to qualify checking instruments at the Ford Motor Co., with the aid of calculated deviations. Thus the involute-master is removed as a source of error in accurate measurement. This important basic principle was suggested by Albert S. Beam then chairman of the Gear Panel of the Industrial Mathematics Society, Detroit).

Die neue Evolventen- und Steigungsprüfmaschine Modell PFS–U (The New Involute and Lead Testing Machine Model PFS–U), K. H. WEBER. Klingelnberg-Nachr v13 n32 Dec 1964 4 p 5 figs. Describes function in detail and how this model evolved from PFS 500 and PFS 600.

10.2.2. Master Gears; Composite Deviation Testing

Device for Testing Truth of Cut Gears. Machy (N.Y.) v15 Jan 1909 p 374–5. Device for rotating gear with master gear and indicating changes in center distance.

Testing Gear for Automobiles, M. E. HIDIEGAN. Am Mach v32–2 Aug 26 1909 p 389–90 3 figs. Illustrated description of a device for the final testing of all spur-cut gears, either soft or hardened for out-of-roundness, etc., by rotating in mesh with a master gear.

Device for Testing and Measuring Gears, C. BOELLA. Machy (N.Y.) v18 Apr 1912 p 635 2 figs. An indicating device for operating spur gears in mesh and determining eccentricity.

Testing Spur and Bevel Gearing. Internal Combustion Eng Oct 16 1912 p 341 4 figs. British machine by Parkinson and Sons in which bevel gear and pinion are run together and errors are recorded on a chart.

Inspection of Spur Gears, D. V. WATERS. Machy (N.Y.) v28 Feb 1922 p 465–6 4 figs. Describes rolling fixture of Gould & Eberhardt, Newark, N.J., in inspecting spur gears, with particular reference to uniformity of tooth spacing and concentricity of pitch circle relative to axis of gear.

Testing Involute Spur Gears, M. ESTABROOK. Mech Eng v45 Jan 1923 p 32–4 and 81 14 figs. Describes Saurer gear-testing machine, a Swiss development by means of which accuracy of tooth curves, spacing, and eccentricities can be determined with high degree of precision ; and odontometer, American instrument for quickly and accu-

rately testing gears for tooth curves and spacing, and with which it is possible to locate troubles in machines or tools.

Gleason Spur Gear Testing Machine. Am Mach v73 Oct 16 1930 p 645. Running qualities of spur gears up to 14½ in. pitch diameter can be tested on this machine. The machine can be used for testing cluster gears as well as gears with integral shafts; also helical, herringbone, and internal spur gears. Heads are adjustable horizontally by means of a lead-screw graduated to 0.001 in. A 5-hp. motor drives the spindle. Specifications: distance between noses of spindles on brake and drive heads, min., 3 in., max., 18 in.; distance from center of brake-head spindle to center of drive-head spindle, min., 3 in., max., 10 in.; distance between adjustable tail center and nose of brake-head spindle, min., 0 in., max., 14½ in. floor space, 61½ by 77 in., and net weight, 4,000 lbs.

Gear testers designed to show combined errors. Iron Age v133 p 27 Apr 26 1934 1 p 1 illus. Parkson gear tester is designed to show composite errors of spur, helical, and bevel gears as well as of worm gears and worms.

Meister-Zahnraeder als Normale fuer die Abrollpruefung (Master Gears as Standards for Rolling-Off Test), K. BUERGER, Werkstattstechnik und Werksleiter v34 n24 Dec 15 1940 p 427–33. Principles governing method and standards for acceptance testing of large numbers of gears; measurement of master gears of different makes; recommended tolerance for tooth dimensions of master gears. Bibliography.

Adaptable Gear-Testing Machine. Machy (London) v57 n1481 Feb 27 1941 p 599–601. Description of machine manufactured by Monarch Tool Co, Huddersfield, designed for testing spur, helical, bevel, spiral, and worm gearing; it is suitable for either laboratory or workshop use; gears are tested by rolling together, thereby eliminating many individual measurements; simple and easily mounted attachments enable whole range of gearing specified to be tested.

Master Gears, H. WALKER. Machy (London) v58 n1486 Apr 3 1941 p 9–11. Description of standard set of master gears and their uses in testing spur and helical gears during manufacture.

Ein neues Einflanken-Abrollprüfgerät für Zahnräder (A New Single Flank Rolling Apparatus for Gear Wheel), K. BÜRGER PTB, Werkstattstechnik und Werksleiter v36 n¾ Jan 1942 p 54–61; VDI Zeit v87 n17/18 May 1 1943. Illustrated description of new and improved type developed at Physikalisch Technische Reichsanstalt; advantages over double-flank system pointed out. Abstract from Werkstattstechnik v 36 1942 p 54–61.

Some Facts About Master Gears, G. H. SANBORN. Am Mach v89 n14 July 5 1945 p 116–7. Study of master gears and their application in inspection of work gears during and after production; details of instrument used in measurement of tolerances; concentricity of teeth and backlash; factors concerning selection and design of master gears.

Gear "Rolling", G. W. BIRDSALL. Steel v117 n8 Aug 20 1945 p 126–7, 164, 166. Description of essential elements of gear rolling fixture for checking spur, helical, spiral and worm gears; gear under test is fully meshed with master gear and change in center to center distances read on dial gage as gears are rolled against each other; explanation of operational details; illustrations of modified designs for checking various types of gears included.

New Concept of Gear Inspection, L. D. MARTIN. Tool z Die J v 15 n4 July 1949 p 42–5, 67–8. Description of model 1-S Conju-Gage intended primarily for checking all types of spur gears commonly used in meter, instru-

ment and watch industries, and of 4-U model incorporating features which increase ease and rapidity of inspecting larger gears up to 4⅛ in. pitch diam; advantages of master worm section used in connection with Conju-Gage over circular master gears; electronic charting device charts radial displacements occurring between master and work.

Functional Checking of Gear Teeth, L. D. MARTIN. Machy (N.Y.) v56 n8 Apr 1950 p 208–13. Procedures and fixtures for checking various types of gears; variable center distance fixtures, Gleason fixture, Fellows Red Liner, etc. described and illustrated; features of new Kodak "Conju-Gage" for checking spur or helical gears pointed out; factors to be considered when measuring backlash of gears.

Functional Checking of Backlash in Gear Trains, L. D. MARTIN. Machy (N.Y.) v56 n11 July 1950 p 161–5. Charts of reliable backlash checks made by rotating gear being checked in contact with master of known accuracy and measuring their radial displacements, are presented; data sheets shown developed for finding change in center distance required to correct backlash in mating gears.

Functional Gear Checking. Illinois Tool Works 1952. Describes various types of rolling fixtures and their uses.

Functional Gear Checking, F. BOHLE. Machy (N.Y.) v58 n8 Apr 1952 p 170–5. Evaluation of gear inspection and its practice; gear rolling fixture designed for functional inspection of internal spur and helical gears; arrangement for making angular velocity test under load; recording of errors on charts; advantages of combining graphic inspection with functional gear checking; photographs.

Die Einzelfehler von Evolventen Stirn- und Kegelrädern im Fehlerschaubild der Ein- und Zweiflankenwälzprüfung (The Single Errors of Involute Spur and Bevel Bears in the Error Presentation of the One and Two Flank Roll Testing), G. ZIEHER. Werkstattstechnik und Maschinenbau, v42 n6 June 1952 p 242–8 6 refs.

What Errors Can a Gear Have? Eastman Kodak Co. Presents Conju-Gage as more accurate than a master gear for the same test.

Standard Master Gears. AGMA Publ. 236, 04, June 1956.

Tables Simplify Calculation of Gear-Testing Center Distances, J. L. WILLIAMSON. Machy (N.Y.) v64 n1 Sept 1957 p 170–1; Machy (London) v91 n2353 Dec 20 1957 p 1445–6. Simple method for computing testing center distance developed by Fellows Gear Shaper Co., Springfield, Vt; difference between involute functions of nominal pressure angle and active pressure angle is first calculated from formulas; numerical value for ratio of cosine of nominal pressure angle to cosine of pressure angle at meshing position is then found by referring to table; example.

Toward More Economical Gear Inspection, F. BOHLE. AGMA 239.05, Oct 1957. Discusses principally various types of rolling checks.

Measurement Errors in Gear Roll Testing. Machy (N.Y.) v66 n9 May 1960 p 145–50. Nature of errors in roll test measurements described; methods of obtaining most accurate results from roll testing equipment.

Complex Checking of Spur Gears in Single-Profile Meshing with a Measuring Screw, M. N. BOKIN. Meas Techns 1960 n3 Dec 1960 p 179–80 1 fig 4 refs. Translated from Izmer Tekh n3 p 1–2 Mar 1960. Method of checking the kinematic error of spur gears in single-profile meshing with a floating measuring screw has the following advantages as compared with the existing methods: the greater

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precision of measuring screws as compared with reference gears makes it possible to measure gears of any degree of accuracy; the possibility of using the measuring screw for checking gears of any diameter providing they are of the same module.

Master Gears and Their Importance in Gear Manufacturing, R. NOCH. Microtecnic v15 n1 Feb 1961 p 20–3. Report on present state of development of using standards in form of master gears for determining cumulative errors of gear wheel by employing suitable gear testers; newest trends of development indicated.

Handbook for the Calculation and Design of Master Gears. Quality Assurance Pamphlet ORDP 608–MC–14, Army Tank Automotive Center, Detroit, Mich., Nov 5 1962 72 p. Deals with fundamental inspection concepts, master gear design preparations and instructions, the master gear drawing, wire sizes, root clearance, and calculation sheets.

Specification for Master Gears. Brit Standards Instn— Brit Stand 3696 1963 8 p. Standard relates to 2 classes of spur master gears for use as reference and inspection standards with pitches in range 2 to 64 normal diametral pitch inclusive; class A master gears are intended to test precision class product gears and Class B to test gears for general purposes; specification may also be applied to helical master gears so far as tolerances are concerned, but tolerances given have been chiefly derived from information from spur master gears.

Checking Backlash in Gears, M. S. BRUNO. Am Mach/ Metalworking Mfg v107 n11 May 27 1963 p 77–81. How to obtain precise data on overall gear quality; roll testing spur gear; standard procedure for inspecting backlash, total cumulative error, and tooth-to-tooth error simultaneously; converting to circular tooth thickness, with example; how to calculate center distance limits; setting center distance limits; master gears inscribed with "testing diameter" value; finding correlated testing diameter.

Das Lehrzahnrad als Mess- und Pruefmittel fuer Stirnraeder, G. LICHTENAUER. Werkstatt u Betrieb v96 n11 Nov 1963 p 807–11. Master gear as measuring and testing device for spur gears; importance of double flank total composite error test devices, and of measuring noise and testing contact pattern with master gears is pointed out; design and construction of master gears.

Goulder Mikron No. 4 Analytical Gear Tester. Machy (Lond) v104 n2678 Mar 11 1964 p 594–5. Design and operation of apparatus for checking gears for concentricity, involute profile, lead and pitch; it incorporates Taylor-Hobson electronic recording equipment of paper strip type, which gives 6 magnifications from 100x to 5000x; gears up to 48 in. diam by 10 in. wide, and weighing up to 3000 lb can be tested; separate attachment is available for carrying out dual-flank rolling tests.

Sammelfehlermessung von Stirnrädern (Cumulative Errors of Spur Gears), R. NOCH. Archiv für Tech Messen V834–2 May 1964 p 105–8 9 figs 35 refs. Deals with form and position errors of gear teeth as detected by rolling. Considers both single and dual-flank contacts.

Master Gears. Proposed Tentative AGMA Information Sheet. AGMA 235.03 June 1964 18 p. Covers masters for checking spur and helical gears operating on parallel axes.

Rights and Wrongs of Gear Checking Pressure, L. D. MARTIN. Indus Quality Control v21 n4 Oct 1964 p 197–202. Physical procedures are described which are helpful in determining optimum checking pressure for small pinions and gears with small bores where bending in either pinion journals or checking pin may be expected.

Lehrzahnräder und ihre Bedeutung für die Zahnradfertigung (Master Gears and their Significance for Finishing of Gear Wheels), R. NOCH, VDI Braunschweig. Preprint available from author 4 p 6 figs 10 refs. Describes master gears and various types of rolling testers.

10.2.3. Lead Measurements

All references under this heading are included in subsection 9.2.

10.2.4. Pin and Ball Measurements of Spur Gears and Splines

References to helical gears are given in subsection 9.3, p. 205. References to tables of numerical measurement values are given in subsections 9.4, p. 212 and 10.1.3.4, p. 220.

Ring and Wire Gage for Measuring Fine-Pitch Gears, A. W. CHAPPELL. Am Mach v41 Oct 15 1914 p 689. Wire method of measuring gear pitch diam. Correction, A. W. CHAPPELL, Am Mach v41 Nov 5 1914 p 825. Correction, S. T. DORT, Am Mach v42 Jan 28 1915 p 167.

Pin Measurement of Spur Gears, R. TRAUTSCHOLD. Machy (N.Y.) v24 Jan 1918 p 406–9 5 figs. Principles governing pin measurement and derivation of formulas used; finding size of pin; discussion of formulas; allowance for backlash. Table of sizes of pins used in measurement of 1 D. P. gears. Methods for even and odd numbers of teeth.

Measuring Gears by the Use of Wires, W. S. HUDSON. Am Mach v49 Aug 15 1918 p 291–2 6 figs. Simplified formulas and tables presented. Method involves use of wires or pins, the diameter of which is constant for all gears of the same pitch, irrespective of the number of teeth. A single gage for testing large numbers of gears of the same size is also described, comprising a suitably shaped holder having two holes suitably spaced, into which pins are pressed. Criticism by J. W. LEE, Am Mach v50 Jan 16 1919 p 123–4.

Formula for Measuring Spur Gears by the Pin Method, M. D. WILSON. Machy (London) v18 Apr 21 1921 p 92–4 4 figs.

The Gauging of Involute Threads, H. E. MERRITT. Machy (London) Apr 5, 19 July 26, Aug 2 1923 p 11–3 79–81 525 569 13 figs. See abstract under subsection 9.3.

Standardized Roller for Checking Spur Gears, W. H. FOLDS. Machy (London) v23 Mar 13 1924 p 765–7 3 figs. Writer proposed to standardize to some extent, roller-check method by use of tables of factors, which makes it possible to use any size roller that will form contact on tooth faces or flanks, and from given diameter of roller overall measurement over roller as it is located in teeth of gear can be calculated.

The Design and Inspection of Gear Teeth for Wear, P. M. GALLO. Blast Furnace & Steel Plant v13 Sept and Oct 1925 p 368–9 and 392–4 2 figs. Presents roller formulas and explains their application to determining the deformations of gears under load.

Checking Gears by the Wire Method, H. G. THUESEN. Am Mach v63 Nov 19 1925 p 824–5. Gives method and formulas.

Normal Pitch the Index of Gear Performance, G. M. EATON. Mech Eng v48 Jan 1926 p 27–32 13 figs. Brings out certain departures from previously accepted practice which are useful in manufacture of heavy involute gear-

ing, as they ease performance during breaking-in stage of operation; shows that material improvement in performance may be secured by adopting proper relation between normal pitches of driving and driven gears, measured at point of tooth engagement; outlines development of normal-pitch indicators.

Measurement of the Thickness of Involute Gear Teeth, ALLAN H. CANDEE. Am Mach v68 n9, 11, 14 Mar 1, 15 and Apr 5 1928 p 365–8 463–7 573–6 12 figs. See abstract under Subsection 9.3.

Constant Chord Gaging, S. TRIMBATH. Am Mach v73 n20 Nov 13 1930 p 769–793. Methods of sizing gear teeth by means of one pair of rolls or pins per pitch, and micrometers; chart giving size for 1 diametral pitch gears with seven different pressure angles.

Pin Inspection of Tooth Profiles, S. TRIMBATH. Am Mach v76 May 26 1932 p 673–4. Method of checking tooth form by measurement across pins placed between teeth; as two teeth contact with four involutes at same time, errors in tooth form caused by difference in pressure angle will be amplified approximately four times by measuring across pins.

Helical Gear Tooth Measurement, S. TRIMBATH. Am Mach v76 Aug 31 1932 p 966–7. See abstract under subsection 9.3.

Checks on Gear Tooth Accuracy, I. J. GRUENBERG. Am Mach v78 n3 Jan 31 1934 p 123–4. Pin measurement at constant chord is recommended for final inspection of spur and helical gears.

Size Measurement of Gears, W. L. CHESLEY. Tool Engr v5 n9 Jan 1937 p 14–5. See abstract under subsection 9.3.

Neuartige Kopfkreisfreie Zahndicken-Messungen für Schrägzahnräder und Evolventen-Schnecken (Novel Method of Measuring Tooth Thickness for Involute Helical Gears and Involute Worms without Use of Addendum Circle), W. F. VOGEL. Werkzeugmaschine v41 n11 June 15 1937 p 253–61. See abstract under subsection 9.3.

Ball Measurement of Helical Gears, A. ZAHORSKI. Am Mach v83 n14 July 12 1939 p 520–2. See abstract under subsection 9.3.

Pruefung von Kerbverzahnungen mittels Draehten (Testing of Stop Gears with Wires), H. ZOELLNER. Werkstatttstechnik und Werksleiter v33 Nov 1 1939 p 503–5. Development of equation by which gears may be tested by 3-wire method.

Contrôle des Cannelures au Moyen de Goupilles Cylindriques (Checking Gear Size by Measurement Over Pins). Pratique des Industries Mecaniques v22 n4 Jan 1941 p 84–6. As applied to straight and involute flanks; determination of tolerances.

Measurement of Spur Gear Teeth, W. T. TAYLOR. Aero Digest v49 n3 May 1 1945 p 90–3 150, charts on p 94–96. Over- or between-pin measurement of involute spur and helical gears is employed to determine circular thickness of gear teeth; simplified involute function spur gear formulas for determining dimensions to center of measuring pins and dimensions over or between pins, presented.

Engineering of Involute Splines, G. L. McCAIN. Chrysler SAE Trans v54 1946 p 245 310. Wire measurements.

Selection of Measuring Rolls for 30-degree Involute Splines, J. SILVAGI. Tool Engr v22 n2 Feb 1949 p 26–8. See abstract under 10.2.1.

Position of Contacting Sphere Between Teeth of Helical Gear, N.J.C. PERES. Machy (London) v77 n1977 Sept 21 1950 p 324 1 fig. See abstract under subsection 9.3.

Gauging Involute Teeth or Splines over Rolls, F. W. HALIS. Machy (London) v78 n2012 June 7 1951 p 952–3. Formulas developed for checking external involute gears and involute splines by roll or wire method; graph and table for selection of roll diameter presented.

On the Influence of Surface Deformations in Over-Pin and Over-Ball Measurements of Spur Teeth, B. W. CARTWRIGHT. Nov 25 1952 50 p 12 figs 5 refs. An essay submitted to the Graduate Council of Wayne State University in partial fulfillment of the requirements for the MS degree in the Dept of Mech. Eng. Subject headings include: Methods of spur tooth measurements; location and character of contact; compressive stress and strain in the contact of solids; special equations adapted to tooth specifications and special relations for standard thickness; establishment of maximum micrometer force; permissible micrometer loads based on stress limitations; permissible micrometer loads based on deflection limitations; conclusions; appendix.

Gears and Splines . . . Checking Pin Measurement Data, J. SILVAGI. Tool Engr v35 n1 July 1955 p 93–8. Five double-check methods and associated formulas presented; checking methods are simple and accurate, and avoid repitition of same type of error.

Geometrische Probleme bei der Vermessung von zylindrischen Evolventen-Schnecken und Evolventen Schrägstirnrüdern (Geometric Problems in the Measurement of cylindrical involute worms and involute helical gears), M. GARY, PTB. Konstruktion v8 n10 1956 p 412–8 2 figs 4 refs. See abstract under 9.3.

Inspection of Fine-Pitch Gears. American Standard ASA B6.11–1956 41 p 27 figs. Publ by ASME, New York. Section 8, Pin measurements of fine-pitch involute spur gears contains 4 tables for external and internal 20° involute spur gears.

American Standard Involute Splines, Serrations and Inspection. ASA B5.15–1960 108 p. Contains extensive data and tabulations relative to measurements over or between pins for space width and tooth thickness for involute serrations and splines and straight-sided serrations.

Determination of Helical Gear Sizes by the Two-Roller Method, I. P. NEZHURIN. Russian Eng J v41 n8 1961 p 11–3 19 3 figs 2 refs. Translation pub by Product Eng 1957. See abstract under subsection 9.3.

Computing the Displacement of the Initial Contour of Gears When They Are Checked by Means of Balls, P. M. DANILYUK. Meas Techns 1960 n7 Feb 1961 p 585–6 2 figs. Translated from Izmer Tekh 1960 n7 p 25–6 July 1960. Measurement of spur gears by means of balls. Obtains an expression for the radius vector in checking gears in both an even and odd number of teeth. Involute function tables are not required.

New Equations Simplify Pin Measurement of Gears, J. H. GLOVER. Prod Eng v32 n11 Mar 13 1961 p 80–1 4 figs 3 refs. See abstract under subsection 9.3.

Vereinfachte Berechnung der Masse fuer die Messung ueber Rollen bei Aussen- oder Innenverzahnungen mit Eingriffswinkel 20° (Simplified calculation of dimensions for measurements over rollers of external or internal gears with 20° angles of pressure), H. BERGMANN. Werkstatt und Betrieb v94 n6 June 1961 p 341–9. Methods are de-

scribed and their application explained by diagrams, numerical tables, and examples.

Measurements of Helical Gears with Pins or Balls, Analysis of Pitfalls and their Elimination, A. S. BEAM, C. E. HALL. AGMA 129.15 June 1962 7 figs 1 ref. See abstract under subsection 9.3, p. 212.

Computation of Ball Diameters for Testing Gearing, P. M. DANILYUK. Meas Techns 1962 n5 Nov 1962 p 371–3 2 figs 8 refs. Translated from Izmer Tekh n5 May 1962 p 12–3. Describes methods of computing diameters of balls and checking dimensions for all the cases encountered in testing involute spur gears. A table of involute functions is not required.

10.2.5. Tooth Index Position Measurement

See also subsections 6.1 and 6.4. For angular spacing tables see subsection 10.1.3.

A Scheme for Making the Universal Dividing Head Universal, W. A. WARMAN. Am Mach v25 May 15 1902 p 698–9. Sketches and description of a device that gives accuracy.

A Hobbing Machine and Dividing-Head Tests, Am Mach v31 Jan 2 1908 p 10–15. Illustrated description of how accurate worm wheels for dividing heads are hobbed in a special machine and the heads afterward tested. Various tests are illustrated.

Die Prüfung von Zahnrädern auf Exzentrizität und Teilungsfehler (Examination of Gears as to Eccentricity and Error of Pitch), G. BERNDT. Maschinenbau v4 Dec 17 1925 p 1232–6 7 figs. Shows that usual methods of testing by means of radially and tangentially displaceable cones or cylinders are of no advantage; radial displacement gives greater accuracy.

"Zeiss" Optical Dividing Head. Am Mach v65 July 1 1926 p 36. Obtains the division of the circle from a glass dial mounted directly on the spindle carrying the work.

Indexing Head for Highly Accurate Spacing, F. C. DUSTON. Machy (N.Y.) v36 n1 Sept 1929 p 14–6 3 figs. Design of precision indexing head employed in making accurate gears and perforated disks required for television equipment.

Precision Angular Work. Machy (London) v39 Jan 14 1932 p 493–500. Accurate master dividing plate made for 23 divisions, obtained by 23 individual ring sectors; design and use of precision taper gage machining and assembling operations.

Notes on Testing of Workshop Dividing Head, F. H. ROLT, C. O. TAYLERSON. Machy (London) v51 n1311 Nov 25 1937 p 229–31. See abstract under 6.4.

Compudex. Compudex Engineering Co., Chicago, Ill. 1946 8 p. A computer to be used with indexing heads and rotary tables. Indexes every number from 1 to 1100 and every even number from 1100 to 2198.

Effects of Alignment Errors in Dividing Heads, C. T. BUTLER. Machy (London) v83 n2144 Dec 18 1953 p 1211–4. See abstract under 6.4.

Automatic Indexing Machine for Measuring Gear Tooth Pitch Errors, C. TIMMS, C. A. SCOLES. Engr v199 n5169 Feb 18 1955 p 229–31; Eng v179 n4649 Mar 4 1955 p 271–4; Machy (London) v86 n2209 Mar 18 1955 p 597–602. Tomlinson hob and gear measuring machine from which automatic pitch testing machine has been developed at Mechanical Engineering Research Laboratory, East Kilbride; it is largely pneumatically operated and functions entirely without presence of observer; repetitive accuracy per cycle found to be of order of 0.000005 in. Before Brit Gear Mfrs Assn.

How Auto-Collimators Measure Gear Errors, T. R. KNOWLES. Machy (N.Y.) v63 n4 Dec 1956 p 137–43; Machy (London) v90 n2312 Mar 8 1957 p 519–24 8 figs. Two Watts auto-collimators used in one of special weapons laboratories of Northrop Aircraft measure directly errors in gears and gear trains in seconds of arc; errors caused by pitch circle eccentricity (runout); determining random errors; errors in gear trains.

Line-of-Action Dontometer Inspects Spur Gears to plus or minus 1 sec of Arc, R. J. ROSS, J. P. WRIGHT. Am Mach v102 n1 Jan 13 1958 p 113–7. Use of gear analyzer at Sperry Gyroscope Co., Great Neck, NY for checking ultra-precision spur gears to maximum permissible nonadjacent tooth spacing error, for entire active profile, to within 1 sec of arc; design, construction and operation of instrument.

New Dividing Head, E. I. FINKEL'SHTEIN. Meas Techns n3 Mar 1959 p 164–6 (English translation of Izmer Tekh) see abstract under 6.4.

World's Most Accurate Dividing Head. Vinco Corp., Detroit, Mich., Bul 56 1960 8 p figs. Vinco optical master inspection dividing head was created in 1937. States total index error at spindle or face plate as 2 seconds. States tolerances on spindle runout, spindle end face, and surface plates; available in several models.

New Method of Testing Divided Circles, C. KÜHNE. Rev Sci Instrum v31 n8 p 882–5 Aug 1960. See abstract under 6.4.

Zur Messung der Kreisteilungsfehler an Zahnraedern und Teilscheiben (Measurement of Errors in Circular Pitch Distribution of Gears), R. NOCH. Werkstattstechnik v51 n3, 4 Mar 1961 p 142–7, Apr p 188–93. Problems of geometry, sources of errors and accuracy of measurements; description of measuring installations; temperature changes which occur and their influence on accuracy. 25 refs.

Widening Applications of Radial Diffraction Gratings, W. H. P. LESLIE. Machy (London) v99 n2559 Nov 29 1961 p 1269–70. Reference made to application at National Engineering Laboratory, of gratings to measurement and subsequent reduction of errors in gear hobbing machine; method is now used to apply overall correction betwen hob spindle and table; further application of radial gratings, now under active development at NEL is for singleflank checking of gears. Abstract of paper before 2d Internat Machine Tool Design and Res Conf, Manchester College of Science and Technology.

New Road to Index Error Evaluation, H. R. RONAN, Jr. ASME-Paper 62–WA–39 for meeting Nov 25–30 1962 10 p. Index error measurement by theodolite system, graduated plate measurements, and pitch variation measurements; in making latter measurements, most important observation is that quantity measured is actually difference between two points on index error curve; use of Laplace transform is explained and illustrated by examples; in addition to providing means to index error plots, analysis technique is suitable to major purpose of span and pitch variation checks, cyclic error analysis; comparison is made of pitch variation system and two approaches in use.

10.2.6. Tooth Thickness, Pitch, and Span Measurements

See Subsection 9.3 for tooth thickness measurement of helical gears. See also subsection 10.2.4 for tooth thickness measurement.

A Micrometer Gear Tooth Gage. Am Mach v23 Aug 30 1900 p 842. Two micrometers at right angles to measure tooth thickness at the pitch line.

A Worm and Spiral Gear Tooth Gage, E. J. LEES. Am Mach v26 June 18 1903 p 875–6. Illustrates and describes a gear tooth caliper provided with scales for measuring circular pitch and normal pitch, and a protractor for reading the angle of the spiral.

The Measurement of the Teeth of Gears, G. W. BURLEY. Prac Engr Jan 16 1913. Describes the measurement by means of the gear-tooth caliper, giving formulas and curves.

Gaging Teeth of Involute Gears, H. E. TAYLOR. Am Mach v38 June 26 1913 p 1071–3. Makes use of vernier calipers. Gives derivation of pertinent equations. (Probably the earliest publication on span measurements of involute gears.) See table under subsection 10.1.3.5.

Teilungsuntersuchung für Zahnräder (Testing the Indexing of Gears), F. GÖPEL. Werkstattstechnik v7 1913 p 643 and 675; Zeit InstrumKde v34 Mar 1914 p 84–91 5 figs. A simple apparatus is described for the determination of the correctness of toothed wheels employed in instruments of precision. The errors are plotted as diagrams showing the correction necessary at any point.

Measurement of Gear Wheels with Ball Micrometer, W. H. COWLIN. Machy v15 (London) Mar 11 1920.

The Wickman Pitch Measuring Machine. Automobile Engr v10 Dec 1920 p 481 4 figs; Am Mach v53 Dec 2 1920 p 1068a. Machine is designed to measure tooth spacing at pitch line as well as concentricity of pitch circle with bore.

Recent Developments in Gauging Apparatus. Eng Prod v2 Jan 13 1921 p 40–44 12 figs. Machines recently introduced by Alfred Herbert, Coventry, England, notably gear pitch and concentricity measuring machine and universal gage measuring machine.

The O d o n t o m e t e r for Testing Gear Teeth. E. BUCKINGHAM. Machy (N.Y.) v27 July 1921 p 1029–31 6 figs; Machy (London) v18 July 7 1921 p 412–3 6 figs. Apparatus consists of section of straight-sided rack with two parallel effective faces, one being fixed and other movable. Third face, set at angle to two working faces, is used to hold fixed working face in contact with flank of gear tooth. Developed by P r a t t and Whitney Company.

The Sykes Gear-Tooth Comparator. Eng v112 July 15 1921 p 103 3 figs; Machy (London) v18 July 14 1921 p 454–5 3 figs. Instrument consists of short bar fitted with one fixed and one sliding jaw, arranged with needle of a dial indicator between the two, and is used for comparison of thickness of gear teeth and uniformity of pitch.

Pratt and Whitney Odontometers. Machy (N.Y.) v28 Aug 1922 p 1010–11 2 figs; Iron Age v110 July 27 1922 p 204. Instrument for testing gear teeth for uniformity of profiles and spacings. Odontometer for gears from ¾ to 4 diametral pitch is shown in fig. 1, and from 10 to 24 diametral pitch in fig. 2.

The Normal Chordal Thickness of a Worm Thread, A. FISHER. Machy (London) v20 Aug 10 1922 p 591–2 3 figs; Machy (London) v21 Oct 26 1922 p 118–9 4 figs. See abstracts under 9.3.

Machine for Measuring Gear Teeth. Eng v114 Sept 29 1922 p 410–1 9 figs. Describe machine by Vickers, for measuring errors in axial pitch and circumferential pitch of helical pinions. The pinion to be tested rests on rollers, and alongside and parallel to it is arranged a straight cylindrical shaft resting freely in vees and bearing an indicator.

The Van West Portable Gear Tooth Testing Appliance. Eng v115 Jan 19 1923 p 74. Simple and handy device for testing the accuracy of the axial pitch of helical gear teeth, and also the truth of the alinement of the pinions and wheels when in place.

Normal Pitch as a Basic Factor in Computing Involute Gears, E. SHELDON. Am Mach v58 Feb 22 1923 p 285–7. A factor based upon parallelism of involutes; does away with many complications and takes account of profile errors as well as errors of spacing; normal pitch easy to measure.

Measuring Tooth Thickness of Involute Gear, E. WILDHABER. Am Mach v59 Oct 11, 1923 p 551–2 1 fig. New method for involute spur gears which is not affected by errors in outside diameter; ordinary vernier caliper used; formula for standard measurement.

Measuring Tooth Thickness of Helical Involute Gears, E. WILDHABER. Am Mach v59 n16 Oct 18 1923 p 587–8 2 figs. There are straight lines along involute surfaces having an inclination equal to the helix angle in the base circle. For actual involute surfaces all of the straight contour lines of the teeth in any one gear are parallel and equidistant. The tooth thickness of helical involute gears may be determined easily and accurately by measuring the distance between the straight contours of outside tooth surfaces, using an ordinary vernier caliper.

Zeiss Optical Gear Tooth Micrometer. Am Mach v59 Dec 27 1923 p 964. For direct reading of the chordal thickness of the tooth at the pitch line, and the addendum. In setting the jaws the tool is held close to the eye and two clear scales, engraved on glass, are seen by looking through the small aperture at the center. The range is from 18 to 1½ diametral pitch and graduations read to 0.001 in., estimating to 0.0001 in.

Measuring Variations in the Pitch of Gear Teeth, G. A. LUERS. Machy (N.Y.) v30 June 1924 p 799–800. Indicating gage for testing the spacing of groups of gear teeth.

Normal Pitch—the Index of Gear Performance, G. M. EATON. ASME Trans v47 paper 1973 1925 p 587–617 20 figs. Brings out certain departures from previously accepted practice which are useful in manufacture of heavy involute gearing, as they ease performance during breaking-in stage of operation; shows that material improvement in performance may be secured by adopting proper relation between normal pitches of driving and driven gears, measured at point of tooth engagement; outlines development of normal pitch indicators. Normal pitch and chordal pitch indicators are illustrated.

A Quick Method for Obtaining Gear Tooth Caliper Settings, H. WALKER. Machy (London) v29 Oct 7 1926 p 17 1 fig. Usual method of measuring size of gear tooth is by means of calipers placed across tooth; points of calipers touch tooth profiles where latter are intersected by pitch line; gives close approximate method for obtaining correction for height of arc which renders reference to such tables unnecessary. Formulas for constant chord gaging.

Gleason Tooth-Spacing Tester. Machy (N.Y.) v33 Nov 1926 p 230 2 figs. Gears of any type can be conveniently checked for accuracy of tooth spacing by means of tester now being placed on market by Gleason Works, Rochester, N.Y., which is equipped with optimeter, an optical device having scale graduated to 0.00005 in.

Now Possible to Measure "Normal" Pitch of Involute Gear, B. WHEELER. Automotive Industries v57 Aug 6 1927 p 186–90 17 figs. Instruments designed to gage distance

between corresponding involute contours on consecutive teeth measured along line perpendicular or normal to contours. Detailed description of use of a normal pitch indicator, which is provided with a locating leg.

Measurement of the Thickness of Involute Gear Teeth, A. H. CANDEE. Am Mach v68 Mar 15 and Apr 5 1928 p 463–7 7 figs and 573–6 2 figs. For abstract see subsection 9.3.

Laying Out and Checking Involute Tooth Forms, F. W. SHAW. Machy (London) v35 Jan 2 1930 p 441–446 Jan 16 p 513–9 11 figs. Jan. 2: How spur tooth forms can be set out or checked by their coordinate dimensions; fallacy of proposition that Grant Odontograph for 15-deg. involute might be usable for 20-deg. involute if contour arcs as tabluated were described from centers on base circles corresponding to obliquity of 20 deg. Trigonometrical functions and the involute function, inv ϕ, (although not yet designated by that symbol, coined by Buckingham in 1928) are used in calculations based on numerical tables given (with examples) in the second article (Jan. 16). For details of these tables see abstracts in subsections 10.1.3.1 and 10.1.3.3, p 217 and 220. The span measurement of involute spur teeth is covered in both articles but without the benefit of special numerical tables.

A Simple Method of Determining the Tooth Thickness of Spur and Spiral Gears, J. W. HAYES. Machy (London) v36 Apr 17 1930 p 69–71 2 figs. Discussion Machy (London) v36 May 29 1930 p 279. Method is not as universally applied to measuring of above types of gears as its simplicity merits; it eliminates the necessity of using pins or rollers placed in tooth spaces, and abolishes tedious calculations involved in ascertaining distance over rollers; disadvantages of roller method; advantages of present method.

Checking Gear Teeth for Smoother Operation, E. N. TWOGOOD. Machy (London) v36 Apr 17 1930 p 82–3 3 figs. Describes methods and fixtures used in checking the concentricity and uniformity of spaces and thicknesses of teeth.

Constant Chord Gaging, W. A. J. CHAPMAN. Am Mach v72 May 8 1930 p 753–4 3 figs; v73 n7 Aug 7 p 250–2 3 figs. Constant-chord method differs from means of tooth measurement now in use solely in computations involved; substitution of constant for variable measurements of gears; since pitch and pressure angle are uniform in set or train of gears, whereas tooth number usually differs, measurements are greatly simplified by possibility of using constant dimensions for chordal length and depth.

The Involute as a Conic Section, F. W. SHAW. Machy (London) v36 June 26 1930 p 405–8 and July 17 p 492–5 13 figs. June 26: How involute functions; points on producing involute; relationships between circular and rectilinear movement in involute cams; varying stroke of involute cam. July 17: Description of method for rectifying involute and relation of arcs and sectors; kinematics of involute cam; notes on involute as parabola.

Sykes Model E Gear-Tooth Comparator. Am Mach v73 July 10 1930 p 70–1. This gear-tooth comparator uses the chordal method and eliminates the necessity of having to use an instrument with two scales. The instrument is a development of the Sykes gear-tooth vernier caliper. Both jaws of the instrument are movable, but the dial indicator spindle is stationary. In addition, the dial gage is adjustable in the holder. Consequently, it is not necessary to change the plunger or spindle of the dial gage for gaging fine and coarse pitch gears.

Constant Chord Gaging. Am Mach v73 n6 Aug 7 1930 p 250–2 4 figs. Summary of comments received on W. A. J. Chapman's article published in Am Mach v72 p 753. V-jawed caliper can be used with existing gear tables;

gear-tooth vernier is proposed to use constant chord principle without special computations.

Gear Cutter Comparator, F. W. SHAW. Am Mach v75 n22 Nov 26 1931 p 803 1 fig. Cutter rolls in relation to steel tapes upon its base circle instead of upon its pitch circle; pressure angle is zero and angle of testing rack tooth zero; device utilized also for testing accuracy of tooth spacing.

New Gear Tester. Automobile Engr v23 n307 June 1933 p 198. Design of S. I. P. optical gear tester evolved for measurement of inaccuracies in pitch and eccentricity.

Messen von Zahndicken bei Stirnraedern (Measurement of Tooth Thickness of Spur Gears), H. HEINSSEN. Maschinenbau v12 n17–18 Sept 1933 p 454–5. Indirect method by measurement of difference between teeth with aid of cylindrical gages; example of application.

New Machine for Measuring Normal Pitch of Gears. Machy (N.Y.) v40 n9 May 1934 p 545. Semiautomatic machine built by Illinois Tool Works, Chicago, Ill., for rapid measurement or normal pitch and space of spur, helical, worm or bevel gears.

Pitch Measurement of Gears I and II, F. W. SHAW. Mech Wld v98 n2549 and 2550 Nov 8 1935 p 451–2 and Nov 15 p 475–6. Possible errors, measurements that can be taken, and instruments that can be used, offer more ways of attempting to check accuracy than are useful; problem analyzed and practical methods discussed.

Contribution a l'Étude des Engrenages (Contribution to Study of Gears), RENAUDIN. Arts & Metiers n191 Aug 1936 p 161–4. Outline of method for measurements of tooth thickness.

Neuartige kopfkreisfreie Zahndicken-Messungen fuer Schraegzahnraeder und Evolventen-Schnecken (Novel Method of measuring tooth thickness for involute helical gears and involute worms without use of addendum circle), W. F. VOGEL. Werkzeugmaschine v41 n11 June 15, 1937 p 253–61. Theoretical mathematical analysis of methods and their application to ball and span measurements. Deals also with pertinent involute spur gear measurements. Bibliography. See detailed abstract in subsection 9.3.

Zur Messung des Summenteilungsfehlers an Zahnraedern und Teilscheiben (Measurement of Error in Overall Circular Pitch Distribution on Gears), K. BUERGER. Werkstattstechnik und Werksleiter v31 n18 Sept 15 1937 p 406–8. Outline of methods and description of new testing equipment.

Zur Praxis der Zahndicken- und Lueckenweite-Messverfahren fuer Evolventen-Stirnraeder (Practical Hints and Outline of Methods for Measurement of Tooth Thickness and Spacing Between Teeth of Involute Gears). K. BUERGER. Werkstattstechnik und Werksleiter v32 n7 Apr 1 1938 p 169–76, 10 figs. Contents: The classification of the different common measuring methods. The concept of the effective tooth thickness (influence of the eccentricity errors). The necessary basic equations for the single measuring methods. Method Ia: Direct measurement of the tooth thickness as a chord of a circular segment. II Direct measurement of tooth thickness with notched measuring piece. IIIa and IIIb Direct measurement of the tooth spacing with inserted plug gages. IV Measurement of tooth span. Results of investigation. Conclusions.

The Chordal Gaging of Spur Gear Teeth, R. PARKES. Machy (N.Y.) v45 n5 Jan 1939 p 326–7. Deals with span measurements for a given number of involute spur teeth, diametral pitch, and pressure angle for control of backlash. Includes selector-table and table of span dimen-

sions for 1 DP. For details see summary table under subsection 10.1.3.5.

Checking Spur Gear Teeth, F. W. SHAW. Mach Wld v105 n2725 Mar 24 1939 p 289–91. Base tangent system described; method (sometimes designated as "span measurement") obviates uncertainties attendant on use of ordinary tooth vernier caliper; measurement is unaffected by differences in diameters of blanks or their eccentricity or by wear in instrument.

Application of Involute Trigonometry to Gear Gauging, F. W. SHAW. Machy (London) v55 n1427 Feb 1940 p 545–7. Complementing information contained in E. Buckingham's "Manual of Gear Design" (Machinery Publishing Co.), article aims mainly at facilitating calculation of caliper measurement of gears by certain of systems therein described; Buckingham's notation employed, but some additions have been made; theoretical mathematical study.

Improved Method of Measuring Thickness of Spur Gear Teeth. R. OLDFIELD. Machy (London) v57 n1471 Dec 19 1940 p 321–3. Details of system of tooth measurement which will eliminate disadvantages of gear tooth caliper method; diagrams given.

Constant Chord Gear-tooth Caliper Settings for Corrected Gears at Standard or Extended Centres. E. E. DAVIES. Machy (London) v58 n1507 Aug 28 1941 p 595–9. Explanation of method of finding correction factor for gear to be measured; from this correction factor, corresponding gear tooth caliper settings can be obtained from tables which are given.

Measuring Gear Tooth Thickness, C. A. YOUNG. Am Mach v86 n7 Apr 2 1942 p 278–9. Simple method described, which avoids errors resulting from variation in gear diameters; two rolls, T-bar and conventional gear tooth caliper used and calculation necessary can be made in drafting room.

Method of Measuring Thickness of Helical Involute Gear Teeth, J. REIMER. Machy (London) v64 n1639 Mar 9 1944 p 266–8. Checking tooth thickness of helical gears by method of measuring across number of teeth; method is independent of outside diameter; it does not require special measuring instruments; it can be applied easily without removing gear from cutting machine; faces of gage, and not corners of edges, are used for measuring.

Improved Gear Tooth Vernier. Passenger Transport J v91 n2305 Sept 8 1944 p 219–30; Transport Wld v96 n3073 Sept 14 1944 p 226; Engr v178 n4625 Sept 1 1944 p 170. Illustrated description of simplified type developed by David Brown & Sons (Huddersfield) Ltd. for span measurement; instrument has advantage of only requiring setting to linear dimension between fixed and moving anvils; measurements are over number of teeth and, as anvils are tangent to tooth flanks definite "feel" is obtained as in using micrometer on cylindrical object, no height measurement being involved.

Gauging of Involute Gear Teeth. Eng v158 n4116 Dec 1 1944 p 426; Engr v178 n4640 Dec 15 1944 p 479. Illustrated description of micrometer for checking tooth thickness of spur or helical gears, developed by David Brown and Sons, Huddersfield; method is commonly known as base tangent method.

Chordal Measurement of Corrected Gears, F. A. BIRCHER. Machy (London) v70 n1799 Apr 17 1947 p

399–401. Explanation of geometry of engagement of enlarged or reduced gears, and use of standard tables showing how appropriate table sizes may be adjusted to suit corrected gears.

Le "Ve-Comparateur" pour le Contrôle de l'Epaisseur des Dentures (V-Comparator for Control of Gear Tooth Thickness), J. BERGERE. Pratique Indus Mécaniques v30 n8, 10 Aug 1947 p 235–42, Oct p 303–11. Description of device and method which can be applied without removing gear from machine; practical applications to various types of gear.

Measuring Chordal Dimension of Helical Involute Gears, A. BUDNICK. Machy (London) v73 n1870 Aug 26 1948 p 314–6. Equations and application of method based on characteristics of circular involute, that normals to tooth flanks are tangent to base circle of gear; measurement is made over definite number of teeth, and gives sum of integral number of pitches and thickness of one tooth, measured on line of action or on base circle.

Checking Gear Tooth Thickness with Variable Center-Distance Gage, L. D. MARTIN, Machy (N.Y.) v 60 n2 Oct 1953 p 205–6.

Span Measurement of Involute Gear Teeth, J. E. VAN ACKER. Machy (London) v86 n2200, 2204 Jan 14 1955 p 66–73, Feb 11 p 292–7. Before AGMA. Span system of measurement involves measurement over two or more teeth, and possesses universal application and high degree of accuracy; formulas presented which are applicable to all spur and helical gears of all proportions and under all conditions of operation; tables of involute and trigonometric functions provided to facilitate span measurement calculations; worked out examples show use of formulas and tables. See also numerical details under subsection 10.1.3.5.

Inspection of Cumulative Circular Pitch on High-Precision Gears, J. LOXHAM. Inst Mech Engrs (advance copy Aug 6, 1958). Describes Sigma gear measuring machine.

Base-Tangent Measurement of Gear-Tooth Thickness, W. A. TUPLIN. Machy (London) v94 n2424 Apr 29 1959 p 948–50. Basic dimensions of involute, spur and helical gears; derivation of base tangent measurement over pins or rollers of given diameter; converse problems; caliper settings; formulas are expressed in terms of lengths that are either given or can be calculated and no reference to trigonometric tables is necessary.

Hoefler Electronic Inspection Equipment for Gears. Machy (London) v98 n2526 Apr 12 1961 p 829–31. Description of German-built EVZM measuring head set up on Lieherr L. 3200 hobbing machine for checking large diameter helical gear for tooth thickness and concentricity; measuring head, and others in Hoefler range, is intended to be connected to electronic base unit incorporating paper strip recorder; equipment may be employed also for checking spur gears, worms, bevel gears, and racks, for pitch accuracy.

Datchik dlya kontrolya izmeritel'nogo mezhtsentrovogo rasstoyaniya na odnom zube (Gage for Checking Measured Center Distance Over 1 Gear Tooth), I. V. MAZURENKO. Stanki i Instrument n9 Sept 1962 p 19–21; see also English translation in Machines & Tooling v33 n9 1962 p 22–5. Gage and electric circuit described are suitable for automating inspection of center distance variations over 1 gear tooth; rejection errors during tests on gage did not exceed plus or minus 3 μ; consequently, gage is suitable for inspecting gears with accuracy not exceeding 7th Class.

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10.3. Bevel, Hypoid, Spiroid, and Worm Gears or Drives

For measurement of worms see also subsections 9.2, 9.3 and 9.4.

German Bevel Gear Testing Device. Machy (N.Y.) v14 Feb 1908 p 377. Protractor for testing the accuracy with which the teeth of bevel gears are cut. Comprises two pivoted arms which are provided with sliding blocks carrying pivots on which are mounted the gears to be tested.

Testing Spur and Bevel Gearing. Internal Combustion Eng Oct 16 1912 p 341 4 figs. British machine by Parkinson and Sons in which bevel gear and pinion are run together and errors are recorded on a chart.

Making and Testing Bevel Driving Gears. Am Mach v38 June 5 1913 p 945–52 12 figs. Method of the White Co. on large bevel driving gear of rear axle. Testing of parallelism of front and back faces is shown in fig. 7. Device is an indicating fixture having a row of balls in a horizontal race just large enough in diameter to support the gear by its outer edge. Fig. 8 shows a fixture for testing tooth bearing of mating bevel gears. Fig 9 shows testing spur gears on bench centers with an indicating surface gage.

The Testing of Worms and Worm Wheels. Mech Engr Nov 14 1913. Illustrated description of apparatus designed by Percy Brown and Francis J. Bostock for the purpose of ascertaining the accuracy of worms and worm wheels.

Spur and Bevel Gear Testing Machine at the National Physical Laboratory, T. E. STANTON. Eng v109 Mar 12 1920 p 334–5 7 figs. Describes Daimler-Lanchester worm-gear testing machine for direct measurement of ratio of torque of driving and driven shafts.

Chordal Thickness of Tooth and Corrected Pitch Depth of Bevel Gears, C. W. MAPES. Machy (N.Y.) v27 Oct 1920 p 169–70 1 fig. Diagram showing dimensions and angles used in determining chordal thickness and corrected pitch depth of bevel gear teeth.

Testing the Accuracy of Teeth of Bevel Gears (Messrs. Saurer). Machy (London) v18 1921 p 717.

The Saurer Bevel Gear Testing Machine. Eng v113 Feb 24 1922 p 228–9 9 figs. Bed of machine is heavy, circular casting, upon which a pair of sliding heads can be locked in any position, so that angle between axes of heads corresponds to that of bevels to be tested, a range from 52 to 150 deg. being obtainable.

The Normal Thickness of a Worm Thread, E. A. LIMMING. Machy (London) v20 Sept 7 1922 p 707–8 1 fig.; v21 Dec 21 1922 p 360–2 4 figs. Apr 21 p 114; May 10 p 191; July 12 p 475 and Sept 20 p 795. See abstracts under 9.3.

The Normal Chordal Thickness of a Worm Thread, A. FISHER. Machy (London) v21 Oct 26 1922 p 118–9 4 figs. Points out that problem of determining normal is not same as determining minimum chordal thickness, and that common term, normal thickness, appears to have different interpretations.

Dial Gage Device Used with Success to Test Spiral Bevel Gears, P. M. HELDT. Automotive Indus v48 May 17 1923 p 1088–9 4 figs. Machine developed to determine inaccuracy of tooth outline and errors of indexing adapted to check correctness of curvature.

Double Helical Bevel Gear-Testing Jig. Machy (London) v23 Feb 28 1924 p 711 3 figs. Special jig for testing both

accuracy and truth of apex in double helical bevel wheels, as used in automobile back-axle drives.

Testing and Adjusting Spiral Bevel Gear Drives for Automobiles. Am Mach v61 Nov 27 1924 p 848–9 14 figs. Printed by permission of The Gleason Works, Rochester, N.Y.

Worm Gear Inspection and Testing, G. H. ACKER. Automotive Indus v57 Oct 29 1927 p 662–3 1 fig. Potential sources of error in worm gearing that must be guarded against by suitable inspection are: eccentricity and correct sizing of worm, index, lead, and profile of worm thread, angle of gear, eccentricity of gear and silence.

Gleason 90-Inch Bevel Gear Testing Machine. Am Mach v67 Dec 1 1927 p 882; Machy (N.Y.) v34 Dec 1927 p 311 1 fig.; Iron Age v120 Dec 1 1927 p 1522 1 fig. Machine for testing for quietness and proper tooth bearing of bevel gears up to 90-in. diameter. The machine is driven by 10 h.p. motor mounted on the drive head, and the spindle may be revolved in either direction. A friction brake on the driven spindle permits testing the gears under load.

Gleason Combination Lapping and Testing Machine. Machy (N.Y.) v35 Dec 1928 p 303 1 fig. Details of 18-in. combination testing and lapping machine developed by Gleason Works, Rochester, for use in production of spiral-bevel and hypoid gears; gears are first tested in this machine after being cut, to determine tooth bearing; after hardening, they are again tested, both for bearing and noise; brake on gear or driven head enables gears to be tested under load.

Gleason 3-In. Bevel Gear Testing Machine. Am Mach v73 Aug 21 1930 p 335–6. This machine is designed to test running qualities of straight and spiral bevel gears of smaller sizes whose shafts intersect at 90 deg. Bevel gears are tested by running them together in pairs or with a reference gear, to check the cutting machine for correct set-up. Gears are also tested after hardening for both tooth bearing and noise, and to determine if the heat-treatment has made changes that must be compensated for in cutting. Gears can be tested with or without load as desired. The pinion spindle is power-driven, and is operated in either direction by push button control. The pinion head is adjustable horizontally on the frame.

Gleason 18-in. Hydraulically Operated Testing and Lapping Machine. Am Mach v73 Oct 16 1930 p 642–3. Both spiral bevel and hypoid gears can be tested and lapped on this 18-in. machine. After the gears are placed on the spindles, the machine is entirely automatic in operation. It is hydraulically operated, and the automatic features and timing are electrically controlled. The automatic control mechanism reverses the direction of rotation of the gears after a predetermined length of time. Time of lapping may be adjusted from 30 sec. to 33 min. per side, and the total time may be varied. The driven head is mounted on a column adjustable horizontally on the frame. This driven head has a vertical adjustment also to permit lapping hypoids. An adjustable back-lash brake, operating on the gear spindle, is provided to maintain an even load during lapping.

Gleason No. 13 Universal Gear Testing Machine. Am Mach v73 Dec 4 1930 p 903. Straight and spiral bevels with any shaft angle, hypoids, helicals, angular helicals, internal, herringbone and spur gears can all be tested on the No. 13 universal testing machine. The driver or pinion spindle can be run in either direction. It is mounted on a head which can be adjusted vertically. The gear or drive head has three adjustments. Specifications: Capacity, 13 in., range of off-set, above center 8 in., below center 2 in.; max. center distance for spurs,

worms, and worm-wheels, 8 in.; minimum and maximum position of nose of drive spindle from cone center of gear to be tested, 4 and 10 in.; minimum and maximum positions of nose of brake spindle from cone center of gear to be tested −5 and +10 in., and net weight 3,500 lbs.

Accuracy in Gaging Gears. J. A. POTTER. Am Mach v74 Feb 19 1931 p 325–7 8 figs. Detailed description of methods of determining depth of tooth at pitch line of spur, bevel, and helical gears by means of a micrometer having a conical measuring contact. Also illustrates a bevel-gear measuring device which uses a dial indicator with sine-bar angle adjustment.

Schranbgetriebe, ihre mogliche und ihre zweckmassigste Ausbildung (Screw Drives, Their Possibilities and Their Most Suitable Development), F. G. ALTMANN. VDI Verlag GMBH Berlin NW7 1932 30p 73figs 36 refs. See abstract in subsection 10.1.2, p. 215. *Compiler's comment:* This paper contains the most complete bibliography on worm gear drives to an incl. 1932.

Zeiss Gear Testing Machine. Am Mach v76 p 218 Feb 11 1932 2 p 5 illus. Measuring precision to 0.0001″ combined with rapid operation are features of this instrument. The gear tester will take spur, bevel, helical, and worm gears and test the following elements; Circular pitch, eccentricity, uniformity of tooth spaces, and uniformity of tooth thickness. The gear is placed between centers, where it can be revolved to bring successive teeth into position.

Analytische Untersuchung des zylindrischen Schneckentriebes mit gerader, die Achse Schneidender Erzeugender (Analytical Investigation of Cylindrical Worm Drive with Straight, Axial Worm Profile), W. F. VOGEL. Omnitypie-Gesellschaft, Stuttgart 1933. See abstract in subsection 10.1.2, p. 215.

Eins neues Messgeraet fuer Waelzfraeser (New Measuring Gage for Worm Hob Milling Cutters). A. FIESELER. Werkstattstechnik und Werksleiter v29 n 14 July 15 1935 p 276–8. Equipment and its application for measurement of profile of pitch, circular pitch and testing of cutting face.

Gauging of Worm-Gears, N. CUMBERLAND. Machy (London) v60 n1536 Mar 19 1942 p 218–9. Description of gage fixture in which component is held between centers, one fixed and other adjustable in use, work is placed between centers and roller or plug is passed between teeth of work and pad.

Messeinrichtungen fuer den Austauschbau von Kegelraedern mit geraden Zaehnen. (Measuring Equipment for Interchangeable Manufacture of Bevel Gears with Straight Teeth.) G. APITZ. VDI Zeit v87 n23/24 June 12 1943 p 366–7. Recommendations made for selection and operation of apparatus for this purpose.

Basic Relationships of Bevel Gears, E. WILDHABER. Am Mach v89 n20 21 22 Sept 27 1945 p 99–102, Oct 11 p 118–21, Oct 25 p 122–5. Analysis of bevel gear relationships; characteristics, as compared to spur gears; review of basic bevel gear formulas; gear generating principles discussed. Oct 11: Observation of tooth normals in providing relative curvature analysis for estimating load capacity of gear tooth surfaces. Oct 25: Special analysis of gear mesh for clarifying curvature conditions of spiral bevel gears wherein individual curvature radii at all points of line of contact are immediately apparent.

Basic Relationship of Hypoid Gears, E. WILDHABER. Am Mach v90 n4 5 6 12 13 15 16 17 Feb 14 1946 p 108–11, Feb 28 p 131–4, Mar 14 p 132–5, June 6 p 110–4, June 20 p 150–2, July 18 p 106–10, Aug 1 p 104–6, Aug 15 p 122–8. Feb 14: Relative motion, kinematic pitch angles, relative translation and direction of instantaneous

axis and instantaneous turning motion about it, considered and determined by geometrical calculations pointed out. Feb 28: Required pressure angles for balanced tooth action indicated. Mar 14: Generation of hypoid pairs; helical segment formulas. June 6: Discussion of tooth contact and development of method for finding required tooth profile curvature. June 20: Conjugate action of hypoid gears, and its effect on their capacity explained. July 18: Gear tooth sliding. Aug 1: Screw hypoid gears. Aug 15: Design for duplex cutting: formulas; examples.

Universal Worm Gear Testing Machine. Engr v184 n4788 Oct 31 1947 p 418; Eng v164 n4269 Nov 21 1947 p 488 · Automobile Engr v38 n499 Mar 1948 p 117–8. Illustrated description of new machine being made by David Brown Tool Co. to provide accurate yet rapid means of checking all dimensions upon which performance and interchangeability of worm depends, and for testing finished wheels in conjunction with master worm.

Pruefen und Tolerieren bei der Fertigung von Getriebeschnecken (Testing and Gaging in Worm Gear Manufacture), H. M. HIERSIG. Werkstatt und Betrieb v81 n9 Sept 1948 p 242–7. Measurement of errors in profile, pitch and eccentricity; accuracy conditions for interchangeability, grinding of involute profiles by shaped and flat wheels; pitch errors more important than tooth thickness errors; backlash between worm teeth and wheel must be greater than in cylindrical wheels; diagrammatic drawings.

Pin Measurement of Face Gears, J. SILVAGI, V. FRANCIS. Am Mach v96 May 12, 1952 p 183–7 4 figs; Van Keuren Catalog and Handb n36 1955 p 248–50 2 figs. See abstract under 10.1.4.

Beveloid Gearing, A. S. BEAM, Mach Design v26 Dec 1954 p 220 (15 p) 23 figs 2 refs. The beveloid gear is an involute gear with tapered tooth thickness and, in most cases, tapered outside diameter. All sections normal to the axis have a common base-circle diameter and thus the same involutes, but the tooth thickness at any diameter increases linearly from the front to the back faces of the gear. Beveloid gears represent the most general form of involute gearing, and they can be engaged with spur gears, helical gears, worms, racks, and other beveloid gears. They can be used with parallel, intersecting, or skew shafts and offer advantages in precision, versatility, and backlash control not previously anticipated. *Compiler's comment:* Beveloid Gears have been known as Conical Involute Gears (Merritt 1955 and earlier editions, see subsection 10.1.2), but were exclusively proposed for meshing with each other in parallel-axes gearing with the purpose of eliminating backlash. Only for this type of mutual axis arrangement will beveloid gears yield linecontact.

The Mathematical Background of Spiroid Gears, O. SAARI. Industrial Mathematics, Detroit, v7 1956 9 figs. Spiroid gears are considered as a generalized form of worm gearing. Develops the general first-order gear tooth action law and its application to skew-axis gear design.

Design of Worm and Spiral Gears, E. BUCKINGHAM, H. H. RYFFEL. Industrial Press, New York 1960 450 p figs tables. Provides (1) a step-by-step guide to the design of worm and spiral gear drives (crossed-axes helical gears) with all-recess action and (2) presents certain basic principles and practices which enter into the successful design and manufacture of gears and gear drives of several types. Chapter 1 deals specifically with worm gear geometry.

Inspection of the Common Normal Generating Lines of Sraight Bevel Gears. P. M. DANILYUK. Meas Techn 1958 n6 Mar 1960 p 633–8 5 figs. Translated from Izmer

Tekh n6 Nov–Dec 1958 p 18.   New method of common normal checking, eliminating need for teeth faces to make contact with flat surface of measuring device, which reduces accuracy of conventional methods by indirect inspection of tooth thickness of spur gears; suggested method is suitable for measuring various types of small, medium and large module gears.

Checking Thickness of Straight-Tooth Bevel Gear Teeth By Their Edges, P. M. DANILYUK. Meas Techn 1960 n1 Nov 1960 p 17–9 3 figs 2 refs.   Translated from Izmer Tekh n1 1960 p 14. Theoretical basis of new method of checking size of straight bevel gear teeth by using balls which run over their edges and measuring distance between extreme points of two balls, inserted into diametrically opposite tooth spaces of gear wheel, these spaces being formed by crossing of side bevel surfaces with additional external bevel surface.

Goulder Testing Machines for Worms and Worm-Wheels. Machy (London) v98 n2537 June 28 1961 p 1473–5. Three machines described; type 2H "long bed" lead tester for worms up to 8 in. diam, with integral shafts up to 54 in. long; No. 3 testing machine for large-diameter hobs and worms; No. 4/3 machine specially designed for checking worm drives which have wheels ranging from 3 to 48 in. diam; light- and heavy-duty saddles are provided which are brought into use as required, according to size of worm gears to be tested.

Mesure de L'Épaisseur de Dent des Dentures D'Engrenages coniques droits (Measurement of Tooth Thickness of Straight Bevel Gears), H. L. DEBY. Rev M v8 n1 1962 p 1–6. How method used for cylindrical gears may be extended to bevel gears by changing one term in formula.

Narezanie vysokokachestvennykh konicheskikh zubchatykh koles na stankakh mod. 5A2T83 i 5A2T84 (Cutting high quality bevel gears on model 5A2T83 and 5A2T84 machines), N. F. KABATOV. Stanki i Instrument n4 Apr 1962 p 12–18; see also English translation in Machines & Tooling v33 n4 1962 p 14–20. Machine setting calculations are given on which jobbing method developed by W. Gleason is based, and that insures reliable check of width, height and inclination of field of contact when cutting spiral bevel gears with teeth reducing in depth; gear and pinion are cut by cutters with alternating teeth, and having number of teeth considerably greater than calculated number.

Mesure de l'épaisseur de dent des dentures d'engrenages coniques droits (Measurement of tooth thickness of straight bevel gears), H. L. DEBY. Rev M v49 n4 1963 p 156–62. Reference is made to description of method in author's article indexed in Engineering Index 1963 p 804; tables are presented which make it possible to eliminate all complex calculations, thereby considerably facilitating application of this method.

Wormgear Standardization Envisages, W. A. TUPLIN. Engr v215 n5603 June 14 1963 p 1066–9. Recently published Brit Standard Specification for Worm Gearing (BS 721, 1963) is considered in relation to worm gear design with regard to both form and dimensions, and in relation to earlier standards; advance made in present standard in defining worm-thread form in terms of basic rack of B.S. 436 is especially mentioned, but it is also noted that worms of "preferred" and "second-choice" dimensions have 5600 different normal pitches.

Addendum to Section 10

10.1.1.   Standards and Nomenclature

Die DIN–Verzahnungstoleranzen und ihre Anwendung (The DIN Gear Tolerances and their Application), G. APITZ, A. BUDNICK, K. KECK, W. KRUMME, H. K. HELLMICH. Friedr. Vieweg und Sohn, Braunschweig 4th ed 1960 31 p 25 refs plus 13 illus and DIN 3960 and 3964 and 3967. No. 13 of series of publications issued by Fachgemeinschaft Getriebe und Antriebselemente im Verein Deutscher Maschinenbau-Anstalten. Contents: The economic significance of gear tolerance systems. Construction of the DIN-tolerance system. Gear qualities in reference to transmission capability, quietness, and accuracy of form. Gear qualities in reference to cost of manufacture. Influences of the gear fits: tooth thickness, tooth space, and axial distance. Establishment of the quality and gear matching. Calculation of general tolerance specifications in the DIN-System specifications. Relationship between tolerances and production processes. Comparison of the German standards for gear tolerances with those of other countries. Glossary.

10.2.5.   Tooth Index Position Measurement

Gear Inspection, J. F. JONES, Jr. AGMA 129.15 June 1962 15p 19 figs. Fellows No. 8 tooth index measuring instrument is illustarted in Figs. 1 to 5. It is stated that the recording system in the machine has sufficient sensitivity and magnification to provide indications to 0.00001 in. The chart produced by the machine has graduations which can be calibrated to 0.000010 in. and obviously estimating is possible.

Section 11. Measurement of Thickness of Thin Films

CONTENTS

11.1. Interferometric Methods

Optische Experimental-Untersuchen; ueber Newton'sche Farbenringe und totale Reflexion des Lichtes bei Metallen (Optical Experimental Investigations; Regarding Newton's Colored Rings and Total Reflection of the Light by Metals) G. QUINCKE. Ann der Phys und Chemie v129 n2 1866 p 177–218 6 figs. To determine the thickness of a metal layer on a plane glass plate the author applied two different methods, both of which are based on the observation of Newton's rings. Experimental results using silver and gold are given.

Ueber die Bestimmung der Constanten für die Absorption des Lichts in Metallischen Silber (Regarding the Determination of the Constants for the Absorption of Light in Metallic Silver). W. WERNICKE. Ann der Phys und Chemie 2ser v8 n1 1878 p 65–82 5 refs. Deals with the production of plane-parallel layers of silver, measurement of the absorbed light, and determination of the thickness of the thin layers, by interference methods.

Ueber die Phasenänderung des Lichtes bei der Reflexion und Methoden zur Dickenbestimmung dünner Blättchen (Regarding the Phase Change of Light by Reflection and Methods for Determination of Thickness of Thin Laminae), O. WIENER. Ann der Physik und Chemie 3ser v31 n8 1887 p 629–72 13 figs. Discusses previous methods of Quincke and Wernicke for thickness determination of thin laminae in general. Develops new methods for both metallic and nonmetallic laminae. Investigates questions as to whether phase change at perpendicular reflection is a retardation or acceleration. Evaluates interference method and determines relation of thickness and color to the amount of phase change. Describes more accurate experiments. Draws five conclusions.

Ueber die Phasenänderung des Lichtes bei der Reflexion an Metallen (Regarding the Phase Change of Light by Reflection on Metals), P. DRUDE. Ann der Phys und Chemie 3ser v51 n12 1893 p 595–624, v51 1894 p 77–104 6 figs. See abstract in subsection 2.2.5.

Ueber normale und anomale Phasenänderung bei der Reflexion des Lichtes an Metallen (Regarding Normal and Anomalous Phase Changes with the Reflection of Light by Metals), W. WERNICKE, Ann der Phys und Chemie 3ser v51 n3 1894 p448–59 6 figs. See abstract in subsection 2.2.5.

Ein einfaches Interferometer zur Messung kleiner Schichtdicken (Simple Interferometer for Measuring Small Layer Thickness), H. FROMHERZ, W. MENSCHICK. Zeit Phys Chem v2 abt B Apr 1929 p 399–404 2 figs. Apparatus and method of operation are described; layer thicknesses of 2 flat bulbs of about 10 and 50 microns thickness were measured to 0.2 per cent.

Silica Gauge for Measuring Thickness by Means of Interference Colors, K. B. BLODGETT. Rev Sci Instrum v12 n1 Jan 1941 p 10–4. Details of construction of gages for measuring thickness of monomolecular films by means of interference of light; monolayers of various substances can be deposited on top of silica film, and thickness of monolayer determined from change in intensity of reflected light produced by added thickness; equations are given for calculating thickness.

Measurement of Thickness of Thin Films, A. F. GUNN, R. A. SCOTT. Nature (London) v158 p 621 Nov 2 1946. Tolansky's technique was used to measure the "step" at the edge of films of collodion, silica and gold of thickness of 100Å and above, supported on a smooth glass plate (e.g. lantern slide cover). Discussion by K. W. PLESSNER, Nature (London) v158 Dec 21 1946 p 915 1 fig 2 refs.

Interferometric Determination of Apparent Thickness of Coatings, W. K. DONALDSON, A. KHAMSAVI. Nature (London) v159 Feb 15 1947 p 228–9 1 fig 6 refs. Describes techniques for depositing film on a high-grade flat and using the reflected film system for measuring thickness.

Coating Thickness Measurement by Interferometry, M. F. BECHTOLD. J Opt Soc Am v37 Oct 1947 p 873–8. Thickness measurements of thin transparent coatings on thick transparent bases by reflection interferometry are made possible through use of an immersion medium of the same refractive index as the base to intensify interference. A convenient interferometer comprising three essential parts, a "pocket" spectroscope, an incandescent lamp and a cylindrical immersion tank, is described. Its use for rapid, precise measurements of thickness of single and double layer coatings and films in the range of 0.2 to 50μ is illustrated with spectra.

Thickness of Inhibiting Films on Glass Electrode Surfaces, D. HUBBARD, G. F. RYNDERS. J Res NBS v41 Sept 1948 p 163–8. The thickness of voltage-inhibiting films produced on glass surfaces by heat treatment after leaching has been studied by means of the glass electrode and the interferometer. The glass electrode gave conspicuous voltage departures (errors) and alternations (swelling) of the surface that were just detectable by the interferometer. This corresponds to approximately 0.01 fringe, or $4\times$ the unit cell dimension for cristobalite. The inhibiting effect of films of electric conductors, such as metallic Ag, has been qualitatively compared with the inhibiting effect of films prepared from electric non-conductors, such as petrolatum and silicone stopcock grease.

Interferometric Determination of the Apparent Thickness of Thin Metallic Films, D. G. AVERY. Letter in Nature (London) v163 June 11 1949 p 916. In connection with the method for determining film thickness by depositing an opaque reflecting layer over the edge of the film and then (interferometrically) measuring the step, evidence is presented showing that there is a "packing-in" effect. Presumably this is due to filling up of the interstices in the film. It is suggested that use of this method may lead to errors of up to 30%.

Interferometric Evaluation of Thicknesses of Thin Films, S. TOLANSKY. J Phys Radium v11 July 1950 p 373–4. A study is made of the validity of the multiple-beam interferometric method for measuring the thickness of thin films. For a Ag film the deposit is made to cover part of an optical flat, and over this is evaporated a much thicker metal film. The step height is measured interferometrically. It is shown that the height measured is affected by the nature of the superposed metal. When Ag is superposed on an Ag film the final step value found is 25% less than that when Cr is deposited on an Ag film. The effect is considered to be due to bedding in of the superposed film on to the porous thin film. Studies are made with intermediate films of cryolite and MgF_2.

Interferometric Method for Accurate Thickness Measurements of Thin Evaporated Films, L. G. SCHULZ. J Opt Soc Am v40 n16 Oct 1950 p 690–2. Fabry-Perot interferometer used directly to measure thickness of uniform thin films to accuracy of $\pm 15A$; separation of D-lines of sodium light used as standard of length; method evaluated by comparison with other methods and in terms of applications and limitations.

The arrangement for the Measurement of Small Film Thicknesses, G. C. MÖNCH. Optik v8 n12 1951 p 550–60 in German. A description is given of optical arrangements for measuring thin film thicknesses by making use of the interference double prism of Kösters. Methods are described whereby the thicknesses of evaporated metal films and also of thin celluloid films and varnish films can be made. Full constructional details are supplied for the mounting. Measurements can be made with white light or with monochromatic light.

The Investigation of "Thick" Metal Films and Their Surface Layers With the Aid of the Absolute Phases, H. SCHOPPER. Zeit Phys v130 n4 1951 p 427–44 in German. A method is described for the determination of the refractive index within metal layers and by this means the refractive index for Ag is found to be 0.11 for the green Hg line. In addition the thickness of the transition layer between the metal and support of the surface film on the air side are evaluated. The surface layer can be followed down to thickness of only a few molecules. The method described is an interference method using slits. Data are reported for Ag on quartz and for silver-iodide surface layers.

Some Applications of Interferometry to the Examination of an Electrodeposited Film, S. TOLANSKY. J Electrodepos Tech Soc v27 Paper 6 1951 8 p. Multiplebeam interference methods are applied to the examination of bright tin-nickel electrodeposit on polished brass. It is shown by precision interferometry that the electrodeposit contours surface irregularities as small as 1 micro-inch, although the deposit is thick as 200 micro-inches. The thickness of the deposit can be measured by the fringes to within 1 micro-inch by visual inspection alone. Some hardness micro-indentation tests are reported using a Vickers pyramid. Although the pyramid penetrates the deposited film yet an apparent increase in surface hardness is found.

The Effect of Phase Changes in White Light Interferometry, L. G. SCHULZ. J Opt Soc Am v41 Apr 1951 p 261–4. The phase change accompanying the reflection of white light from metal films was studied experimentally by interferometric methods. As predicted by electromagnetic theory, the phase change was found to vary with the wavelength of light. Corrections for this variation must be made in white light multiple-beam interferometry if the full sensitivity of the method is to be used in making thickness measurements. Practical suggestions are given for making the required corrections. It is demonstrated experimentally and theoretically that these corrections are practically independent of the film thickness. Precise measurements of phase changes on Ag films gave results closely consistent with those calculated from published values of the optical constants of Ag. No such agreement was found for Al.

Measurement of Thickness of Thin Films by Multiplebeam Interferometry, O. S. HEAVENS. Phys Soc-Proc v64 pt5 n377B May 1 1951 p 419–25. Study of measurements of thin films by multiple beam Fizeau fringes in order to assess accuracy attainable; application of method to examination of small scale irregularities on surfaces of glass plates and flats used in thickness determinations; measurements of films of lithium fluoride and of silver using five different metals as reflecting layers. The results for the different reflecting layers show agreement to within the observational error provided that measurements are made within a short time of the preparation of the film. With Ag as the reflecting layer an accuracy of ± 10 Å can be expected if suitable precautions are taken. Bibliography.

The Measurement of Thin Film Thickness by Interferometry, S. TOLANSKY. Letter in J Opt Soc Am v41 June 1951 p 425–6. A critical analysis of a method recently proposed by Schulz for measuring thin film thickness by a Fabry-Perot interference method. A number of optical defects are pointed out. These apply mainly if the method is used in transmission with thin metal films. A number of the objections raised do not apply if measurements are made on dielectric films, or on metal films using reflection instead of transmission methods.

Interferometer for Thickness Measurement of Thin Transparent Film, N. SIDJAK. Can J Technol v29 n7 July 1951 p 362–70. Interferometer described; measurement involving only counting of dark interference bands in continuous spectrum is particularly suited to measurement of mica and other thin transparent materials used for windows on counters and apparatus employed in work on radioactive substances.

The Interference of Thin Films and the Estimation of Their Thickness, G. C. MÖNCH. Optik v9 n2 1952 p 75–83 in German. A rapid estimation of the thickness of thin films from interference colours is described. A simple interferometric system involving slits permits the approximate thickness to be derived from the table of interference colours given. The table is calibrated by means of altering the angle of inclination of the light on the thin film. Interference colours are given for films of thickness from 0–900 Å. There is a good deal of objective judgment required in estimating the colours.

Measurement of Thickness of Microscopic Objects Using Three-Beam Interference, B. MENZEL. Note in Naturwiss v39 n17 1952 p 398–9 in German. A microscope modification of a technique formerly described, wherein the thickness of a thin object is obtained from change in localization of fringes produced by three slits. A microscopic reduced image of the three slits is projected on to the small object on the microscope stage and by observing changes in localization of fringes with beams going through and missing the microscopic object, thicknesses can be measured as small as 100 A units.

The Limit of Accuracy in the Measurement of the Thickness of a Thin Film Using the Kösters Interference Double

Prism, U. ZORLL. Optik v9 n10 1952 p 449–55 in German. An arrangement permitting the application of photometric methods is described. Fringe width is narrowed by multi-photographic copying and this permits an accurate measurement of fringe separation. Three photometric methods of evaluating displacements are described. The method permits the measurement of the thickness of deposited thin films. A square centimetre film can be measured with the thickness down to about 20 mμ.

A Discussion on Friction: An Optical Method of Measuring the Thickness of Adsorbed Monolayers. J. S. COURTNEY-PRATT. Proc Roy Soc A v212 May 22 1952 p 505–8. The interferometric techniques developed by Tolansky have been used to study films adsorbed on solid surfaces. A monomolecular layer of fatty acid was spread by the retraction technique over part of a selected facet of a piece of mica. A highly reflecting layer of silver was then deposited on both sides of the mica specimen, and the thickness of the acid layer determined by multiple reflection interferometry. The values so obtained were in agreement with X-ray data on the length of the fatty-acid molecule. Examination showed that the layers were uniform in thickness; polymolecular layers were absent. The method provides direct and independent evidence that molecules of a fatty acid, spread by the retraction technique, are adsorbed on a solid surface as a uniform monomolecular layer.

Ein interferenzoptisches Gerät zur Messung der Dicke dünner Metallschichten (An Interference Apparatus for Measurement of the Thickness of Thin Metal Layers), M. DÜHMKE, G. GEORGI. Metall v7 n23/24 1953 p 1000–2 7 figs. 4 refs. Describes an interference method and apparatus for measurement of layer thicknesses in the range from several microns to a few millimicrons within an uncertainty of +1 mμ.

An Interferometer Microscope for the Accurate Measurement of Optical Thickness. J. DYSON. Letter in Nature (London) v171 Apr 25 1953 p 743–4. A polarization-interference microscope arrangement is described for the determination of the thickness of thin transparent films. The interferometric phase difference is determined with a modified half-wave plate. Settings to within a quarter degree can be made, corresponding to a path difference of 0.003 wave-lengths in interference film.

Film Thickness Measurement for Grating Blanks, F. A. McNALLY. Letter in J Opt Soc Am v48 June 1953 p 540. A simple interferometric method for the measurement of the thickness of metallic films deposited on grating blanks is described. The method can be applied to films greater than 500 Å in thickness.

Fringes of Equal Reflection Coefficient Ratio and Their Application to Determination of Thickness and Refractive Index of Monomolecular Films, R. E. HARTMAN, R. S. HARTMAN, K. LARSON, J. B. BATEMAN. J. Opt Soc Am v44 n3 Mar 1954 p 192–206. Production of families of spectral fringes by use of surfaces having equal reflection coefficient ratios; applications in determining thickness and refractive index of monomolecular films; determination of thickness and refractive index of barium stearate double layers. Films prepared by the method of Blodgett, but using a different piston oil, were found to have a thickness of 45.7 Å and an ordinary refractive index of 1.508.

Simple Interference Prisms for the Evaluation of the Thickness of Thin Films, G. C. MÖNCH. Optik v12 n5 1955 p 226–32 in German. A variety of prisms in interferometric arrangements is described using in each case right-angled prisms. The systems are somewhat related but different from that of the Kösters double prism. The prism mounts are described in detail and illustrated

schematically. Application of the interferometric system to the measurement of thin films is considered and an example quoted.

Tolansky Gauge for Rapid Measurement of Film Thickness, T. M. GREEN, L. N. HADLEY. Letter in J Opt Soc Am v45 n3 Mar 1955 p 228–9. A device is described which speeds up the measurement of thin film thickness when using the method of multiple-beam interference fringes. It is based on the displacement produced by an inclined glass plate. An image of the fringes is projected on to a glass plate which is itself viewed by a lens system. The angle to produce one fringe shift is determined. The angle to eliminate the fringe shift due to the stepped film is then measured. From these the mean fringe displacement from several fringes is rapidly evaluated. An accuracy of 50 Å in film thickness obtains.

The Influence of Dispersion on the Optical Determination of the Thickness of Thin Films, G. KOPPELMANN, K. KREBS. J Phys v145 n4 1956 p 486–95 in Russian. The dispersion in reflectivity measurements of vacuum-evaporated ZnS films was determined and the effect of the dispersion on the thickness determination was investigated theoretically and experimentally. The results are expected to hold in general for any thin film showing interference effects.

Neuere optische Verfahren zum Bestimmen der Dicke dünnster Schichten (New Optical Methods for Determining Thickness of Very Thin Films), H. SCHOPPER. Forschung auf dem Gebiete des Ingenieurwesens (Ed B) v22 n2 1956 p 56–62. Includes corrosion films; new interferometer arrangements, which can include intensity compensation, or with which phase can be measured by comparison of intensity; examples of thickness measurement of thin metal layers and tarnish films. Bibliography.

Interferometric Evaluation of Thickness and Shape Using the Two-Sided Technique, G. SCHULZ. Optik v13 n9 1956 p 404–10 in German. A method is described for measuring the thickness of transparent or opaque thin films using a Michelson interferometer type of arrangement (interference microscope) with incident illumination. A knowledge of the refractive index is not needed. The interference pictures obtained are sharpened by the equidensity photographic procedure. Fringe patterns from the two sides are copied on to one plate and this offers information about thickness variations from point to point. A CdS microcrystal is examined as an example.

On the Thickness and the Dispersion of the Refractive Index of Thin Aluminium Oxide Layers, M. HENNIG. Zeit Phys v144 n1–3 1956 p 296–310 in German. The dependence of the thickness of the layer of aluminium oxide films on the oxidation voltage is studied interferometrically. Measurements are made for different ammonium citrate concentrations. The relation is found between the film thickness and the formation voltage. The refractive index measurements are made for different wavelengths. The refractive index in the range 3600 to 6500 Å decreases from 1.577 to 1.560. In the region 4360 Å a dispersion anomaly is established.

Measurement of the Thickness of Thin Films by Multiple-Beam Interference, C. WEAVER, P. BENJAMIN. Nature (London) v177 June 2 1956 p 1030–1. Experiments have been carried out on the measurement of the thickness of thin silver films, using both silver and chromium as the overlayer material. A standard experimental procedure was adopted for the deposition of these films, which were evaporated on to selected glass microscope slides. The thicknesses of the silver films were measured by multiple-beam interference fringes of equal thickness viewed in reflection. The results indicate that when the chromium overlayer is opaque, then there is no discrepancy in the thickness of the silver films as measured by the two differ-

ent overlayers. However, when the chromium overlayer is not opaque, then a discrepancy of the type found by Avery occurs. The discrepancy in the thickness measurements when a non-opaque chromium layer is used may be caused by a difference in the phase change at reflection on the two sides of the step-edge since the underlying substances are different.

Recent Attempts to Determine the Thickness and Refractive Index of Unimolecular Films, R. D. MATTUCK. J Opt Soc Am v46 n8 Aug 1956 p 615–20. The Hartman method for measuring the thickness and refractive index of nonabsorbing unimolecular films is investigated. Both theoretical and experimental evidence lead to unfavourable conclusions. A test experiment is reported in which the Hartman method is used to measure the optical constants of barium stearate multilayers from 50 Å to 250 Å in thickness. The results obtained disagree with the relatively wellknown properties of barium stearate films. To determine the cause of the disagreement, the method is investigated theoretically. It is shown by numerical calculation and algebraic analysis that, in terms of the present accuracy of the optical measurements involved, the Hartman method is too insensitive to be of practical use for films of molecular thickness.

The use of an Interference Microscope for Measurement of Extremely Thin Surface Layers, W. L. BOND, F. M. SMITS. Bell Systems Tech J v35 n5 Sept 1956 p 1209–21. A method is given for the thickness measurement of p-type or n-type surface layers on semiconductors. This method requires the use of samples with optically flat and reflecting surfaces. The surface is lapped at a small angle in order to expose the p–n junction. After detecting and marking the p–n junction, the thickness is measured by an interference microscope. Another application of the equipment is the measurement of steps in a surface. The thickness range measurable is from 5×10^{-6} cm to 10^{-3} cm.

Calculator for Thin Film Measurement, W. A. FEIBELMAN. J Opt Soc Am v46 n11 Nov 1956 p 994–5. The design and operation of a calculator for determining thin film thicknesses measured by the multiple beam interferometer method is described. A photograph of the instrument and layout of the calculator dial are included.

Thickness Measurement of Microscopic Objects by Three-Slit and Two-Slit Interference (Probe Method), E. MENZEL. Optik v14 n4 Apr 1957 p 151–64 in German. A commercial microscope for direct and reflected illumination is adapted for the measurement of thickness by triple-slit interference. The object plane together with the reduced image of the triple slit is projected to infinity and observed by means of a telescope. The characteristic planes of interference are now equidistant and will appear in the telescope after insertion of a cylindrical lens the axial displacement of which may be read off. Phase contrast facilitates the required covering of the two slits. A filament lamp together with filters provide the light source. The arrangement may also serve to measure longer path-differences using then the double-slit interference. The two methods are particularly suitable for the measurement of the thickness of microtome sections and thin films.

Corrections of Interference Thickness Measurements of Thin Films on Account of Boundary Reflections, P. J. LINDBERG. Optica Acta v4 n2 June 1957 p 59–68. Multiple-beam interferences show a remarkable effect owing to boundary reflections when a transparent film is interposed between the interferometer flats. Similar conditions occur in all interferometric thickness measurements of transparent films. The phase-shift so caused is calculated and represented in diagrams with rolling circles. Measurements were made with multiple-beam interference on zinc sulphide films deposited on silver, and the results agreed satisfactorily with the calculations.

If the boundary reflections are neglected in the case of multiple-beam interference, the error in the determination of the film thickness is at most about $\lambda/2\pi$, even if the difference in refractive index is small. The consequences of this are considered for the interferometric measurement of biological specimens.

The Measurement of Thin Films by Interferometry, J. DYSON. Physica v24 n6 1958 p 532–7. In view of the high accuracy of comparison of path-differences attainable in polarimetry, experiments were made to achieve some of this accuracy in thin film measurements. It is shown experimentally that setting accuracies are obtainable corresponding to an error of thickness measurement of ± 1 Å.

Measurement of Thickness of Films Using Equal-Chromatic-Order Lines, I. N. SHKLYAREVSKII. Optika i Spektrosk v5 n5 1958 p 617–19 in Russian. In 1945 Tolansky used equal-chromatic-order lines in the study of the topography of almost plane surfaces, using white light. Later Sinel'nikov and Rapp (1950) and the author (1954, 1956) applied Tolansky's method to the thickness measurement of films deposited in vacuo on glass plates. A scratch is made across such a film. The film is then covered (by vacuum deposition) by an opaque layer of silver which repeats the scratch contours forming a small step. The height of this step is equal to the original film thickness. A second glass plate is covered by a semitransparent layer of silver. The two plates are pressed together and are placed in front of a spectrograph slit in such a way as to position the step, referred to above, at right angles to the slit. These plates are illuminated with a parallel beam of white light. An achromatic lens is used to focus the air gap between the glass plates on to a spectrograph slit. In the focal plane of the spectrograph camera objective two systems of equal-chromatic-order lines are observed and the separation between the two systems of lines is a function of the original film thickness. The paper gives formulae necessary for the calculation of thickness from the observed interference pattern.

Remarks on the Three Slit Method, A. C. S. VAN HEEL. Physica v24 n6 1958 p 529–31. The three-slit method of Zernike is adapted to the Francon crystal interferometer for the measurement of the thickness of a thin film of area as small as 0.1 mm². The advantage of placing the slits in the frontal focal plane is discussed. Thickness changes with time are reported for MgF₂ films.

The Determination of the Thickness, Dielectric Constant, and Other Properties of Anodic Oxide Films on Tantalum from the Interference Colours, L. YOUNG. Proc Roy Soc A v 244 Feb 25 1958 p 41–53. The thickness of anodic oxide (Ta₂O₅) films on chemically polished tantalum was determined from the wavelengths of the minima in the specular reflectivity using a value of the refractive index of 2.20 ± 0.02 at 5900 Å which was measured on detached flakes of the oxide by the immersion method. An auxiliary measure of increments of thickness was required for the analysis of the spectrophotometric measurements. This was provided by the quantity $(Q\Delta(1/C))^{\frac{1}{2}}$, where Q was the charge which was required to form the increment of thickness, and $\Delta(1/C)$ was the corresponding increase in the reciprocal capacity. This measure of thickness, like that provided by the colours, is independent of the area. The analysis gives the refractive index between 2800 and 6000 Å, the net phase-change in the two reflections (with certain assumptions), and a value of ϵ/ρ, where ϵ is the effective dielectric constant under the conditions used, and ρ is the density; ρ was determined by weighing specimens in air and water. The value obtained for ρ was 7.93 (error $\pm 3\%$), which gives $\epsilon = 27.6$ (error $\pm 5\%$), at 1 kc/s. The effective surface area was then calculated, and was found to be very little different from the apparent area. The field strength during the formation of oxide at 9.55 mA/cm² and 25.8° C

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was found to be $6.61 \times 10^6 \text{V/cm}$ and to be constant within experimental error, independent of thickness.

Optical Apparatus for Depth Sensing, U. GERHARDT. Optik v15 n2-3 Feb-Mar 1958 p 132-4, in German. An interference microscope was used to determine the distance between two nearly coplanar parallel faces of two metal end gauges wrung together. Using both white light and monochromatic light, accuracy of a fraction of a micron is claimed. Observations could be made at up to 70 cm from the gauges.

Some Methods for Measurements on Thin Films, A. C. S. VAN HEEL, A. WALTHER. Optica Acta v5 n 1-2 Mar-June 1958 p 47-52. Four modifications of Francon's interference eyepiece are given which enable one to measure the step in a wave-front and at the same time the light-loss. As it is possible to carry out measurements while depositing the layer, the methods described can be used for monitoring purposes, the non-optical windows not doing much harm to the appearance of the field of view. With the available apparatus a precision in the determination of the light path of $\lambda/200$ is easily obtainable for all layer thicknesses.

Nondestructive Interferometric Thickness Measurement of Thin Transparent Films, R. L. SAUER. J Opt Soc Am v48 n4 Apr 1958 p 275. The thickness of anodic oxide coating of A1 is measured interferometrically in the range 0.00005 to 0.01 inch.

An Application of Tolansky's Method to the Measurement of Films with Variable Thickness, A. HEISEN. Zeit InstrumKde v66 n5 May 1958 p 87-91 in German. Multiple-beam fringes of equal thickness are applied to the evaluation of step heights (film thickness). It is shown how the method can be applied to a film of constant thickness, or to a wedge film in which there is regular increase of thickness, or an irregular change. It is described how measurements can be made when the steps are either perpendicular to, or alternately in the direction of, the change in thickness. With thin films which are not too absorbing the refractive index can be obtained.

Eine Anwendung des Tolanskyverfahrens zur Messung von Schichten mit sich aendernder Dicke (Application of Tolansky Techniques to Measurement of Films with Varying Thickness), A. HEISEN. Zeit InstrumKde v66 n5 May 1958 p 87-91. Thickness measurement by means of multiple beam fringes of equal thickness on steps parallel and normal to direction of increasing thickness.

Thickness Measurement of Epitaxially Grown Films, O. S. HEAVENS. D. C. PANDEYA. Nature (London) v181 May 17 1958 p 1394. The thicknesses of Fe and Ni films grown on a rocksalt substrate were determined by floating the film off the rocksalt on to a glass flat where, by silvering the film edge and using Fizeau fringes, the step-height was measured. The results agreed, within the accuracy of measurement (± 20 A), with those for similar films deposited simultaneously, but directly, on glass. The films were deposited at room temperature and were 130 to 450 A thick.

Measurement of the Optical Constants of Thin Dielectric Films by Means of Frustrated Total Reflection, B. P. SANFORD. J Opt Soc Am v48 n7 July 1958 p 482-6. It is shown that the transmission of light through a thin dielectric film under conditions of frustrated total reflection can be used to measure the refractive index and thickness of the film. The refractive index and thickness were measured for each of several magnesium fluoride films. The thickness was checked in each case by multiple beam interference and the refractive index compared with the results obtained by other authors for similar films. It appears that many present concepts on which the theory of the optical properties of thermally evaporated films is based are inadequate for the problems involved.

The Interferometric Measurement of Metal Oxide Films, J. C. KELLY. Optica Acta v5 n3-4 Sept-Dec 1958 p 75-8. A method is described for investigating oxide films in situ on the metal surface. The method yields the surface finish of the inside and outside surfaces of a metal oxide film, its volume ratio, its thickness and the location of the original surface with respect to the two oxide surfaces. All this information is contained in a single photograph provided the refractive index of the oxide is known. Some results for anodic oxide films on aluminium are given.

Errors in the Measurement of Film Thickness by Multiple-Beam Interferometry, C. WEAVER, P. BENJAMIN. Nature (London) v182 Oct 25 1958 p 1149-50. It is shown that an error in estimating thin-film thickness by interferometry can arise, if the step edge is produced on the film by a scratching technique. The substrate (glass) can be deformed appreciably, to an extent depending on the scratching load. Even light loads of as low as 5 gm can induce error or as much as 18 A and a 100 gm load leads to a 273 A error. This method of scratching the film is considered unsatisfactory.

Obtaining Low Orders of Interference in Measuring Film Thicknesses by Multiple Beam Interferometry. G. D. SCOTT. J Opt Soc Am v48 n11 Nov 1958 p 858. In multiple-beam interferometry as used for the measurement of the thickness of thin films it is desirable to use low orders by bringing the surfaces very close together. A holder is described for mounting on a microscope stage which permits easy manipulation for this purpose.

A Haidinger Interferometer with Linear Scale for Thickness Separation of the Plane Parallel Plates, R. RIEKHER. Optik v15 n12 Dec 1958 p 713-23 in German. An instrument for measuring separation between plane parallel plates is described, using Haidinger's rings. By employing a parabolic mechanical linkage the instrument works on a linear scale. Use of the system is described. Errors are discussed.

Measurement of the Thickness of Very Fine Transparent Films by the Interference Method, B. GADŽUK. Slaboproudy Obzor v20 n2 1959 p 85-7 in Czech. A beam of white light is directed, at an angle of less than 90°, on to the film, and the interference fringes observed, the number of the fringes being directly proportional to the thickness of the film. The method is suitable for the measurement of the glass foils in image orthicons having a thickness of $1-10\mu$. It can also be employed for the measurement of films up to 100μ.

Zero Point One, A. M. DEXTER, JR. ASTE 59 Tech Paper 195 1959 20 p. Presented at the April 29, 1958 meeting of the American Society of Tool Engineers, Hartford Chapter. Describes and discusses wringing films of various media between gage blocks and measurement of film thicknesses.

Control of Thickness of Evaporated Layers During Evaporation, G. PAPP. Rev Sci Instrum v30 n10 Oct 1959 p 911-12. Method for control of evaporated layer thickness for transparent substances; progress of evaporation can be checked by method at any moment, simply by counting number of interference fringes on control plate located in vicinity of target.

A Thickness Measurement Technique Using a Three-Beam Interference Arrangement for Objects of Thickness Less than 1 Micron, H. WESTMEYER. Exper Tech Phys v8 n1 1960 p 18-25 in German. It is often required to know the thickness of an ultramicrotome section. An application of the Zernike three-beam interference method for

doing this measurement is described. The elementary theory of the method is reviewed, adjustments are described and a simple setup is discussed.

Measurement of the Optical Thickness of Absorbing Specimens with the Three-Beam Interferometer, P. HARIHARAN, D. SEN. J Sci Instrum v37 n11 Nov 1960 p 417–19. A simple modification of the three-beam interferometer is described which permits measurements of the optical thickness of absorbing specimens with a high degree of accuracy.

Interference Method for Measuring the Thickness of Epitaxially Grown Films, W. G. SPITZER, M. TANENBAUM. J App Phys (USA) v32 n4 Apr 1961 p 744–5. Since the dielectric constant of semiconductors is dependent on the carrier concentration, radiation can be reflected from the boundary between a heavily doped semiconductor and a lightly doped layer deposited on it by an epitaxial process. Interference effects will occur between the radiation reflected at the boundary and that reflected from the surface of the epitaxial layer, and the thickness of the layer can be deduced from the reflection spectrum. Results are given for layers of germanium and silicon.

Thickness Measurement of Epitaxial Films by the Infrared Interference Method, M. P. ALBERT, J. F. COMBS. J Electrochem Soc (USA) v109 n8 Aug 1962 p 709–13. The infrared interference measurement has proved to be an accurate and nondestructive means for evaluating the thickness of epitaxially grown films on silicon. The measuring technique is discussed and the necessary relationships are presented. A fringe wavelength versus film chart is constructed, which enables rapid thickness determination without calculation. The chart is derived for use with silicon films of relatively low carrier concentration deposited on silicon substrates of high carrier concentration (0.007 ohm cm N-type). The chart is most useful for low order interference fringes including 12th order. Similar charts are applicable for other semiconductor materials.

Ein Interferenzflaechenpruefer als Schichtdickenmessgeraet (Interference Device for Surface Testing Used as Film Thickness Measuring Device), M. DUEHMKE. Zeit InstrumKde v70 n12 Dec 1962 p 300–2. Application of interference microscope as multiple beam interferometer to measure thicknesses of thin films with accuracy of plus or minus 0.001 μm.

Apparatus for the Determination of the Thickness of Thin Films, YU. A. DURASOVA, E. N. RYBAK. Pribory i Tekh Eksper (USSR) 1963 n1 p 195–6 Jan–Feb in Russian. English translation in: Instrum exper Tech (USA). Tolansky's fringes were used to determine the thickness to within 10–15 A.

Thin Film Thickness Measurement Using Silver-Modified Newton's Rings, B. J. STERN. Rev Sci Instrum v34 n2 Feb 1963 p 152–5. Interference technique for measurement of electric films is described that consists of silvered lens placed over stepped film with silver overlay; resultant interference pattern, when viewed in reflection, is series of sharp dark rings against bright background; step in film to be measured causes shift in rings from which thickness is calculated; step heights in silver films, vacuum deposited on fire-polished microscope slides, of 160 and 780 A were measured.

Interference Method of Measuring the Thickness of Thin Transparent Flms, V. F. SHVETS. Meas Techns 1962 n7 Feb 1963 p 538–40 1 fig 1 ref. Translated from Izmer Tekh n7 p 5–6 July 1962. Method based on observing two sets of white light fringes, one from the film and one from the back surface. Various advantages are cited.

Interferometric Evaluation of Thickness of Canada Balsam and Collodion Films and Its Relation to Concentration of Solutions, N. BARAKAT, A. A. A. MOHAMED, A. EL BIALY, K. A. AZIM. Brit J App Phys v14 n3 Mar 1963 p 144–6. Thin films of collodion and Canada balsam were prepared on water surfaces. Their thickness was evaluated interferometrically over the range $\frac{1}{2}$–$\frac{1}{50}\lambda$ and the relation between concentration and thickness studied. The effect of temperature on film thickness was evaluated at 25, 100 and 150° C.

Very Precise Thickness Measurement of Thin Films, J. DYSON. Nature (GB) v197 Mar 23 1963 p 1193. Equality of path length between two polarized light beams in a modified interference microscope is detected photoelectrically, and film thickness may be determined to better than 1 angstrom unit.

Comparaison de Deux Méthodes de Mesure des Couches Minces d'Oxyde de Silicium (Comparison of Two Methods for Thickness Measurement of Silicon Oxide Thin Films), J. ENCINAS. Vide v18 n104 Mar–Apr 1963 p 95–9. Thickness determined from Newton's color scale using normal incidence; interference order is obtained by counting green rings which appear when each pit is made by fluorhydric acid droplet; second method consists of measuring displacement of monochromatic interference fringes; both methods are in very good agreement for thickness range 6.16–1.5 μ.

Dichroic Multiple Beam Interferometer Microscope, M. J. IRLAND, E. B. SCHERMER. Appl Optics (USA)·v2 n5 May 1963 p 540–1. A description is given of the preparation of multilayers of high abrasive resistance suitable for reflectors in multiple-beam interferometry especially for the measurement of the thickness of thin films. The reflector used for germanium measurement consists of a triple layer built from TiO_2 and SiO_2. This has a reflectivity of about 65% in the green and is almost transparent near 4700 A. The abrasion resistance is found to be extremely good and is more satisfactory than any metal or dielectric film previously used, remaining unmarred after 100 applications, whereas other films have shown significant damage after this much use.

Diffused Light Interferometry for Measurement of Isopachics. P. S. THEOCARIS. J Mech Phys Solids (GB) v11 May–June 1963 p 181–95. A simplified optical method, based on interference phenomena of diffused light, is described for the determination of isopachic patterns. The procedure consists in using a monochromatic diffused light beam to illuminate the model surface. If an optically flat glass plate, used as datum plane, is brought in contact with the model front surface an interference pattern is produced related to the thickness of the air-film between the datum plane and the surface of the model. Interference patterns before and after loading of the specimen allow the determination of isopachics. Curves of variation of interference fringes throughout the surface of the specimen, before their use for the determination of thickness variation, must be readjusted in a convenient scale as well as for the elimination of superimposed simple interference patterns due to arbitrary inclination of the datum optical plane before and after loading. The method does not necessitate a complicated equipment. It is straightforward and very sensitive. It can be applied to transparent as well as to opaque models made of metal sheets. It can also be used as a supplementary means to measure thickness-strains in the birefringent coating method. The surface of the model, though polished, could not be obligatorily optically flat. The method was applied to several illustrative examples with transparent and opaque models. The results obtained are in good agreement with those yielded by theoretical or other experimental solutions.

Interference Microscopy of Thin Films and Semiconductor Structures, A. E. FEUERSANGER. Solid State Design v4 n10 Oct 1963 p 29–32. Operating principles of dual beam interferometer are outlined, and its potential for

applications in measurements on variety of electronic devices in solid state research is discussed, including thickness and uniformity measurements of metallic and dielectric layers.

Nondestructive Determination of Thickness and Refractive Index of Transparent Films, W. A. PLISKIN, E. E. CON-RAD. IBM J Res & Development v8 n1 Jan 1964 p 43–51. Simple interferometric methods of determining thickness and refractive index of films on reflective substrates; sensitive method of obtaining thickness of films less than 1 μ by combined use of monochromatic filters and interference pattern chart; color chart for thicknesses of thermally grown SiO_2 films up to 1.5 μ thick.

11.2. Polarimetric Methods (Ellipsometry)

Ueber Oberflächenschichten (Regarding Surface Films), P. DRUDE. Ann der Phys und Chemie 3ser v36 n2 and 4, 1889 p 532–60, 865–97. Develops equations for relationships among optical constants and film thicknesses of transparent thin films, applying polarimetric methods.

Eine Methode zur Bestimmung der Dicke und optischen Konstanten dursichtiger Metallschichten (Determining Thickness and Optical Constants of Transparent Metal Films), W. BETZ. Ann d Physik v18 n8 Nov 21 1905 p 590–605. (Extract from Dissert, Leipzig, 1905.)—The required quantities were calculated from the elliptic polarisation of the transmitted light and observations of intensity, the method enabling the thickness, index, and coefficient of absorption to be determined simultaneously. The author's formulae were derived from the theoretical investigations of VOIGT and DRUDE [Wied. Ann 25, p 25 1885; and 43 p 126 1891]. His measures of elliptic polarisation were made with the spectrometer described by DRUDE [Optik p 238] and a banded compensator, as a compensator with homogeneous field gave too little light. A table of results for three silver and two copper mirrors is given. With gold and platinum, consistent results could not be obtained. Under the microscope with strong homogeneous immersion, a grain-like structure was discovered in the gold films, the grains being apparently diffraction phenomena due to small holes.

The Thickness of Spontaneously Deposited Photoelectrically Active Rubidium Films Measured Optically, H. E. IVES, A. L. JOHNSRUD. J Opt Soc Am and Rev Sci Instrum v15 Dec 1927 p 374–81. Measurements were made of the thin films which deposit in a high vacuum on polished platinum or glass, which are invisible, but which are photoelectrically sensitive to the same extent as thick layers. Plane polarised light, polarised at an azimuth of 45°, was directed on the surface, and the reflected light examined with a Babinet compensator and nicol prism, the shift of the azimuth or phase caused by the film being measured. The theory of the calculations of the thickness has been given by T. C. FRY. The result is that the layer of rubidium formed on glass is about one atom thick, but as the theory may not hold exactly for such thin films, it is possible that the actual thickness may be five or even ten atomic diameters. The effect of such a rubidium film on the optical behaviour of platinum is so small as to lie within the errors of observation, and this could not be measured.

Elliptical Reflexion and the Optical Study of Thin Layers, R. DE MALLEMANN, F. SUHNER. Rev. Dpt (Théor Instrum) v23 Jan–Mar 1944 p 20–38 in French. A lengthy survey is given of the theory and the derivation of formulae for the state of polarization of the reflected light in the case of two media in contact. The general case is considered for both isotropic and anisotropic media, after which the special case of thin layers is dealt with (from a thickness of 10 Å up to several microns). The argument is on geometrical lines. Details are also given of the experimental determination of the thickness and refractive index of thin layers, deposited on solids, using elliptically polarized light.

Ellipsometer, Apparatus to Measure Thickness of Thin Surface Films, A. ROTHEN. Rev Sci Instrum v16 n2 Feb 1945 p 26–30. Apparatus designed to determine thickness of films deposited on metal slides is described; based on measurement of change that takes place in ellipticity of light reflected after slide has been coated with film; apparatus is capable of measuring film thickness within ±0.3 A.

Optical Methods of Studying Films on Reflecting Bases Depending on Polarization and Interference Phenomena, A. B. WINTERBOTTOM. Trans Faraday Soc v42 June–July 1946 p 487–95. The optics of metals and of film-covered surfaces is discussed and a description given of the techniques employed in polarimetric investigations. A detailed account is also given of the methods of computing thickness/reflectivity curves and interference thicknesses based on strict film optics.

The Reflexion of Light from Glass with a Transparent Homogeneous Surface-Layer, M. BRDICKA. Bul Int Acad Tchèque Sci v48 1947 p 63–70. The electromagnetic equations are applied to a beam of light incident upon a thin surface layer on glass. These equations are transformed into a 5th order algebraic equation which can be solved to give the thickness and refractive index of the layer from practical measurements of the angle of refraction, the elliptical polarization of the reflected beam and the phase difference between the two components.

Polarimetric Methods for the Determination of the Refractive Index and the Thickness of Thin Films on Glass, A. VAŠIČEK. J Opt Soc Am v37 Mar 1947 p 145–53 623. A general method and various modifications are developed for the determination from polarimetric measurements of the reflected light, using plane polarized incident light. The mathematical problem involved cannot be solved in explicit form but, as shown by numerical examples, exact results can be obtained by graphical interpolation.

The Reflexion of Light from Glass with a Natural Transparent Inhomogeneous Surface Layer, M. BRDICKA. Bul Int Acad Tchèque Sci v49 1948 p 81–9. The reflected beam from a glass-air surface shows elliptical polarization which is believed to be due to the presence of a surface layer. The dielectric constant is assumed to vary within the layer in a regular manner with the distance from its surface. The electromagnetic equations then allow the mean refractive index and thickness of the layer to be determined from the amount of elliptical polarization and the phase differences. Experimental results show good agreement with calculated values.

Optical Determination of Thin Films on Reflecting Bases in Transparent Environments, A. B. WINTERBOTTOM. J Opt Soc Am v38 n12 Dec 1948 p 1074–82. The classical theory of metal and film optics is recapitulated and its implications in connection with various optical methods of studying films and surfaces are indicated. The experimental technique of determination of thin films in situ from the change produced in the reflection of a polarized wave is then outlined. Optical techniques are not advocated to supplant other methods of studying surfaces such as weight increment, gas absorption, electron diffraction, X-ray diffraction and electrochemical analysis, but rather to supplement these in selected cases. In particular, the optical techniques are of value in making continuous studies of films in situ in transparent environments when

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conditions render the application of other methods difficult. Examples of application are given.

Optical Measurements of Surface Films. I. A. ROTHEN, M. HANSON, Rev Sci Instrum v19 Dec 1948 p 839–41. Practical information is given concerning the calibration of an instrument called the ellipsometer, which is used to measure thicknesses from 1 Å up to >1000 Å of transparent films deposited on polished metal slides. It is a half-shadow instrument taking advantage of the ellipticity of polarized light reflected from film-coated metallic surfaces. The half-shadow is produced by depositing a different thickness of transparent material on the lower and upper part of the slides, or by evaporating a thin layer of Au directly on the lower part of Cr slides.

The Apparatus for Measuring the Thickness of the Thin Film on Metal Plate, Y. YONEYAMA, K. IMAHORI. Sci Papers College Gen Education Univ Tokyo v3 Dec 1953 p 145–50. The thickness of a film of denatured protein (1–300 Å) deposited on a metal slide is found by measurement of the change in ellipticity of light reflected from the slide before and after deposition. Standard polarized light techniques are employed using a half-shade analyser. Films of barium stearate of known thicknesses are used to calibrate the instrument.

Improved Method to Measure the Thickness of Thin Films with a Photoelectric Ellipsometer, A. ROTHEN. Rev Sci Instrum v28 n4 Apr 1957 p 283–5. Describes the advantages of a photoelectric ellipsometer over a visual instrument for the measurement of the thickness of films from 1 A up to many thousand A. Experimental curves are given showing the unambiguous correlation between film thickness and position of two rotating elements, a λ/4 plate and an analysing Nicol prism.

Note on the Limits of the Polarimetric Method of Thin Film Measurements, A. VAŠÍČEK. J Opt Soc Am v47 n6 June 1957 p 565–6. Details are given to support the statement that the method is able to indicate the existence of films having atomic dimensions and should permit accurate measurements for a film of thickness 10 A.

Comment on the Rothen Photoelectric Ellipsometer, R. D. MATTUCK, A ROTHEN. Rev Sci Instrum v28 n10 Oct 1957 p 844–5. Mattuck states that to determine film thickness d by the Rothen method a value for the refractive index n is essential. Refractive indexes cannot be determined for values of d less than 300 A, so that for such thicknesses the Rothen method cannot be used. Reference is made to a method that gives d and n simultaneously for the range from 10 to 250 A. Rothen states that his method refers to optical thicknesses, and for these the instrument is sensitive to changes of 0.1 Å in the range from 0 to 300 A.

Application of the Standardized Vašíček procedure to Nonabsorbing Singly Evaporated Films on Glass Substrates, J. RASSOW. Zeit Phys (Germany) v170 n4 1962 p 376–92 in German. The author modified Vašíček's polarimetric theory to a graphic method for determination of optical constants of thick homogeneous films on glass substrates. The method is verified for single layers deposited by heating salts. The kind of salt determines the gradient of the refractive index. This gradient and the state of the surface of the glass are responsible for deviations from the theoretical curves. A suitable method was found for determining the refractive index and the thickness of the deposited film. In a modified form the method can also be used for inhomogeneous films. Sometimes it is possible to determine a change in thickness less than 10 A during the deposition of the film. The thickness can be calculated accurately only by measuring at three different light-frequencies, because the curves are periodic. The values for the different light-frequencies agree well

with each other, differing only by about 5%. The agreement is much better for films thicker than 10 000 A. The thickness of the films as obtained by applying this method is almost identical with the one given by an interference microscope.

Testing the Standardized Vašíček Procedure, for Inhomogeneous Nonabsorbing Films on Glass Substrates. J. RASSOW. Zeit Phys (Germany) v170 n4 1962 p 393–408 in German. In the use of Vašíček's polarimetric method for a single layer, differences from the theoretical curves have been observed which can not be explained theoretically. These differences can be increased experimentally by the deposition of double films. The author suggests four rules, by which the inhomogenity of the films can be calculated from the measured curves. It is possible to determine the thickness and refractive index quantitatively and the index gradient approximately. For the same salt all the four possible types of inhomogenity can be produced. With the rules the differences in the results can be eliminated. The fifth rule limits the applicability of the four other rules.

Automatic Optical Thickness Gauge for Thin Film Measurements, T. P. MURRAY. Rev Sci Instrum (USA) v33 n2 Feb 1962 p 172–6. An automatic ellipsometer for measurement of the thickness of thin films in the monomolecular range is described. The instrument is capable of pushbutton operation by untrained personnel, and has been in use in an industrial laboratory for about two years.

Theoretical Treatment of Ellipsometry, F. PÀRTOVI. J. Opt Soc Am v52 n8 Aug 1962 p 918–25. Exact expressions are obtained in closed form for the phase and amplitude of the reflected light when a light beam is incident upon a multilayer of a number of homogeneous media. The assumption is made that Maxwell's equations and Ohm's law hold. These equations are applied to the special case of dielectric coated metals and the results are compared to ellipsometry measurements made in chromium slides covered with barium stearate films of known thickness. When the conductivity and the dielectric constant of the metal are allowed to assume complex values, and when precautions are taken to reduce the inaccuracy introduced by the residual oxide and gas layer on the metal, the agreement is good.

Determination of the Properties of Films on Silicon by the Method of Ellipsometry, R. J. ARCHER. J Opt Soc Am v52 n9 Sept 1962 p 970–7. The use of exact reflection theory to interpret data allows the application of ellipsometry to the determination of the thickness and optical constants of surface films without the thickness limitations of approximate theory. Ellipsometer measurements as a function of the thickness and optical constants of a variety of different films on silicon substantiate the predictions of exact theory and yield the properties of the films.

Theory of Frustrated Total Reflection Involving Metallic Surfaces, T. R. YOUNG, B. D. ROTHROCK. J. Res NBS (USA) v67A n2 Mar–Apr 1963 p 115–25; J Opt Soc Am v51 n9 Sept 1961 p 1038–9. The theory for frustrated total reflection was developed for the case where the third medium is metallic of complex index. Using parallel polarized light a unique minimum in reflectance occurs at a definite film thickness. Experimental verification of the theory is made and indicates the theory applicable to the precise measurement of thin contact films existing between metallic and dielectric surfaces.

Measurement of the Thickness and Refractive Index of Very Thin Films and the Optical Properties of Surfaces by Ellipsometry, F. L. McCRACKIN, E. PASSAGLIA, R. R. STROMBERG, H. L. STEINBERG. J Res NBS (USA) v67A n4 July–Aug 1963 p 363–77. The use of the ellipsometer for the measurement of the thickness

and refractive index of very thin films is reviewed. The Poincaré sphere representation of the state of polarization of light is developed and used to describe the reflection process. Details of the operation of the ellipsometer are examined critically. A computational method is presented by which the thickness of a film of known refractive index on a reflecting substrate of known optical constants may be calculated directly from the ellipsometer readings. A method for computing both the refractive index and thickness of an unknown film is also developed. These methods are applied to the determination of the thickness of an adsorbed water layer on chromium ferrotype plates and on gold surfaces. In the former case the thickness was 23–27 Å, and in the latter was 2 to 5 Å. The measurement of the thickness and refractive index of barium fluoride films evaporated on chromium ferrotype surfaces is used as an illustration of the simultaneous determination of these two quantities.

Some Observations on the Use of Elliptically Polarized Light to Study Metal Surfaces, F. P. MERTENS, P. THEROUX, R. C. PLUMB. J Opt Soc Am v53 n7 July 1963 p 788–96. Measurements and calculations using elliptically polarized light to determine the thickness and index of refraction of barium stearate films on a variety of substrates are described. Attention is focused especially upon problems associated with the study of very thin films, that is, films which are less than 100 Å thick. Measurements of the optical constants of metal substrates are presented. An apparent dependence of the index of refraction n and extinction coefficient k and independence of the absorption coefficient k upon the angle of incidence is observed and is discussed. Several effects, including accuracy and sensitivity, of the angle of incidence in studying film growth are noted. It is shown that there exists a characteristic angle of incidence at which the growth of a film produces a negligible change in the ellipticity, and it is shown how advantage may be taken of this to facilitate measurements of rapidly changing surfaces. It is demonstrated that extraneous films are satisfactorily accounted for in measuring thin films by means of the Drude equations through their effects upon the apparent optical constants of the substrate. Advantage may be taken of this fact to extend the thickness range over which the Drude linear equations are applicable by a computational procedure. The problem of the anomalous index of very thin films as determined by the Drude equation is considered. It is concluded that the anomalies revealed by the Drude equations are associated with the system under study and are not caused by any inherent limitation in the Drude equations. It appears that at the interface between a dielectric layer and metal system there is an absorbing region which produces the anomaly in the refractive index calculated by the Drude equations and for which explicit allowance must be made in order to make accurate measurements of the thickness of very thin films.

Photoelectronic Device for Measuring the Thickness of Thin Films, V. D. PEREVERTAEV, V. M. KUPRIYANOV, M. S. METSIK. Pribory Tekh Eksper (USSR) 1963 n3 May–June p 193–5 in Russian. English translation in Instrum Exper Tech (USA) n3 May–June 1963 ; publ. Nov. 1963 p 568–70. Describes an improved modulation method for anlyzing polarized light which is reflected from a material coated with a thin film.

Ellipsometry—A Valuable Tool in Surface Research, K. H. ZAININGER and A. G. REVESZ. RCA Rev (USA) v25 n1 Mar 1964 p 85–116. Ellipsometry is a technique that allows the determination of the optical properties of a surface, or the optical properties and thickness of a thin film, by measuring the effect of reflection on the state of polarization of polarized light. In this paper, the fundamental equation governing ellipsometry is developed starting from the problem of reflection and refraction of light at a boundary between two homogeneous, isotropic media, and reflection from a film-covered surface. A pictorial representation and the classical mathematical specification of polarized light is given. Various solutions of the ellipsometry equation are discussed, the actual ellipsometer is described, and experimental techniques are outlined. Areas of applications are summarized and the value of ellipsometry is examined in terms of possible errors and obtainable accuracy. Finally, some of the deviations in the optical properties of thin films from those of the bulk are briefly outlined.

Ellipsometry for Frustrated Total Relection. T. R. YOUNG, J. M. FATH. NBS Misc Publ 256 Sept 15 1964 p 349–59 4 figs 7 refs. The practical length of a gage block is dependent upon the thickness of the film between two contacting surfaces. The relationship between this wringing film thickness and its effect upon incident parallel and perpendicular polarization has been theoretically determined for the case where the light is incident upon the first or transmitting surface at an angle greater than the critical angle and where the second surface is metallic (complex index). The theoretical results indicate that when the optical constants of the two contacting surfaces and the wringing film are known, a polarization analysis of the reflected light by the methods of ellipsometry offers an extremely sensitive and unique determination of the wringing film thickness. Attempts to verify the theory experimentally are discussed.

Ellipsometry in the Measurement of Surfaces and Thin Films, Symposium Proceedings Washington 1963, E. PASSAGLIA, R. R. STROMBERG, J. KRUGER. NBS Misc Publ 256 Sept 15 1964. A symposium on the Ellipsometer and its Use in the Measurement of Surfaces was held at NBS in Sept 1963. This volume contains 19 of the papers included in the program, together with any discussions which followed oral presentation. Topics covered include historical review, theory, computational techniques, measurement techniques, and the use of ellipsometry in measuring metal surface oxide films and organic films.

11.3. Miscellaneous Methods

Eine neue Methode zur Dickenbestimmung dünner Blättchen (A new Method for Determining the Thickness of Films), C. H. SHARP. Ann Phys v3 n2 Oct 1900 p 210–20. The thickness of a thin deposit is obtained by making a model of it in a mixture of equal parts of colophonium and burgundy pitch. At the place where the thickness is to be determined, a small portion of the film is removed, and the mixture is laid on and warmed to 75° in a thermostat. It is lightly pressed in with the finger, after which the whole is allowed to cool slowly, and the impression is lifted off. It has a brilliant black surface. It is pressed on to a glass plate, and two systems of interference fringes are seen, one corresponding to the film and the other corresponding to the blank space. The discontinuity between

the two systems is indicated by a displacement of the fringes, and the amount of the displacement measures the thickness. The author has devised a special spectrometer arrangement for exact measurements. He has measured the thickness of various layers of gelatine by this method. When the impression is lifted off, it does not stick, owing to a slight contraction on cooling. This contraction, while sufficient to facilitate detachment, is not large enough to interfere with the correctness of the measurements, since the mixture remains practically liquid until it arrives at the ordinary temperature.

New Method of Thickness-Measurement of Metal Films, S. TANAKA. Tokyo Imperial Univ Aeronautical Res

Inst Rept v7 n91 Jan 1933 p 291–306 3 supp plates in English. Optical measuring methods and equipment for determining thickness of extremely thin sprayed on or chemically deposited metal films, applicable to thicknesses of less than 0.01 micron.

Thickness Measurement of Thin Coating by X-ray Absorption, H. FRIEDMAN, L. S. BIRKS. Rev. Sci Instrum v17 Mar 1946 p 99–101. The method is applicable to coating thicknesses in the range 10^{-5}–10^{-2} cm on crystalline bases. An X-ray source and a Geiger counter are both situated on the same side of the coating. The X-rays pass through the coating and are reflected at a Bragg diffraction angle from the base, back to the counter, their intensity being reduced by absorption due to the double transmission through the coating. The thickness of the coating is computed from the measured absorption.

On A Method for Measuring the Thickness of Thin Coating Films by Means of X-ray Reflex Photography, F. REGLER, Elektrotech und Maschinenbau [EuM] v65 July–Aug p 109–13 Sept–Oct 1948 p 148–52 in German. The general fundamentals of X-ray reflex photography and some known methods for the measurement of film thicknesses are discussed. A new method is described for measuring the thickness of a film deposited on a crystalline base. It utilizes the difference of absorption of X-rays diffracted by the base under different glancing angles. The measurement is preferably made by photometric evaluation of pictures taken with a conical or ring-film reflex system. The photometric method may be replaced by ionometric intensity measurement. Disturbances caused by the coincidence of lines, by a coarse grain structure or irregularities in the lattice structure of the base, may be overcome by special experimental means which are described in detail.

Direct Electron Microscopic Thickness Determinations of Ultramicroscopically Thin Crystals. J. H. L. WATSON, W. HELLER, W. J. WOJTOWICZ. Chem Phys v16 Oct 1948 p 999–1000. A procedure is described for measuring the thickness of platelets formed from a solution of tungstic acid. Intense electron bombardment of the supporting film (Formvar) near the platelet selected for measurement generally results in the film rupturing in a direction parallel to the major axis of the platelet. If the platelet adheres to the film, the net result is a rotation of the platelet about its major axis, from which its thickness may be determined. For a particular specimen the observed dimensions were 14.6μ long, 5.0μ wide and 0.35μ thick. In certain cases, the method may be used to compare the rigidity of colloidally thin crystals.

X-ray Measurement of the Thickness of Thin Films deposited on Microcrystalline Supports, C. LEGRAND, CR Acad Sci Paris v227 Oct 27 1948 p 831–3 in French. The method of Friedman and Birks is modified to avoid the necessity of constant tube output. Two reflections from the support are measured, the angle of incidence of the X-ray beam being chosen so that one emerges at a small angle α_1 ($\sim 3°$), the other at a larger angle α_2. If the ratio of the intensities for the bare support is R and for the coated support is R', the thickness ϵ is given by $\mu\epsilon(\sin \alpha_2 - \sin \alpha_1)/\sin \alpha_1 \sin \alpha_2 = \log R/R'$, where μ is the linear absorption coefficient of the coating.

Method for Measuring Extremely Small Non-Uniformities in Optical Thickness of Evaporated Films, A. E. GEE, H. D. POLSTER. J Opt Soc Am v39 n12 Dec 1949 p 1044–7. Methods for measuring half-widths of frustrated total reflection filters of very narrow pass bands; detection of extremely small non-uniformities in spacer layers of these filters. The latter method, permitting observation and measurement of thin film non-uniformities appreciably <1 unit cell provides a very sensitive means of studying thin film structures and the mechanism of formation.

The Determination of the Index [Refractive] and of the Thickness of Thin Transparent Films, F. ABELÈS. J Phys Radium v11 July 1950 p 310–14 in French. Spectrophotometric methods are surveyed; although simple, they are not generally applicable, failing for thicknesses below $\lambda/4$. A new method is described for evaluation of refractive indices involving determination of reflectivities for two different wavelengths. The method is applied to evaluating the refractive index of TiO_2. For a particular film the reflectivity as a function of wavelength is given for the range $\lambda\lambda 400$–$7\,500$ Å. For a thickness of 19 $m\mu$ the index found is 2.48 for $5\,000 < \lambda < 6\,600$. Calculations are made for both normal and oblique incidence. Data are reported for MgF_2, CaF_2, LiF, cryolite and aluminium fluoride. Polarimetric methods are also discussed. The methods developed can also be applied to films on an opaque base.

A Method of Determining Concurrently the Thickness and Refractive Index of a Thin Film or Lamina, P. D. FOCHS. Letter in J Opt Soc Am v40 Sept 1950 p 623.

On the Simultaneous Determination of the Optical Constants and the Thickness of Very Thin Metallic Films, F. ABELÈS. CR Acad Sci Paris v231 Nov 6 1950 p 958–60 in French. For extremely thin films an approximation can be used permitting development of an expansion series in the theory formerly developed for the optical characteristics of thin films. It is shown that the reflectivities measured respectively from both sides of the film and the transmission are related. Further, it is shown how both thickness and optical constants can be derived in terms of transmissions, absorptions and the refractive indices of the media on either side of the thin film.

The Determination of Optical Constants and Film Thickness of Absorbing Layers by Means of Measuring Absolute Phase Changes, R. FLEISCHMANN, H. SCHOPPER. Zeit Phys v129 n3 1951 p 285–99 in German. By using the complex amplitude which is derived from phase and intensity measurements a new method can be developed for the simultaneous evaluation of the optical constants and the thickness of an absorbing layer in which internal multiple reflection is disregarded. The determination of opaque layers by optical methods has so far not been possible. The new method is applied to antimony sulphide and the values of the constants and thickness determined for various wavelengths in the visible region of strong absorption. Thicknesses up to about $\lambda/3$ are studied. Because the material is transparent in the red, optical controls on the thickness can be made and the newer technique is confirmed as reliable. The method functions at normal incidence and is thus not affected by anisotropy which might arise at other angles of incidence. The test is non-destructive, which is advantageous.

The Thickness of the Helium Film, E. J. BURGE, L. C. JACKSON. Proc Roy Soc A v205 Feb 7 1951 p 270. A description of an optical method for determining the thickness of the He II film. Linearly polarized light is reflected from a stainless steel mirror, the upper part of which is coated with a layer of Ba stearate one molecule thick and the lower part with a similar layer three molecules thick. The reflected light passes through a mica compensating plate and a Nicol prism. Adjustment of the mica plate and Nicol gives equality of illumination on the "1" and "3" areas. If now a film of He II covers the mirror the Nicol must be rotated to restore equality of illumination. The rotation is a measure of the thickness of the He film, the relation between the two quantities being calculated in terms of the angle of incidence and the optical constants of liquid He, Ba stearate and stainless steel. The observed thickness at any given height above the liquid He was found to be nearly independent of the temperature between 1·1 and 2·18 °K, but then decreased rapidly to zero at the λ-point. In the formula

$d = k/h^{1/z}$ for the thickness d and height h cm for any given temperature, the value of z varies from $3 \cdot 5$ at $1 \cdot 1$ °K to $2 \cdot 5$ at $2 \cdot 1$ °K. The thickness at 1 cm and $1 \cdot 5$ °K is provisionally given as $1 \cdot 9 \times 10^{-8}$ cm.

Determination of Thickness of a Thin Film Obtained by Condensation of Artificial Radioactive Elements, M. DE-VIENNE. CR Acad Sci Paris v232 Mar 12 1951 p 1088–9 in French. A method of measuring the thickness of films of radioactive Sb is described. The films were obtained by condensation from molecular beams on to a plate, precautions being taken to ensure a uniform deposit. The activity of the film is measured and compared with that of standards deposited on identical surfaces. These standards were prepared by evaporating a drop of a solution of $SbCl_3$ obtained by the action of aqua regia on a known mass of radioactive Sb. The plate was covered with a very thin film of paraffin to ensure that the liquid spread uniformly over the plate.

An Alignment Chart for Computing the Thicknesses of Evaporated Films, A. L. SCHOEN, R. H. DAVIS. Letter in J Opt Soc Am v41 May 1951 p 362–3. Describes a chart which serves as a convenient guide to the thicknesses of evaporated films in situations where the evaporation material and geometry are subject to frequent change.

A Non-Destructive X-Ray Method for the Determination of the Thickness of Surface Layers, P. GAY, P. B. HIRSCH. Brit J App Phys v2 Aug 1951 p 218–22. The intensity of reflection of a parallel, monochromatic X-ray beam is measured as a function of the angle (ϕ) between the lines given by the intersection of the plane of incidence with (a) the surface, and (b) the reflecting planes of the matrix crystal. If a surface layer is present, both incident and reflected beams suffer absorption. A general expression is quoted for the intensity (which falls to zero when ϕ = the Bragg angle) in terms of the geometrical, absorption and intensity constants, it being shown how a suitable plot of functions of the experimental values yields the layer thickness. Experimental procedure for single crystal and polycrystalline bases is explained and brief results are shown for an abraded surface on a LiF crystal, and for an Al layer on polycrystalline Cu. The method is applicable to all layers with reflection coefficients different from that of the matrix.

New Method for Liquid Film Thickness Measurement, A. M. PENNIE, J. Y. BELANGER. Can J Technol v30 n2–3 Feb–Mar 1952 p 9–19. Method employs micrometer needle in conjunction with electric method for detection of point of contact; illustrated description of apparatus and test procedure; results discussed.

A Tracer Method for the Thickness Measurement of Thin Bi Films, J. J. ANTAL, A. H. WEBER. Rev Sci Instrum v23 Aug 1952 p 424–6. The use of radioactive Bi^{210} as a tracer in thin Bi films prepared by evaporation in a vacuum has resulted in a simple and direct method for the measurement of film thickness in the range 1–300 Å. The radioactivity of a standard, prepared by evaporating a weighable amount of active Bi on a piece of glass, is compared to that of a specimen of unknown thickness. For films 300 Å or less in thickness, the ratio of counting rates of the "unknown" and standard yields the mass of Bi on the unknown which, together with the film area (measured with a planimeter) and the density of Bi, yields the average Bi film thickness. Two levels of activity occurring in the standards were assigned after an electron diffraction study to a difference in structure of the Bi films. The method is accurate for extremely thin films (probable error is less than 4% if counting statistics are carried to probable error of 3%), simple procedures and calculations are used, calibration is continuous, and the specimen is not altered in any way.

On the Choice of Measurements to be Made for Simultaneous Determination of the Optical Constants and Thickness of Thin Absorbing films, D. MALÉ. CR Acad Sci Paris v 235 Dec 22 1952 p 1630–1 in French. An approximation formerly proposed by H. Wolter relating reflectivities, absorptions and transmission for thin films is re-examined graphically. Using existing experimental data it is confirmed that the Wolter relation holds for thickness less than 0.027 of the wavelength of the light used. Further in the region of optical constants for Ag in the visible the relation holds whatever the thickness. The method described enables constants and thickness to be obtained with only three measurements.

Two New Methods Allowing the Determination of the Index and the Thickness of a Thin Transparent Film, F. ABELÈS. CR Acad Sci Paris v236 Apr 8 1953 p 1412–3 in French. It is shown how one can derive the index and the thickness of a thin transparent film deposited on a transparent base by measuring the transmission factor of the parallel and perpendicular polarized beams relative to an incident vibration, polarized parallel and perpendicular to the plane of incidence, the two measurements being affected at the same angle of incidence. Mathematical relations are derived so that constants can be obtained having different angles of incidence. The effect of errors of measurements of the values calculated are discussed. The method has been applied successfully to titanium oxide layers.

Measurement and Control of Thickness of Thin Films, K. M. GREENLAND. Vacuum v2 n3 July 1953 p 216–30. Films may in general be measured by gravimetric, photometric, polarimetric, or interferometric methods; principles and some refinements of methods are described, together with examples of some other methods (X-ray, radioactive tracer, and electrical) of more limited application; how methods have been adapted for indication or control of thickness of films deposited by high vacuum or sputtering. Bibliography.

The Determination of the Film Thickness and Optical Constants of "Thin" Films, C. VON FRAGSTEIN. Zeit Phys v139 n2 1954 p 163–74 in German. Wolter's formulae [Z Phys v105 p 269 1937] connecting the optical constants n and k with the film thickness d are re-examined and found to be valid only for very small values of d. It is shown that for very thin films the electric, but not the magnetic, vectors of the incident and emergent rays are related as if d=0. The new expressions and (previous) values for n and k of Ag, Pt, Pd and Cu show that the upper limit for d for which the theory is valid is 60–70 A.

A New Method for the Rapid, Approximate Determination of the Optical Constants and Thickness of a Thin Absorbing Film, F. ABELÈS. CR Acad. Sci Paris v238 Feb 22 1954 p 881–3 in French. The complex refractive index of a thin film and its thickness can be found rapidly from the positive root of a quadratic equation involving the reflection coefficients and transmission of the film. A simplified equation is also given for the case of a highly absorbing film. Comparison of the values derived for a gold film by this and a more exact method shows that the results are within the limits of experimental error.

Film Thickness by X-Ray Emission Spectrography, H. A. LIEBHAFSKY, P. D. ZEMANY. Analyt Chem v28 n4 Apr 1956 p 455–9. When a polychromatic X-ray beam excites the characteristic line of an element in a thin film, the intensity of the line may increase with the thickness of the film, in which case a measurement of line intensity can be used to estimate the thickness. Owing to absorption of X-rays by the film, however, the relationship of intensity to thickness is not generally simple. This absorption filters and attenuates the polychromatic beam, and attenuates the characteristic line. As a conse-

quence, the number of quanta per second contributed to the emergent beam by a layer of atoms decreases with the distance of the layer beneath the surface. Furthermore, quanta originating beyond a critical depth will have no measurable effect on the detector because not enough of them will reach it. For the measurement of film thickness by the method under discussion, this critical depth may be regarded as a critical thickness.

Beta Gauge for Localized Measurements of Thin Films, O. U. ANDERS, W. W. MEINKE. Rev Sci Instrum v27 n6 June 1956 p 416–7. Uses a narrow pencil of rays from a 5 mc Pm^{147} source mounted on a Lucite disk, a Lucite collimator and a thin-window G. M. tube. An exploded diagram shows details of the source and collimator assembly. The gauge was developed to determine the thickness of films used as cyclotron targets and is most sensitive for films up to 6 mg/cm^2.

The Measurement of Film Thickness with a Pneumatic Hypodermic Needle Mechanism, N. STOLOW. J Sci Instrum v33 n9 Sept 1956 p 333–7. An apparatus is described by means of which the measurement of film thickness may be made on supported polymer films in a non-destructive manner. This apparatus is based on the principle of flow of a gas, e.g. nitrogen, through the space formed by the tip of a cut-off hypodermic needle and a given surface. The theory, an extension of a previous one for a swelling measurement apparatus, is presented and appropriate sensitivity expressions are derived. Agreement with the theory is good except when the rate of flow parameter is high, and kinetic energy corrections must then be applied. The r.m.s. error in the location, at a fixed distance away, of a point on a surface is found to be $\pm 0.2\mu$. The films are ordinarily cast on optically selected flat-faced glass plates which are mounted on the flat base plate of the apparatus. By lateral sliding action of the support on the base plate, a number of surface locations are made on the film and around the film edge from which the mean film thickness is obtained. The r.m.s. error in the mean film thickness is found to be $\pm 0.4\mu$ for films ranging from 10μ to greater than 200μ in film thickness.

The Measurement of the Thickness and the Optical Constants of Very Thin Metal Films, H. WOLTER. Zeit Phys v147 n1 1957 p 1–23 in German. For a thin metal film on a glass substrate one may calculate the reflection from each side and the transmission in terms of n, the refractive index, k, the absorption coefficient, and d, the thickness. A phase change is associated with each of these intensities, and at normal incidence the six quantities depend, to a high accuracy, only on the product ndk. Measurement of any two of the quantities gives the other four, as they are interdependent. The errors involved are discussed and tabulated. At non-normal incidence, with the electric vector parallel to the plane of the film, similar considerations apply. Using light at glancing incidence with the magnetic vector parallel to the plane of the film, a different combination of n, k and d can be measured.

Photometric Determination of Thickness of Semitransparent Metal Layers, L. S. PALATNIK, G. V. FEDOROV. Dokl Akad Nauk SSSR v113 n1 1957 p 100—3 in Russian.

Measurement of Thickness of Thin Carbon Films, A. W. AGAR. Brit J App Phys v8 n1 Jan 1957 p 35–6. Reference to use of evaporated carbon films prepared by method of D. E. Bradley widely used in electron microscopy; nearly linear relationship has been found to exist between optical density and thickness of evaporated carbon films; determination of film thickness by density measurements is shown to have number of advantages over measurement by interferometry particularly for very thin films.

Different Methods for Determination of Thickness of Silver Film, P. SEN, P. S. RAO. Glass Indus v38 n2 Feb 1957 p 89, 112. Comparison of methods for silver film deposited on glass surface, including: volumetric analysis (by titration), direct weighing, and Fizeau's iodine crystal test.

On the Reflection Coefficients of Thin Lacunal Film, P. DUMONTET, M. PERROT, J. TORTOSA. CR Acad Sci Paris v244 n20 May 13 1957 p 2488–91 in French. It is pointed out that the observed variation, with thickness, of the complex reflection coefficient for the substrate side of a silver film deposited on a transparent support differ markedly for thicknesses less than 100 A from that expected theoretically. A transitional layer at the substrate is suggested as the cause of the anomaly.

Optical and Electrical Methods of Measuring Thickness of Thin Metallic Films, Y. G. NAIK, E. M. BALSARA. Indian J Phys v31 n12 Dec 1957 p 607–10. Measurement of thickness of chemically deposited thin films of silver are made from (i) the study of the absorption of light and (ii) from the electrical conductivity of these films. It is shown that the thicknesses determined by the two methods are of the same order.

Film Thickness Determination From Substrate X-Ray Reflections, D. T. KEATING, O. F. KAMMERER. Rev Sci Instrum v29 n1 Jan 1958 p 34–6. A method is given for the determination of the thickness of films using X-rays diffracted from the substrate. The X-rays pass through the film and are diffracted by the substrate back to the counter, the intensity being reduced by absorption due to the double transmission through the film. No assumptions need be made about the substrate reflection. Unknown conditions of the substrate are eliminated by measurement of the intensity of two orders of a reflection, or measurement of the intensity of a reflection using two different incident radiations. The method is suitable for all types of film, and is particularly useful in measurements of films containing elements of the substrate for which cases X-ray fluorescence techniques are of little value. The procedure is illustrated with a measurement of the thickness of zirconium nitride on a zirconium substrate.

Swept Frequency Eddy-Current Device to Measure Overlay Thickness, E. A. HANYSZ. Rev Sci Instrum v29 n5 May 1958 p 411–5. An instrument is described which enables nondestructive measurements to be made of film and overlay thicknesses. It utilizes the change in electrical impedance of a composite sample resulting from differences in the thickness of the material being measured to cut-off a swept-frequency oscillator at a frequency determined by that thickness. Operating frequencies from 200 kc/s to 20 Mc/s have been used with frequency-sweep widths, or deviations, up to 10% to measure overlay thicknesses ranging from 0.00005 to 0.007 in. on composite samples in which the conductivity-to-permeability ratios of the base and overlay differ by at least a factor of two. Equations are developed to illustrate the conditions for which a reactance-tube oscillator is employed in a unique manner to make the measurement automatic.

The Measurement of Critical Thickness of Aluminium Films, V PUČÁLKA. Czech J Phys v9 n5 1959 p 668–9 in German. The critical thickness referred to is that at which a finite electrical conductivity can be measured. The value measured in vacuum is smaller than that in air because oxidation will isolate particles which make good contact in vacuo. In vacuo the critical thickness is about 23 A and the transparency is about 73%.

Semiempirical Method of Determining Thickness Along a Wedge-Shaped Thin Layer, M. P. LISITSA, V. M. MAEVSKII. Instrum & Exper Techns (English translation of Pribory i Tekhnika Eksperimenta) n3 May–June 1959

p 459–66. Method makes it possible to determine thickness distribution along wedge-shaped thin layer deposited on hard base layer; formulas, taking into account coefficient of substance accommodation on base layer, variation of layer density with thickness, imperfections of evaporator construction, and other factors.

Calculation of Thickness of Films Resulting From Vaporization in Vacuum, A. P. RUMYANTSEV. Instrum & Exper Techns (English translation of Pribory i Tekhnika Eksperimenta) n5 Sept–Oct 1959 p 802–5 17 refs. Distribution functions for thickness of thin films, taking into account commensurability of dimensions of vaporizer and distance from it to point of condensation, as well as spatial distribution law for vaporization products.

Measuring the Thickness of Thin Celluloid Films, I. S. DMITRIEV, YA. A. TEPLOVA, V. S. NIKOLAEV, L. N. FATEEVA. Pribory i Tekh Eksper. (USSR) 1959 n6 p 131 Nov–Dec in Russian. A photometric method was developed for measuring the thickness of organic films in the range 2–20 g/cm². Although their light-absorption coefficient is so small, use was made of the effects of interference in reducing considerably the transmitted intensity; the transmitted intensity first falls with increasing thickness of the film, reaching a minimum at about 0.1μ thickness, after which it begins to rise again and vary periodically. In addition, the colour of the reflected light gives a guide to the particular absorption cycle corresponding to the measured intensity, thus eliminating indeterminacy. A formula relating the transmitted intensity to the incident intensity in terms of film thickness, refractive index, absorption coefficient, and illumination wavelength is given. [English translation in: Instrum Exper Tech. (USA) n6 p 987–8 Nov–Dec 1959; publ. Sept 1960].

Measurement of the Thickness of Thin Foils, G. M. OSETINSKII, M. V. SAVENKOVA. Pribory i Tekh (USSR) 1959 n6 p 114–6 Nov–Dec in Russian. The thickness of thin foil windows for gas target applications was measured in terms of the sharp fall off in absorption of Po^{210} a-particles at the end of their range. The foils were introduced into a vacuum chamber between a polonium source and a ZnS crystal with photomultiplier detector. The particle count taken at various air pressures in the range 100–760 Torr was plotted with and without the foil in position to obtain complete absorption curves. The displacement of the curves in terms of differences in air pressure (at half height) could be interpreted directly in terms of the equivalent foil density in mg/cm². The apparatus was used for nickel foils from 0.8 to 1.5μ (0.9–1.6 mg/cm²). The achievable accuracy was investigated by comparison with weighed samples and was estimated to be of the order of 1.5% for foils of similar thickness to a standard and 3–4% if samples are of considerably different thickness. [English translation in: Instrum Exper Tech (USA) n6 p 971–3 Nov–Dec 1959; publ Sept 1960].

A New Device for Measuring Thickness of Evaporated Metal Film by Use of X-Ray Interference Fringes, Y. FUJIKI, T. YOSHIDA. J Phys Soc Japan v14 n12 Dec 1959 p 1828. A modification of Keissig's method is described, in which a comparatively broad source of X-Rays can be used.

On the Possibility of Determining the Optical Constants and Thicknesses of Very Thin Metal Films Using Measurements at Normal Incidence, C. SCHWINK, H. PEHLAND. Zeit Phys v158 n1 1960 p 12–25 in German. A theoretical examination of the deductions possible from a knowledge of the complex amplitudes transmitted, and reflected from either side. If the thickness d is assumed to be small with respect to the wavelength, the equations expanded in powers of d and the first terms only taken, then a complete solution is impossible; by taking into account higher powers, d and the optical constants n and k can be calculated, but for small d the equations are ill-conditioned; in general only the product nkd can be calculated with good precision when d is small. It is shown also that Schopper's three-line method is invalid since the method involves taking only the first terms in the above expansion. If d is known then n and k can be calculated.

Messung kleiner Schichtdickenunterschiede in duennen nichtmetallischen Schichten (Measurement of Small Thickness Differences of Thin Non-Metallic Films), G. KOPPELMANN. Ann Phys v5 n7–8 1960 p 397–404. Apparatus based on recording of reflections from various points measured; results for cryolite evaporation characteristics of particular furnaces; application of method to multiple layers and to dispersion effect of film substances.

Variation des Constantes optiques du Bismuth en Couche Mince, en Fonction de l'Épaisseur, entre 2.5 et 10μ. (Variation of Optical Constants of Thin Bismuth Films as Function of Thickness Between 2.5 and 10μ), R. BURTIN. CR Acad Sci v250 n11 Mar 14 1960 p 1998–2000. X-ray and electron microscopic study of films evaporated in high vacuo; thickness measurements; calculation of indices n and k.

Simple Method of Determining the Thickness or the Refractive Index of Thin Films, K. V. KRISHNA RAO. Am J Phys v28 n5 May 1960 p 447–9. A simple method of determining the thickness or the refractive index of thin films using double-slit Fraunhofer diffraction fringes is described. To illustrate the method, the thickness of grey photographic film and the refractive index of a cellulose acetate film have been determined.

Measurement of Thickness of Thin Transparent Films Using Fluorescence, B. P. BUNT. Brit J App Phys v12 n4 Apr 1961 p 175–7. Molecular fluorescence method of comparing thickness of transparent films (in range 3×10^{-5} to 10^2 cm) is described; instrument for use in middle of this range (10^{-1} cm) is also described; results show that accuracy is better than plus or minus 2%; applicability e.g. to organic coating of tinplate or etc.

A Determination of Thin Oxide Film Thickness by Integrated Intensity Measurements, B. BORIE, C. J. SPARKS. Acta Cryst (Int) v14 Pt6 June 1961 p 569–70. The thicknesses of thin single-crystal oxide films are determined by integrated measurements in absolute units. The method is illustrated with measurements of Cu_2O films grown on copper single crystals. Thicknesses determined from two different Bragg maxima agree well with each other, and are reasonably consistent with the thicknesses determined from the line shapes.

The Use of X-Ray Fluorescence in the Nondestructive Measurement of Thin Film Composition and Thickness over Small Areas, R. WEYL. Zeit angew Phys (Germany) v13 n6 June 1961 p 283–8 in German. The beam from a tungsten fine-structure tube was reduced to about 1 mm² at the specimen using a diaphragm. The fluorescence radiation was analysed in a vacuum using lithium fluoride crystal; a proportional counter was used as a detector. The intensity variation of the excitation radiation was also analysed in the same way using a scintillation counter and pulse-height analyser. Calculations showed that the mass distribution of thin nonhomogeneous films could be determined by taking into account the intensity distribution of the exciting radiation, the fluorescence field and all losses in fluorescence radiation on the way to the detector. The accuracy of the method was tested for nickel-iron layers of thickness up to 1000 Å. In a theoretical investigation it is shown that secondary excitation can be neglected in the case of thin films. In films consisting of two types of atoms the intensity ratio of the secondary to the primary fluorescence radiation of the lighter element is proportional to the mass coverage of the heavier element and independent of the mass coverage of the lighter element.

Measuring Thickness and Composition of Thin Surface Films by Means of Electron Probe, B. W. SCHUMACHER, S. S. MITRA. Proc Electronic Components Conf 1962 p 152–61. Tests to show that thickness measurements with electron probe, utilizing range-energy relations for electrons, can be of same order of resolution that can be attained with multiple beam interferometry; lateral resolution of electron probe may be even better; results of experiments with gaging probe are also of interest in connection with microprobe X-ray analysis of thin films.

Measurement of the Thickness of Vacuum Deposits Using the Electron Microscope, D. CHESCOE, J. S. HALLIDAY. Nature (GB) v193 Feb 3 1962 p 434–7. Shows that the thickness of vacuum-deposited films ranging from 20 to 2000A can be determined accurately in the electron microscope. The method is that of Bradley in which a layer of condensed hydrocarbon molecules is used as a marker against which the deposited material piles up. The film thicknesses measured in this way are in good agreement with those obtained by optical interference methods.

A Note on Silicon Oxide Film Thickness Measurement, H. M. ROBERTSON, J. E. MCNAMARA, R. M. WARNER, JR. J App Phys (USA) v33 n9 Sept 1962 p 2909. A standard interferometric technique can be used to measure the thickness of an unmetallized silicon oxide film if allowance is made for the film's optical properties.

Use of Frustrated Total Internal Reflection to Measure Film Thickness and Surface Reliefs, N. J. HARRICK. J. App Phys (USA) v33 n9 Sept 1962 p 2774–5. When total internal reflection of light occurs, radiation penetrates beyond the reflecting surface into the rarer medium where the intensity decreases with distance from the interface in an exponential manner. Since the degree of coupling to this radiation can be controlled by adjusting the proximity of another object to this interface, it is possible to utilize this phenomenon in the measurement of film thickness and to obtain high contrast images of surface reliefs.

Film Thickness Determination with a Scintillation Counter, H. R. LUKENS, JR. Analyt Chem (USA) v34 n11 Oct 1962 p 1396–7. A long-lived luminescence induced in organic lubricant films by ultraviolet light has been employed to determine the thickness of the films. The luminescence is measured and recorded with a multiplier phototube and scaler, and has been found to be proportional to film thickness. The phenomenon, long-lived luminescence, has been observed in many organic materials, which indicates that the method should be widely applicable.

The Use of Ferromagnetic Domain Structure to Determine the Thickness of Iron Foils in Transmission Electron Microscopy, D. H. WARRINGTON, J. M. RODGERS, R. S. TEBBLE. Phil Mag (GB) v7 Oct 1962 p 1783–90. The thickness of foils of f.c.c. metals can be determined in the electron microscope by observations on slip systems or twin boundaries. In b.c.c. metals these methods fail, and estimates from extinction contours are not very accurate. A method is proposed for iron which relies on the deviation of the electron beam in passing through a magnetized layer. The specimen is positioned so that a domain boundary is in the beam, which thus passes through two regions in which the orientation of the magnetic vector differs. The beam is split into two parts, giving two diffraction spots, the angular separation of which is a function of the film thickness as well as of the angle between the magnetic vectors. By selecting simple domain configurations in which the magnetic orientation is clear, the film thickness can be found from the spot separation. The specimen must be placed outside the magnetic field of the electron lens. Results are given of a comparison between this method and the extinction distance method.

Examination of Surfaces With Aid of X-Ray Reflection, R. SCHEIDEGGER. Brown Boveri Rev v49 n11–2 Nov–Dec 1962 p 555–68. Description of asymmetrical X-ray reflection method; calculation of layer thickness of diffracting surfaces; features of Legrand camera and use of counting-tube goniometer for examination of surfaces; examples of how method can be applied in practice; quantitative investigations on crystalline powders.

Method for Measuring Thickness of Thin Bent Foils in Transmission Electron Microscopy, P. DELAVIGNETTE, R. W. VOOK. Physica Status Solidi v3 n4 1963 p 648–53. New method of thickness measurement of thin monocrystalline foils in range of 1000 A; method is based on observation of Kossel-Moellenstedt fringes in transmission electron microscopy; it differs from classical Kossel-Moellenstedt method by fact that, no divergent beam is needed; however, foil should be bent and method is based on measurement of radius curvature.

Nondestructive Method of Measuring Thickness of Transparent Coatings, T. M. MANSOUR. Matls Res & Stand v3 n1 Jan 1963 p 29–32; Quality Engr v 27 n2 Mar–Apr 1963 p 46–9. Method utilizes commercially available optical instrument, Zeiss light-section microscope; it is applicable to thickness measurement of transparent coatings of 0.1–10 mils, over both metallic and non-metallic substrates; main limitation is its ineffectiveness with substrates that are highly light diffusing; comparison with other methods is shown for aluminum oxide on A1, clear synthetic enamel on steel, clear plastic and microscope slide glass on air.

Activation Method of Measuring Thickness of Thin Films and Foils, F. P. DENISOV. Instrum & Exper Techns (English translation of Pribory i Tekh Eksper) n1 Jan–Feb 1963 p 146–8. Simple method of measuring thickness of film, with and without backings, is based on use of artificial radioactivity and can be used to measure films with thickness down to $1\mu g$/sq cm.

Determination of the Thickness of Coatings by Recording Scattered Beta Radiation, YU. S. ZASLAVSKII, G. I. SHOR, A. D. STUKIN, E. D. STUKIN. Pribory i Tekh Eksper (USSR) 1963 n1 p 149–52 Jan–Feb in Russian. English translation in: Instrum Exper Tech (USA). A simple beta-ray back-scattering gauge, incorporating an end-window Geiger counter and a $1\mu c$ source, is described.

A Simple Method for the Measurement of Small Thicknesses and Length Variations, A. H. BOERDIJK. Ned Tijdschrift Natuurkde (Netherlands) v29 n2 Feb 1963 p 53–5 in Dutch. The apparatus uses a convex lens and a glass plate—a sort of inverted spherometer—to measure the thickness of thin wires etc. Length changes can also be measured.

Interferometric Evaluation of Thickness of Canada Balsam and Collodion Films and Its Relation to Concentration of Solutions, N. BARAKAT, A. A. A. MOHAMED. A. EL BIALY, K. A. AZIM. Brit J App Phys v14 n3 Mar 1963 p 144–6. Films prepared using fixed area of water surface; graphs and tables enable preparation of thin films of known thickness for electron microscope techniques in which exact thickness of carbon or silicon replicas deposited on films is required; effect of temperature on film thickness studied; heating films enabled production of thinner films of known thickness.

Sur l'Épaisseur limite au-dessous de Laquelle on ne Peut Plus Déterminer séparément les constantes optiques et l'Épaisseur d'une Couche Mince Absorbante (Thickness limit below which it is not possible to measure separately optical constants and thickness of absorbent thin films), D. MALE. CR Acad Sci v256 n21 May 20 1963 p 4381–3. Method of normal incidence cannot be used below certain thickness because curves giving factors of

reflection, transmission, and phase change may be actually confounded with their tangent lines.

Measurement of Thickness of Foils and Films by Means of Soft X-Rays, S. I. LOBOV, V. A. TSUKERMAN. Instrum & Experimental Techniques (English translation of Pribory i Tekhnika Eksperimenta) n4 July-Aug 1963 p 757–61. Soft bremsstrahlung and characteristic X-ray emission excited by tritium are used to measure thin foils and films in thickness range 10^{-2}–10^{-5} cm; Geiger counter is used as detector; sensitivity of 3×10^{-6} g/sq cm can be obtained with method when wavelength of characteristic emission is chosen to correspond with selective absorption at K, L, or M levels of foil material; method is effective for measurement of metal foils and opaque films in mass range $(5–30)10^{-6}$ g/sq cm.

Method for Continuous Measurement of Thickness and Deposition Rate of Conducting Films during Vacuum Evaporation, J. A. TURNER, J. K. BIRTWISTLE, G. R. HOFFMAN, J Sci Instrum v40 n11 Dec 1963 p 557–61. In method described, operational amplifiers are employed to monitor change in resistance of deposited layer, and their outputs used to serve control deposition rate and automatically cut off vapor stream, when deposit has reached predetermined thickness; equipment allows close control of deposition rate and thickness, thereby increasing uniformity of deposited layers during successive evaporations.

Survey of Methods of Measuring Thin Film Thicknesses and Surface Irregularities, P. WRIGHT. Electronics Reliability & Micro-miniaturization v2 n3 Dec 1963 p 227–33. Methods of measuring thin film thickness and surface irregularities are evaluated; 2-beam interference microscope and multiple grid light profile technique are found to be most useful in research; other methods and their properties are summarized in chart.

Détermination Simultanée des Indices et de l'Épaisseur des Couches Minces Absorbantes, D. MALE. J de Physique v25 n1–2 Jan–Feb 1964 p 74–7. Simultaneous determination of optical constants and thickness of absorbent thin films; it is advanced that optical indices of metallic thin films determined before 1950 are not valid; graphical method is indicated for simultaneous determination of optical constants and thickness; method uses three measurements at normal incidence of intensities and phase differences; method cannot be applied to very thin layers; results are compared with those of other authors.

Microscopic Observation of Film Cross Sections Having Steep Contours, B. R. FRIEDEN. App Optics v3 n3 Mar 1964 p 395–8. New method is proposed for microscopic

observation of thickness distribution across thick (greater than about $12\ \mu$) transparent film; quality of observation is analyzed by expressing resolution error, image intensity, and depth of focus in terms of refractive index and geometrical constants of thickness distribution; constraints are derived governing design of viewing system by algebraically demanding that resolution error be sufficiently small, and image intensity and focal depth be sufficiently large; constraints upon system parameters seem to be physically realizable.

Instrument Measures Thin Film Thickness. Electronic Products v7 n6 Nov 1964 p 36 127. Probe and circuit design of measuring instrument for detection and thickness measurement of nickel, cobalt, aluminum, copper, and iron thin films; instrument has 0.001 in. full-scale reading with minimum increment of 20 μin.; it is applicable to nondestructive testing and can be used as flaw detector to determine cracks and imperfections in metal strips.

Film-Thickness Measurements, J. G. COLLIER, G. F. HEWITT. ASME—Paper 64–WA/HT–41 for meeting Nov 29–Dec 4 1964 19 p 53 refs. Methods which have been applied to estimation of thickness of liquid films in various types of film flow can be divided into two general classes—measurements of average thickness over considerable length of film—measurements of local thickness; both types of determination have been used to obtain temporal mean averages and second type has been used to present information on time variation of thickness; practical problems associated with application of various techniques are discussed; relevance to lubrication is noted.

Optical Constants of Thin Films, P. ROUARD, P. BOUSQUET. Progress in Optics, E. WOLF, North-Holland Pub. Co., Amsterdam, v4 1965 p 145–97 26 figs 184 refs. A review article dealing with optical constants and structure of transparent thin films and optical constants of absorbing thin films.

Routine Mass-Thickness and Nonuniformity Determinations of Thin Films, K. F. WYLIE, and G. R. HAGEE. Nuclear Instrum Methods (Netherlands) v32 n2 Feb 1965 p 201–3. A routine technique to rapidly determine the thickness and uniformity of thin plastic films and of thin plastic films coated with beryllium was developed. The thicknesses of Formvar films approximately 20 to 100 μg/cm^2 and beryllium coated films (approximately 20 to 70 μg/cm^2 of beryllium) were determined using alpha-particle attenuation techniques. Film thicknesses were determined by both alpha counting and destructive weighing. The difference between the two techniques was within the experimental error of 7.5%.

Addendum to Section 11

11.2. Polarimetric Methods (Ellipsometry)

Optical Measurement of Oxide Thickness on Titanium, R. C. MINARD. General Mills, Inc., Electronics Group, Research Dept., Minneapolis, Minn. J Opt Soc Am v52 n4 Apr 1962 p 427–31 4 figs 18 refs. Reflectance of thermally oxidized, mechanically polished titanium surfaces was measured with a spectrometer at 5889–5895 A. The principal aim of the experiments was to furnish an optical means of measuring the thickness of thermal oxide layers on titanium. These measurements also provided a method for determining the optical constants of the metal and the thermal oxide.

Error in Dielectric-Film Ellipsometer Determinations due to Neglect of Film Absorption, D. W. PETERSON, N. M. BASHARA. J Opt Soc Am v55 n7 July 1965 p 545–50 13 figs 13 refs. The error in the calculated refractive index of an absorbing dielectric film, which is determined by approximate equations that neglect absorption, is influenced by the true refractive index of the film and the controllable parameters—substrate and measuring wavelength. Such equations give two relations for calculation of thickness. It is shown why one of these equations gives an insignificant error when small absorption is present and an independently determined refractive index is used in the thickness calculation.
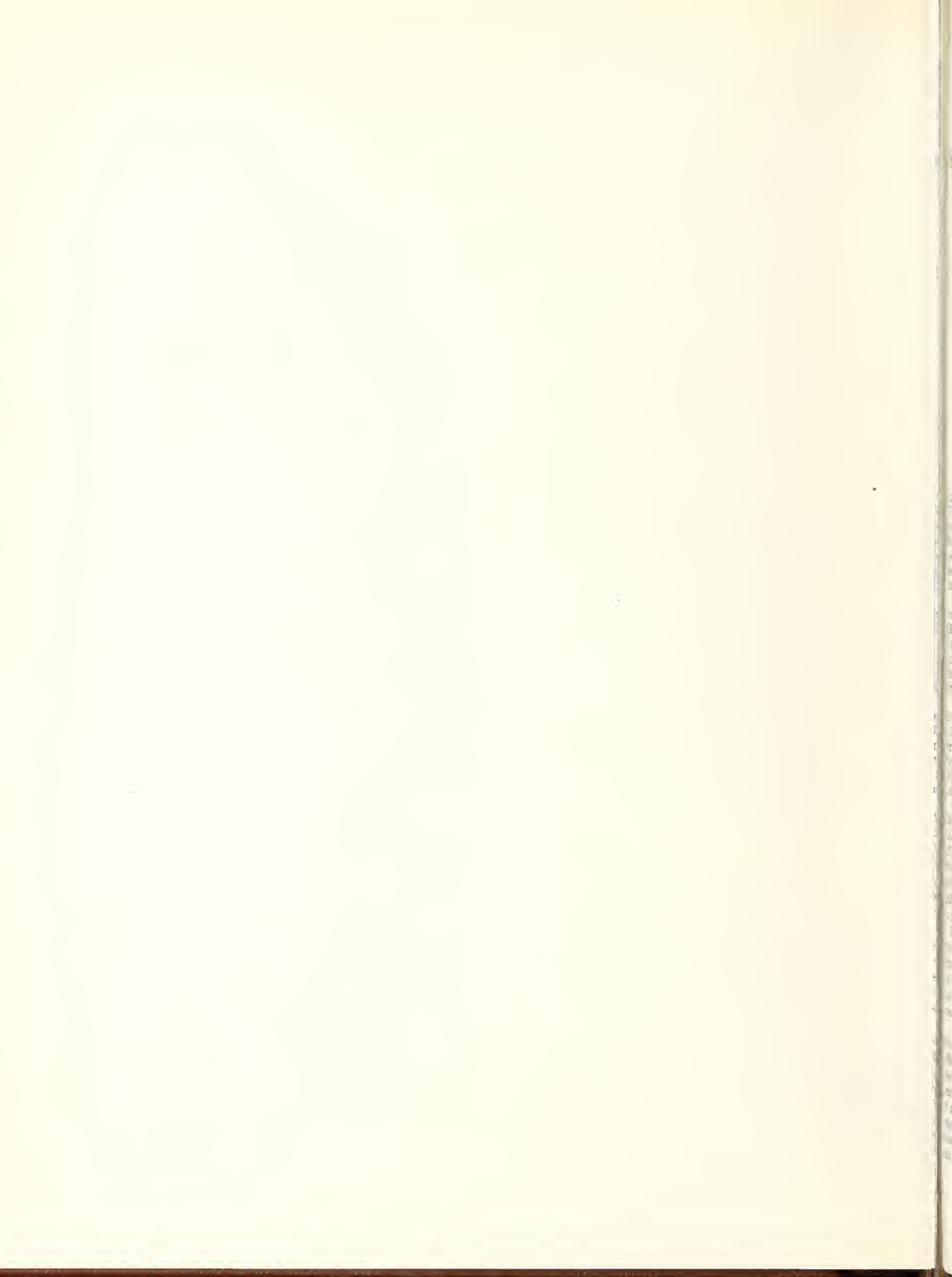
Section 12. Measurement and Production Techniques for Accurate In-Process Control of Size and Form

CONTENTS

12.1. General

On Plane Metallic Surfaces or True Planes, J. WHITWORTH. Pub. in Miscellaneous Papers on Mechanical Subjects, J. WHITWORTH, Longman, Brown, Green, Longmans, and Roberts, London 1858. Paper read at meeting of the British Association in Glasgow, 1840 p 3–19. Describes method of generating a true plane by matching three surfaces.

Problem of the Theoretically Correct Involute Hob, N. TRBOJEVICH. Machy (N.Y.) v25 Jan 1919 p 429–33 3 figs. Discusses interchangeable involute gears, generating an involute surface, analysis of involute tooth surface, theory of pressure angles, correct tooth curve of straight-gashed hobs, and hob versus spiral gear.

Hobbing Spiral Bevel Gears, N. TRBOJEVICH. Machy (N.Y.) v23 n582 Nov 22 1923 p 225–35 16 figs 6 refs. Describes a hobbing process for producing accurate spiral bevel gears or hyperboloidal gears having spiral teeth. It is stated that gears produced by this method are more nearly correct than any so far produced.

The Pratt and Whitney Gear-Shaving Process, H. D. TANNER. Machine Shop Practice (ASME Trans) v50 n27 Sept–Dec 1928 p 17–22 22 figs; Automotive Industries v59 n18 Nov 3 1928 p 625–7 12 figs; Am Mach v69 n17 Oct 25 1928 p 659–61 11 figs; Iron Age v122 n16 Oct 18 1928 p 949. Practical method of generating involute spur or helical gears at zero degrees which was invented by J. H. BARNES, Dayton, Ohio. Active profiles of gear teeth are generated by rolling gear in mesh with zero-degree rack; active profiles of this rack are top edges of its teeth, which coincide with cutting edges of tools; tools have straight cutting edges slightly longer than face of gear to be cut.

Mechanical Generation of Form. Eng v156 n4049 Aug 18 1933 p 163–4. Definition of word generation in sense used by engineer; author inclines to belief that true generation of forms other than primitive forms demands use of mechanism involving nothing but link work and that only those forms which are capable of being expressed by combination of links are capable of being generated in true and proper sense.

Precision Workshop Methods, H. J. DAVIES. London, Edward Arnold & Co.; New York, Longmans, Green & Co. 1935 306 p illus diagrs charts tables. Essential ideas upon which precise machining of machine parts depends; methods of setting out work, devices for setting work for machining, graduating and indexing, screw cutting, profiling, cutting gear teeth, and lapping and grinding limit gaging, testing machine tools, and related topics discussed. Eng Soc Library N.Y.

Instruments in Machine Tool Industry, B. R. HILL. Western Machy & Steel Wld v27 n9 Sept 1936 p 328–9. Quantities which must be easily and quickly determined by operator to obtain most from any motorized production tool; application of instruments; selection of ratings; measurement of speed and position; position shown electrically. From talk before representatives of 40 machine tool manufacturers.

The Honing Process for Cylindrical Bore Finishing, J. E. ANDRESS. Tool Engr v6 n2 June 1937 p 14–5, 26 28–9 4 figs; Machy (N.Y.) v43 n8 Apr 1937 p 526–9. Work adaptable to honing; preparation; metals and holes honed; honing angle of cross hatch; hydraulic dwell; strokes and cycles; size and position of holes honed; connecting rod honing; coolant.

Bearbeitungsfragen der Feinmechanik (Machining problems in precision parts manufacture), H. HEMSCHEIDT. Maschinenbau v16 n13/14 July 1937 p 343–6. Illustrated description of modern methods and tools for machine cutting and stamping operations on precision parts; measuring and testing methods.

Materials for Precision Machinery, C. FUJII. Japan Nickel Rev v6 n1 Jan 1938 p 53–76. In English and Japanese. Requirements for precision machines and tools and properties required in materials for this purpose; materials for beds of machine tools and measuring instruments, for spindles, guide screws, bearings, gears, standard scales, gages, etc; use of nickel in these materials emphasized.

Generating Small Precision Gears, A. THOMPSON. Tool Engr v9 n1 May 1940 p 9–12 85 14 figs; Can Machy v51 n3 Mar 1940 p 70 72 74 116. Essentials of gear tooth generat-

ing considered; fundamentals of cutting teeth; cutting gears on turret lathes; cutting precision gears.

Tolerance and Dimensional Control—Its Effect Upon Airplane Production, H. ADAMS. Mech Eng v65 n10 Oct 1943 p 739–40. Major problem confronting aircraft industry is attempt to eliminate rework required on assembly to make parts fit; handwork is required because of cumulative errors in wrong dimensions and wrong tolerances; major part of solution lies in engineering, by designing to avoid overconstraint, exact dimensioning and application of correct tolerances; tooling steps should be reduced in number and improved in accuracy.

Generation of Conic Sections with Machine Tools, R. T. HINKLE. Prod Eng v18 n8 Aug 1947 p 162–5. Application of two theorems from projective geometry duplicated by kinematic linkages, for generation of ellipse, hyperbola; kinematic schemes for generation in accordance with these theorems are illustrated; basic machine dimensions are analyzed and conversion of design dimensions of parts into machine settings for production is described.

New Appliance for Measuring Angles of Pieces Being Machined, G. KANN. Microtecnic v3 n5 Sept–Oct 1949 p 232–3. Illustrated description of appliance designed for checking dimensions and angles of pieces in course of manufacture without separating them from machine.

Modern Methods of Gear Manufacture. National Broach and Machine Co., Detroit. 3rd ed 1950 revised 1964 164 p 170 figs. Contents: Gear design principles; gear formulas; selection of gear steels; heat treatment of gear steels; machining gears; advanced production practices; special gear problems and case histories; red ring products; gear broaching. Chapter 6 on advanced production practices describes in detail the shaving process of finishing gear teeth.

Method of Controlling Profiles, A. MIRAU. Rev Opt v32 July 1953 p 418–22. In French. Control method for machining profiles, giving about 0.01 mm accuracy for pieces several centimeters in size.

Zahnräder: Stirn- und Kegelräder mit geraden Zähnen (Gear Wheels: Spur and Bevel Gears with Straight Teeth), W. LINDNER. Springer-Verlag 1954 133 p 183 figs 37 refs. Consists of two main parts: (1) the kinematic and mathematical tooth cutting in the radial plane; (2) application of the mathematical fundamentals. Contains a chapter (p 96–108) on the production of gears by form milling, form grinding, rolling, and lapping, and the errors involved.

Ein Beitrag für Ermittlung von Schleifscheiben- und Fräserprofilen zum Erzeugen geradflankiger Gewinde (A Contribution for the Ascertainment of Grinding-Wheel and Milling-Cutter Profiles for the Production of Straight-Flank Screw Threads), M. GARY. Werkstattstechnik und Maschinenbau, v46 n10 Oct 1956 p 510–3 2 figs 7 refs. With a given position of the grinding-wheel or milling-cutter axis with respect to the thread axis, the article develops the fundamental equations for calculating the workpiece profile in an axial section. The process is applicable to both straight and taper threads, external and internal.

How to do Precision Machining in Uncontrolled Temperatures, H. K. EITELMAN. Am Mach v103 n21 Oct 5 1959 p 96–8. Problem of eliminating heat expansion which can move part dimension completely out of tolerance; simple temperature correction method described which makes it possible to standardize machining and gaging when perfect temperature control is impossible; how and when to compensate; type of equipment needed.

Determination of Errors in Mechanisms with Lower Pairs, V. A. SHISHKOV. Meas Techns 1958 n6 Mar 1960 p 626–9 5 figs. Translated from Izmer Tekh Nov–Dec 1958 p 12. In the calculation of errors in a real mechanism the permissible variations in the dimensions of its links and the deviations in the positions of the centers of pins or slots on the column are usually given. The errors in position of other links for the given position of the driving link have to be found. The method developed by the author makes possible the construction of a single polygon of small displacements without drawing the transformed mechanism. The polygon of small displacements provides the complete solution of the problem of determining the effect of all links upon the position error of the driven link (and also upon the position error of any of the links of the mechanism).

Making Parts to Millionths, R. LeGRAN, H. SOKOLSKY. Am Mach/Metalworking Mfg v106 n4 Feb 19 1962 p 105–8. How Raytheon Co. made sudden switch from experimental output to full-scale production of missile servos, to accuracies of 10 millionths in. for size, roundness, and taper; major steps in making missile control valves.

Development of Modern Electrical Instrument-Making, A. M. DAMSKI, G. I. KAVALEROV. Meas Techns 1962 n1 June 1962 p 4–9. Translated from Izmer Tekh n1 Jan 1962 p 4–8. Discusses many phases of the design and production of electrical instruments. States that the automation of production control raises a number of problems in the production of specialized devices and systems which would provide, in addition to normal measurements, the control of complicated aggregate specialized measuring equipment operating with controlling computers.

Die Fertigung von Genauigkeits-Grosszahnraedern (Production of large marine gears of high precision), W. DREYHAUPT. Werkstatt und Betrieb v95 n11 Nov 1962 p 733–43. Details of gear hobbing machine and operating conditions, manufacturing procedure and measuring and safety devices employed; numerous measurement results presented indicate accuracy of gears.

Female Centers Influence True Roundness, G. L. DANNE-HOWER. Tooling and Production Jan 1964 3 p 7 figs. Stresses the importance of true geometric center holes, established alinement of axis, and close dimensioning tolerancing between centers.

Temperature Variation Effects on Dimensional Accuracy in the Machining of Aluminum, D. WEISMAN. Tool and Mfg Engr v52 Feb 1964 p 91–6. This paper is an investigation of temperature variation effects on dimensional accuracy in the machining of aluminum. It examines the thermal expansion differences between aluminum and steel and discusses the techniques of controlling the aluminum work-steel gage dimensional difference. Tolerance ranges are presented for appraisal of the dimensional error with reference to ± 0.000050", ± 0.0001", and ± 0.00025". This investigation is significant for manufacturing capability in the manufacture of precision components.

Application of the Least Squares Method for Evaluating the Precision of the Technological Operation in the Process Control of Components' Dimensions, I. V. DUNIN-BARKOVSKII. Meas Techns n5 Nov 1964 p 374–8 1 fig 5 refs. Translated from Izmer Tekh n5 p 10–3 May 1964. A method for evaluating the precision of technological operations with process control of component sizes based on the least squares method is suggested in this article. The method is convenient in practice and avoids the theoretical difficulty in selecting the number of observations which would ensure a given precision and reliability in evaluating for instantaneous distribution parameter without at the same time distorting its value by variations with time in the position of the size dispersion center.

12.2. Machine Tools

Checking Lathes for Accuracy, American Tool Works. Machy (N.Y.) v30 Nov 1924 p 195–9 12 figs. Discusses testing lathe beds for straightness and parallelism, inspection of lead screws, checking of headstock spindle, inspection on the erecting floor, truing the faceplate and setting the compound rest, alining the taper attachment, and other detail tests.

NPL Test on Carson Jig Boring Machine. Machy (London) v33 Nov 8 1928 p 186; Am Mach v69 1928 p 113. Gives results of tests on motion of table, motions of drilling head along slide, other motions, flexure of supporting column, abutment faces for gages, squareness of drilling spindle to table, measurements of sample jig produced on machine.

Refinements in Finishing Cylindrical Bores, J. W. HINDES, J. G. YOUNG. ASME Advance Paper for meeting June 9–12 1930 9 p; Automobile Engr v20 Aug 1930 p 303–4; Abrasive Industry v11 Aug p 25–7 and Sept 1930 p 28–30 6 figs. Limitations of boring, reaming, burnishing, and broaching; outline of grinding practice; operation and advantages of hone; coolant and abrasive.

Das Arbeiten mit Messeinrichtungen neuzeitlicher Waagerecht-Bohr- und Fraeswerke (Application of measuring Equipment to Modern Horizontal Boring and Milling Machines), E. ZIEGENHALS. Werkstattstechnik 27 n6 Mar 15 1933 p 114–7. Accuracy obtainable with special regard to application of end measures and recording scales; examples of practical application.

Precision Finish Machining, O. SCHLIPPE. Eng Progr 16 n1 Jan 1935 p 29–32. Trend of development in design of fine turning and boring machines, cutters, lapping and honing machines; illustrations.

Boring Equipment Adapted for Close Limit Machining of Automotive Pistons and Cylinders, W. F. WISE. Iron Age v135 n9 Feb 28 1935 p 20–3. Precision boring equipment arranged for diamond turning of pistons with elliptical and tapered skirt to limit of 0.00005 in. on major and minor diameters and on taper, and set-up for single-point finish boring of cylinders to unusually close limits.

Internal Surface Finishing to Finer Limits, A. W. SCHNEIDER. Can Machy v46 n11 Nov 1935 p 13–5, 32. Development of standard precision boring machines due to rigid requirements of manufacturers of automobiles, airplanes and electric refrigerators for increased accuracy without increased cost; automatic control.

Der heutige Stand der Feinstbearbeitung (Present status of precision working), C. BUETTNER. Zeit Metallkunde 28 n4 Apr 1936 p 91–6; (discussion) Metal Progr v30 n6 Dec 1936 p 54–5. Results of investigation of precision boring, cutting, lapping and grinding; purpose of precision machining demonstrated by examples of journal bearings, diesel-engine fuel pumps, etc.

Étude des Dispositifs de Mesure des Déplacements Linéaires (Study of Equipment for Measurement of linear displacement in Machine Tools), L. COMPAIN. Mechnique v22 n280 Sept–Oct 1938 p 205–12. With special reference to use of micrometer calipers in certain processes of precision production:

Das Mechanische Schaben von Flaechen (The Mechanical Scraping of Surfaces). Werkzeugmaschine v43 n4 Feb 1939 p 86, 88. Mechanical scraping of surfaces in machine tool manufacture; advantages over manual operation; description of scraping machines; rotating table for mounting of work piece.

Optik an einum Lehrenbohrwerk (Optical gages on precision drilling machine). E. ROTZOLL. Werkstattstechnik und Werksleiter v33 n9 May 1 1939 p 238–40. For accurate centering of hole, discussed as example showing usefulness of optics for practical application on machine tools.

Influence of Temperature on Lathes, G. SCHLESINGER. Am Mach v86 n9 Apr 30 1942 p 379–81. Observation on changes in alignment of machine tools during warming up period; compensation for misalignments is discussed; illustrations show arrangement of dial gages for measurement of spindle movement during warming up tests, and method of mounting dial indicator for testing alignment of tool holes and recesses in turret faces by turn around method.

Accuracy Requirements for Heavy Machine Tools, J. H. RIVERS. Machy (London) v70 n1802 May 8 1947 p 486–90 7 figs. Discusses spindle bearing design; cambering mechanism used on a roll grinding machine; instrument designed to accurately measure roll camber.

Measurement of Progressive Errors in Machine Tools by High-Speed Photography, C. TIMMS, NPL. Machy (London) v75 Dec 15 1949 p 27–31 6 figs 1 ref. Describes an investigation of the errors in the linear movements of the hob saddles of a gear hobbing machine, using a camera of simple design to record errors relative to a divided scale of known accuracy by direct comparison. Describes recording equipment and gives test results.

Les Fabrications Mécaniques du Point de Vue de leur Précision (Machining from Viewpoint of Precision), O. PETERS. Rev Gén Mécanique v35 n29 May 1951 p 160–3. Influence of position of tool, and angle of projection of cutter; effect of control.

Roll Generation of Approximately Plane Surfaces, P. GRODZINSKI. Mech Wld v132 n3396 July 1952 p 12–5. Principle used hitherto mostly for describing ellipses has been applied to generation of approximately flat surfaces by increasing ratio of elliptic axes; method explained and kinematic basis of method analyzed; mechanism on Wickman multiple spindle automatic; extension of kinematic principle to arbitrary number of cutting points and polygons; Tellschow mechanism.

Machine Tool Metrology, D. F. GALLOWAY, NPL. Eng Dimensional Metrology, Proc of Symposium held at NPL, 2 vols, Her Majesty's Stationary Office (London) 1955. Paper n17 p 289–301 4 figs. Discusses deflection tests, temperature effects, spindle bearings, vibration, testing of slides. Discussion.

Testing the Accuracy of Jig Boring Machines, T. R. OAKLEY, NPL. Proc of Symposium held at NPL, 2 vols, Mer Majesty's Stationery Office (London) 1955. Paper n18 p 303–21 7 figs test chart. Discusses measuring equipment, testing site, temperature, preparation for tests, worktable, co-ordinate movements, and calibration. Discussion.

Fixture Generates Large Radius, H. OSTRANDER. Am Mach v100 n14 July 2 1956 p 118–9. Fixture constructed of Meehanite castings generates true circular arc with good accuracy and reliability, and is adaptable to various standard machine tools; fixture is designed so that work will occupy position at arbitrarily convenient distance from center of large circle and be fixed to small circle so that it will rotate with it.

Tough Problems Solved with Tricky Tooling, F. P. BROWN, C. E. PELANDER. Machy (N.Y.) v64 n1 Sept 1957 p 149–55; Machy (London) v91 n2349 Nov 22 1957

p 1199–1204. Ingenious attachments developed in Shops Division at National Bureau of Standards for producing scientific instruments and equipment are described and illustrated; wide angle taper turning attachment; vertical milling machine adapted to jig boring; roll forming of thin wall conical components; special tool holder and base developed for ceramic tools.

Practical Alignment of Machine Tools by Means of Optical Equipment, R. OSWALD. S African Mech Engr v8 n6 Jan 1959 p 194–200. Alignment of machine tools, both in initial setting and during course of their lives; importance of sufficiently thick concrete foundations, and use of vibration absorbers such as rubber, cork, or systems of springs to reduce shock impact; principle of optical auto-collimator and its application in setting up and maintaining alignment.

Optische Möglichkeiten der Positionierung an Werkzeugmaschinen (Optical Possibilities of Positioning on Machine Tools), K. HERKT. 4 FoKoMa, Munich Oct 1959 p B93. The advantages of embodiment of optical measuring equipment for positioning of machine tools were placed under proof over a decade by the installation of this equipment on a jig borer.

Das statische und dynamische Verhalten von Werkzeugmaschinengestellen (Static and Dynamic Behavior of Machine Tool Frames), J. BIELEFELD. Acta Technica (Prague) v5 n4 1960 p 311–29. Method for investigating rigidity of elements of metal cutting machines; optimum design of machine frames.

A Kinematic Method of Making Details with Curvilinear Cross Sections and a Technique of Evaluating Its Accuracy, N. M. KARELIN. Meas Techns 1959 n8 July 1960 p 586–92 4 figs 1 ref. Translated from Izmer Tekh n8 Aug 1959 p 9. The author aims to develop a method of constructing kinematic devices for nonduplicating machining of cylindrical details with curvilinear cross sections (such as cams, templets, outside surfaces of noncircular wheels, polyhedrons, etc.) Developing kinematic schemes on this basis leads to a problem of the theory of function approximations.

Optical Check-Out of Machine Tools for Missile Production, G. W. DONALD. Machy (N.Y.) v66 n8 Apr 1960 p 149–51; Machy (London) v97 n2491 Aug 10 1960 p 333–5. In checking out machine tools such as horizontal boring mills and jig boring machines in Ordnance Department of General Electric Co, first bedway flatness is established with optical instruments; flatness of table on large boring mill checked with auto-collimator, corner mirror, and mirror carriage; column squareness with table determined by using alignment telescope, stride level, pentaprism, and target attached to spindle.

Machine Tool Research at the Technological University of Munich, F. EISELE. Int J Machine Tool Design Res v1 1961 p 249–74 35 figs. Discusses typical examples of vibration research and reports the scope, content, and the most important results on subjects as follows: stiffness investigations and their practical application, mechanisms of excitation, the avoidance of vibration, disturbance research, investigation of structural groups and elements, foundation investigations, damping and stability investigations, research on cutting forces, methods of measurement and measuring instruments, and electrical analogies.

Machine Tool Research, Design, and Utilization, D. F. GALLOWAY. Machy (London) v98 n2515 Jan 25 1961 p 196–204; Engr v210 n5475 Dec 30 1960 p 1081–2; Chartered Mech Engr v8 n2 Feb 1961 p 72–83 95 133. Reference is made to criteria of performance, terminology and specification, necessity for increased static and dynamic stiffness of machine tool structure, vibration, automation, and ergonomics. Abstract of James Clayton Lecture before Instn Mech Engrs, Dec 14 1960.

A Kinematometer for Screw Cutting Lathes, Y. M. AN DRUSHEVICH, M. K. KLEBANOV, M. Y. TSLAF, A. L RABHIN. Meas Techns 1960 n7 Feb 1961 p 588–9 2 figs Translated from Izmer Tekh n7 July 1960 p 27–8. De scribes an instrument for measuring the degree to which the errors of separate elements of the screw-cutting lathe kinematic chain affect the accuracy of the thread. Ex perimental investigations were made.

UPPS for Ultraprecision Machining. Du Pont Eng Dep Mech Development and Mech Res Labs July 1961 5 p 5 figs Defines ultraprecision machining and discusses importance of precision, program results, accuracy of motion, accuracy of positioning, machining sequence, and applications.

Graphical Method for Determination of Dynamic Stability of Machine Tools, J. P. GURNEY, S. A. TOBIAS. In J Machine Tool Design & Res v1 n1–2 Sept 1961 p 148–56 Use of harmonic response locus, so far applied with most effect in electrical engineering is considered very useful to describe characteristics of machine structure; method being essentially graphical, is equally applicable when mode of structure are not well defined, and it takes effect o rotational speed of tool or workpiece into account; stability conditions for regenerative chatter determined by thi method are set out in form of stability charts.

Zmniejszanie Obciazen Dynamicznych W Mechanizmacl Obrotu Maszyn Roboczych Ciezkich (Reduction of Dy namic Loads on Drives of Machine Tools), H. HAWRY LAK. Archiwum Budowy Maszyn v9 n1 1962 p 29–5 Analysis of dynamic overloads and possibility of reducing them by introducing spring elements in drive; choice o spring elements; theoretical considerations are based o two-mass model; for experimental verification test stan has been constructed; description of stand; measuremen methods and apparatus; analysis of measurement results English summary.

Dynamic Acceptance Tests for Machine Tools, S. A. TO BIAS. Int J Mach Tool Design & Res v2 n3 July–Sep 1962 p 267–80. It is proposed that dynamic quality o machine tools, in particular of radial drilling machines be measured by coefficient of merit; this coefficient is prod uct of static stiffness between tool and workpiece, in direc tion of cutting thrust, and nondimensional ratio deter mined from harmonic response locus of machine structure determination of coefficient for radial drilling machine is discussed and its relationship with stability chart o drilling process elucidated; it is shown that coefficient o merit is proportional to maximum drill diameter which is stable at all speeds.

Ispytanie stankov obshchego naznacheniya na vibrousto ichivost pri rezanii (Vibration Resistance of Genera Purpose Machine Tools During Cutting), V. A. KUDINOV T. S. VOROB'EVA. Stanki i Instrum n8 Aug 1962 p 8–12 see also English translation in Machines & Tooling v33 n 1962 p 11–15. Laboratory investigations and shop test are reported on basis of which method for investigatin vibration resistance of center lathes and knee-type millin machines was developed by ENIMS.

Koroblenie chugunnykh basovykh detalei pretsizionnyk stankov i metody ego ustraneniya (Warping in Mai Castings of Precision Machine Tools and Methods o Eliminating It), O. YU. KOTSYUBINSKII, A. M. GEF CHIKOV, YA. I. OBERMAN, S. A. SHEVCHUK, E. CF GINI. Stanki i Instrum n9 Sept 1962 p 1–5; see als English translation in Machines & Tooling v33 n9 196 p 2–6. Investigation was carried out into warping of iro castings used in precision machine tools (aged naturall and artificially); fact that even in case of high leve of residual stresses iron casting may retain its dimensiona stability, is extremely important in determining cond tions for artificial aging; aging before rough machinin is inadvisable, because it does not insure subsequent sta bility in shape of machined components.

Primenenie teorii podobiya dlya rascheta metallorezhu-
shchikh stankov na ravnomernost podachi (Applying The-
ory of Similarity When Calculating Working Traverses in
Machine Tools), B. G. LUR'E. Stanki i Instrum n11 Nov
1962 p 11–14; see also English translation in Machines
& Tooling v33 n11 1962 p 13–16. New data on problem
of uniform slow motion of machine tool units are de-
scribed; problem is solved on basis of experimental data,
with help of theory of similarity; method suggested for
experimental and theoretical analysis of nature of slow
movements in machine tools, and for determining slide-
way and feed drive parameters necessary for designing
machine tool with small movements of required degree of
uniformity and accuracy.

Role of Tracer Attachments in Contour Machining, L. S.
MAGOR. Automat v10 n5 May 1963 p 83–5. Discussion
of modern tracer attachments that can be mounted on
existing machine tools to control automatically contour
machinery.

On New Feedback Controlled Precision Gear-Hobbing
Machine, T. NAKADA, T. MASUDA, S. MIWA, T. MAT-
SUMOTO, Y. FUKUDA, Y. MORITA. Japan Soc Mech
Engrs—Bul v6 n23 Aug 1963 p 556–67. Basic analysis
and design of new hobbing machine; average and mini-
mum of angular position error is 20 sec and 11 sec,
respectively, when gear module is one pitch circle, diam-
eter is 72 mm; such accuracy is obtained by virtue of
electrohydraulic servomechanism that corrects error of
driving worm wheel; mechanism performance is analyzed
and experimental results discussed.

Results Obtained When Using Vibrating Tools and In-
formation on Energy Dissipation in Machine Tool Vibra-
tion from Russian Sources, R. WEILL. Int Prod Eng
Res Conf Proc Sept 9–12 1963 p 459–64. Published by
ASME. Variation of cutting forces during vibration is
discussed, and results obtained in this field reviewed;
Russian work on defining and measuring damping capacity
of various machine tool components is discussed; frac-
tural energy loss per cycle of vibration was measured for
number of materials, and machine tool components; by
setting energy loss equal to energy input, due to re-
generative copying of surface waves on workpiece, method
of predicting stability is obtained.

Stability of Machine Tool against Self-Excited Vibration
in Machining, J. TLUSTY, M. POLACEK. Int Prod Eng
Res Conf Proc Sept 9–12 1963 p 465–74. Published by
ASME. Influence of characteristics of machine tool on
occurrence of self-excited vibration is described, in order
to be able to get higher stability of machine tools at mini-
mal weight; theory of self-excited vibration presented
explains all basic characteristics of this phenomenon, and
some of effects of changes in machine tool on vibration;
example of change of orientation in case of boring bar with
rectangular cross section is described.

What Can Vibration Research Contribute to Machine Tool
Development, J. PETERS. Proc Int Prod Eng Res Conf
Sept 9–12 1963 p 486–93. Published by ASME. Surface
roughness produced in turning operations is shown to be
related to natural modes of spindle and lathe bed; struc-
tural weaknesses contribute to surface roughness, espe-
cially when forced vibrations from gears, ball bearings,
etc. are small; chatter studies.

Applied Vibration Research on Lathes, K. E. WETZEL,
R. DORNHOFER. Int Prod Eng Res Conf Proc Sept
9–12 1963 p 494–501 23 refs. Published by ASME. Re-
sults of dynamic studies of new lathe designs are reported,
including vibration behavior of lathe beds, and studies of
saddle and cross-slide and self-excited vibration on slide
ways; methods of raising stability of headstock spindle;
vibrational correct design of tailstock and center point;

sources of severe vibrational disturbances are reviewed
including forced vibrations, vibrations from high speed
drives, belt drives etc; chatter problems of boring tools
and self-excited vibrations of gun drills.

New Concepts Concerning Machine Tool Structures, F.
KOENIGSBERGER. Int Prod Eng Res Conf Proc Sept
9–12 1963 p 535–42. Published by ASME. Effects of im-
portant parameters, such as design shapes and loads, ma-
terials properties, methods of manufacture, joint design
and efficiency and stiffness-to-weight ratios are described,
and problems of accuracy discussed, particularly that of
alignment error correction; application of results to de-
signs in past and present, and possible future develop-
ments considered; some results of recent research work
are reported.

High Precision Components-Analysis of Engineering De-
sign and Manufacturing, J. LOXHAM. Proc Int Prod
Eng Res Conf Sept 9–12 1963 p 634–44. Conditions neces-
sary for obtaining precision products within allowed tol-
erances are discussed, including design of machine tools,
as illustrated by design of grinding machine; product
measurement problems in design of machine and inspec-
tion.

Osevaya zhestkost shpindel'nykh uzlov vysokotochnykh
metallorezhushchikh stankov (Axial rigidity of precision
machine tool spindle units), A. M. FIGATNER. Stanki i
Instrument n12 Dec 1963 p 1–5; see also English transla-
tion in Machines & Tooling v34 n12 1963 p 2–6. It has
been established by calculations and by experiments that
axial rigidity of such units depends to great degree on
accuracy of manufacturing of bearings and adjoining
parts; methods of calculations and graphs for determi-
nation of axial rigidity are given; high axial rigidity is
assured by selection of high precision bearings with axial
play not exceedng 1–3 μ; recommendations for selection
of bearings are given.

Errors in Measuring Geometrical Accuracy of Machine
Tools by Means of Automatic Checking Devices,
A. SADOWSKI. Microtecnic v18 n2 Apr 1964 p 45–53.
Analysis of errors when measuring machine tool accuracy
by means of dial gages, leads to conclusion that dial
gages with 1/100 mm divisions have large intrinsic error
and should be replaced by micro-indicators with error
not exceeding two microns; revision of international
standards for testing machine tool accuracy should in-
clude metrological indications relative to measuring
equipment such as dial comparators, precision squares
and rules, test mandrels, and universal stands.

Some East German Machine Tool Developments, R. E.
GREEN. Machy (Lond) v105 n2698 July 29 1964
p 302–9. New designs of grinding, lapping, and honing
machines shown at 1964 Leipzig Spring Fair; automatic
universal thread-grinding machine fitted with equipment
for automatic loading and unloading of taps of 0.394 in.
diam; new design of shoe centerless grinding machine
with automatic feeding and diameter size control; ma-
chines for rough- and finish-grinding of ball raceways by
plunge-cut method; internal grinding machines fitted
with recently developed HF spindles running at 24,000
rpm; grinding machine for gears employing generating
principle; Naumburg flat-lapping machine; semiauto-
matic vertical honing line.

Optical Setting Devices for Machine Tools. Machine
Shop v25 n10 Oct 1964 p 484–6. Despite recent develop-
ments in electronic measuring methods, optical devices
are still favored for many applications; direct reading
microscope has now been replaced by projection type unit
consisting of precision divided scale and micrometer pro-
jector; either element can be part of moving equipment

or remain stationary; two units manufactured by Hilger & Watts are described.

Das Multiprismat—ein neuartiges optisch-elektronisches Positioniersystem (The Multi-Prism—A New Optical Electronic Positioning System), W. SELIGER. Optik (Germany) v21 n10 Oct 1964 5 figs p 546–50 in German. The multiprism itself is a glass plate with a parallel array of 90° prisms cemented to one face. A grating is imaged by an optical system, via the multiprism, onto a receiving grating and then to a photocell. Movement of the multiprism then gives a sinusoidal output which can be used to determine the position of the multiprism. The resolution of the system is about 10 μ. Some possible uses are described, particularly in the machine tool industry.

12.3. Automatic Control

Where Close Timing of Operations Rests on Machine Controls. Elec Mfg v15 n6 June 1935 p 23–4. New gear-tooth lapping machine of Fellows Gear Shaper Co., for lapping gear teeth after heat treatment, is designed for full electric control; automatic timing of machine operations and shut-down upon completion of cycle of effective work are two control problems carefully developed in new designs.

Electronic Control and Its Relation to Machine Tool Operating Cycles, E. H. VEDDER. Steel v100 n21 May 24 1937 p 64–5. Typical industrial applications of photoelectric control to indicate possible machine tool application. Before machine tool electrification forum, held under auspices of Westinghouse Elec & Mfg Co.

Successful Electronic Controls, R. A. POWERS. Elec Mfg v20 n6 Dec 1937 p 50–4 96–7. General discussion of fundamentals of theory and application of photoelectric control machine tool operation.

Steuerung von Werkzeugmaschinen durch Fotozellen (Control of Machine Tools by Photoelectric Cells), R. SPIES. Werkzeugmaschine v42 n18 Sept 30 1938 p 391–9. Types and operating principles of cells; replacement of mechanical control equipment by photocells; control of photocells and templets; circuits.

Air Size-Control, J. E. KLINE. Machine Design v19 n10 Oct 1947 p 88–91. Features of gaging device which measures workpiece during machining or other operations; application to honing machines as exemplified by 6-spindle machine which simultaneously finishes all cylinders in block, or single spindle machine in which gaging control automatically indexes fixture, transferring operations through successive bores.

Thickness Gage for Moving Sheets, J. W. HEAD. Electronics v21 n5 May 1948 p 90–2. How glass and other non-magnetic sheets ranging in thickness from ⅛ in. to 1 in. can be continuously gaged to close tolerances; material is run between primary and secondary of measuring transformer; variations in material thickness change coupling, upset bridge balance and are directly indicated.

Dimensional Control. Aircraft Prod v11 n132 Oct 1949 p 339. Technique developed by Sigma Instrument Co to provide operator with continuous dimensional information of component being produced and at economical price, consists of employing Sigma vertical comparator with range of fixtures so constructed that all dimensions on component can be measured as distinct from being gaged, without resetting comparator; it is particularly intended for checking of large quantities of parts produced on automatic machinery.

Automatic Positioning Device Allows Precision Machining of Delicate Optical Instruments, E. E. JEFFERY. Western Metals v10 n10 Oct 1952 p 54–6. Design of 340–T Giddings & Lewis boring, drilling and milling machine installed recently at Northrops Anaheim division; number of operations can be performed from single setup position; machine used for manufacturing main housings of range finders, machining jigs and fixtures for production of optical instruments, etc.; how positioning cycle operates.

Machine-Control Gaging, L. O. HEINOLD, JR. Machy (N.Y.) v63 n3 Nov 1956 p 217–22; Machy (London) v90 n2308 Feb 8 1957 p 299–303. Discussion of gaging which performs functions of inspecting work, changing speed or direction of machine tool spindle or slide, and signaling needed resetting of machine tool member; in-process and post process gaging; four available control systems include pre-process gaging, combination gaging, electric and air electric, and electronic and air electronic gaging systems.

Kontinuierliche Pruefmethoden in der industriellen Fertigung (Continuous Testing Methods in Industrial Manufacturing), M. DUEHMKE. Metall v11 n7 July 1957 p 579–82. Continuous testing methods in work shops, particularly in interchangeable manufacture; statistical control by sampling; built-in control apparatus in machine tools; examples of most recent developments in continuous automatic control.

A Critical Evaluation of High-Precision Electromechanical Linear Measuring Systems, F. BROUWER. Elec Mfg v60 n2 Aug 1957 p 128–41 28 figs 5 refs. Discussion of accuracy, linearity, resolution and sources of error in position measuring transducers suitable for closed loop machine tool controls, including: differential transformers and capacitors; linear potentiometers; ultransonic systems; lead screw and rack systems with rotary signal pickoffs; optical systems; digitally coded scales; and proprietary Pratt & Whitney "Electrolimit", Farrand "Inductosyn" and Canadian Westinghouse "Nultrax."

Dimensional Controlling Systems, R. A. SOULER. Automat v4 n11 1957 p 76–80, v5 n1 3 Jan 1958 p 81–4, Mar p 73–4. Nov 1957: In-Process Gaging Provides Reliable Machine Control. Jan 1958: Post Process Gaging Provides Versatile Machine Control. Mar: Combination Gaging Systems.

Basic Gages and Gaging Considerations for Automatic Machine Control, J. W. HOPPER. ASME-Paper n58-AUT–6 for meeting Apr 14–16 1958 4 p. Consideration of basic concepts of measuring manufactured parts, specifically for purpose of controlling manufacturing machine; problems of compartor type gages and control systems; air gaging; electromechanical-type gaging; precision gaging.

Gage Modules Advance Machine-Control Design. Elec Mfg v62 n1 July 1958 p 110–13, 258. Adaptation of basic design principles, such as modular construction, plug-in component and connects, and sliding panel circuit subassemblies to gaging instruments and controls; application of gages to machine tools, parts segregation systems, and automatic assembly machines.

Instruments for the Control of Kinematic Accuracy of Linkages and Machine Tools, B. A. TAITS, V. P. KOROTKOV. Meas Techns 1959 n6 June 1960 p 406–10 7 figs. Translated from Izmer Tekh n6 June 1959 p 12. Describes instruments for the accuracy control of linkages

and machine tools and, especially, the method without standards provides for a high-accuracy control of the kinematic accuracy of gears, lead screws, and kinematic chains. However, a further improvement is necessary.

An Automatic Method of Ensuring Accuracy of Dimensions in Centerless Grinding, S. S. VOLOSOV, G. B. TURBIN. Meas Techns 1960 n5 Jan 1961 p 379–81 2 figs 1 ref. Translated from Izmer Tekh n5 May 1960 p 7–9. Discusses limitations of self-adjusting systems of active automatic control and prerequisites to successful application.

Automation Development—Machine Tool Trends, D. F. GALLOWAY. Machy Market n3140 Jan 19 1961 p 21–2. Example notes First State Ball Bearing Plant, Moscow, where automatic line comprises 150 machine tools, heat treatment furnaces, assembly presses, inspection equipment, and unit for greasing and packaging, all connected by handling devices; problems in work handling, from machine to machine, with regard to feedback and numerical control systems, and design of tool elements in relation to automatic control are considered. Abstract of paper before Instn Mech Engrs.

An Automatic Electronic Coordinate Measuring Equipment for a Heavy Boring Machine, E. L. ABRAMZOM, G. L. GRIN, A. Y. PELIKS, S. S. PODLAZOV. Meas Techns 1960 n7 Feb 1961 p 579–83 6 figs. Translated from Izmer Tekh n7 July 1960 p 20–4. Equipment for measuring displacement coordinates, both vertical and horizontal, of heavy boring machine, by means of two circular inductive transducers, and reversible electronic counter which operates with decatrons.

Automatic Control of Dimensional Accuracy in Internal Grinding, H. CH'ANGKEN. Meas Techns 1960 n8 Apr 1961 p 235–8 3 figs 2 refs. Translated from Izmer Tekh n9 Sept 1960 p 7–10. Describes method of measuring under optimum conditions by which it is almost possible to eliminate completely the effect of allowance variations on the accuracy of the ground ring diameters. It is possible to grind details without subsequent precision grinding.

Staveley Group Research Department, P. A. SIDDERS. Machy (London) v98 n2534 June 7 1961 p 1309–12. Three main sections are concerned with mechanical engineering, control systems, and electronics; examples of work given include studies dealing with hydrostatic nut and leadscrew system for traversing machine tool slide, research connected with stiffness of hydrostatic slides, use of Perspex models of machine tools to predict dynamic behavior of design, investigating hydraulic drives for machine tool feed system, and tape-controlled contour milling machine.

Ferrodynamic Transducers for Automatic Monitoring and Controlling Devices, M. D. GAFANOVICH. Meas Techns 1961 n2 Oct 1961 p 100–4 3 figs 4 refs. Translated from Izmer Tekh n2 Feb 1961 p 8–12. Transducer developed for angle of rotation into appropriate voltage, on basis of which new improved telemetering system has been designed and several computing circuits developed; advantages of system, including better linear relationship between output emf and angle of rotation, etc.

Developments in Moiré Fringe Measurement Systems, A. T. SHEPHERD. Machy (London) v99 n2562 Dec 10 1961 p 1424–6. Machine tool control system is described which gives digital subdivision of $\frac{1}{10}$th of pitch and could be extended to $\frac{1}{20}$th of pitch without use of carrier; with 1000-line/in. grating system affords digit size of 50 or 100μin, which would meet all normal engineering requirements including jig borer applications; principle of operation.

Success of TV on Open-Side Machine Leads to Use of Digital Read-Out, S. C. BROWN. Machy (N.Y.)

v68 n7 Mar 1962 p 89–91. Examples of machining jobs done at Waterbury Farrel Foundry & Machine Co. by television read-out on Ingersoll open-side milling, boring, and drilling machine whose movable column provides 22 ft of longitudinal and 6 ft of cross travel, with 5 ft of boring-bar feed; 78- by 78- by 24-ft split-table, planer type milling machine, by employing Norden multiple-axis measuring system with digital read-out, eliminates guesswork as factor in setting machine positions.

Automatically Controlled Machine Tools, C. A. SPARKES. Chartered Mech Engr v9 n6 June 1962 p 298–305 40 refs. Review considers automatic features of machine tools in 3 broad groups; single-purpose unit is often highly automated; in various combinations, it is used for mass production; modern universal center lathes, milling and planing machines, drillers and grinders are used for several types of operation but, to keep cost down, automatic features are kept to minimum; third range of tools, often high in capital cost, incorporate features intended to reduce to minimum cost of components produced.

Wide-Range Pneumatic Instrument for Automatic Checking of Dimensions (during Machining), E. I. PED'. Meas Techns 1961 n12 June 1962 p 949–51 3 figs. Translated from Izmer Tekh n12 Dec 1961 p 12–4. Presents experimental and theoretical investigation of a new pneumatic measuring system having wide measuring limits applied for automatic checking of the dimensional parameters of components during machining.

Digital Techniques in Precision Dimensional Measurement, R. J. MARMORSTONE. Automatic Control v17 n1 July 1962 p 32–4. Review of electromechanical shaft position encoders with sliding contacts: typical encoder applications for measurement and control in machine tool industry and for general laboratory use.

Some Performance Limiting Features of Machine Tool Control System, A. COWLEY. Int J Mach Tool Design & Res v2 n4 Oct–Dec 1962 p 379–92. Simplified linear considerations, giving reasonable indication of system response, are discussed; effects of principal nonlinearities within servo loop considered; describing function is useful tool for dealing with single nonlinearities and will usually provide results with accuracies better than 50%; if effect of several nonlinearities acting simultaneously is to be predicted, then use of analog computer may be necessary and is certainly desirable.

Automatic Position-Setting, Aircraft Prod v24 n10 Oct 1962 p 350–8. GSP-Matic machine, installed at works of Sperry Gyroscope Co, Ltd, is highly ingenious and unorthodox example of numerically controlled machining systems; developed from jig-borer, it has two spindles and is fitted with automatic tool changing system; one spindle is for heavy duty machining, other high speed spindle for lighter work; all machine functions, including tool changing, are programmed on 35-mm film.

Computerless Programming vs Simple Control System and Simple Computer, R. CLEGG. ASTME Creative Mfg Seminars-Tech Paper SP63–42 Dec 1962 5 p. What numerical programmer must do to produce tapes required; features of computer routine; computerless programming is considered desirable at start of numerical control; after using variety of numerically controlled equipment, computer may become useful by simplifying programming for all numerically controlled machines; therefore, question is really computerless programming versus computer programming.

New Photo-Optical, Random-Access Memory, W. RENOLD. Soc Photographic Instrumentation Engrs J v1 n2 Dec 1962–Jan 1963 p 44–8. New concept for high capacity rapid access and readout photo-optical data storage system, combining recent advances in precision film movement with extreme accelerations, new optical-electronic scanning methods, and digital positioning tech-

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niques developed for automatic machine tool control; integration of elements into system is described; immediate and potential capabilities are discussed; diagrams are included.

Ferranti Mk. IV Continuous Path Phase Control System, D. F. WALKER. Int J Machine Tool Design & Res v3 n1 Jan–Mar 1963 p 61–73. Background of Mk. IV system which was developed to supersede original continuous path tape control unit and to exploit benefits to be gained from use of transistors in place of thermionic valves; measuring system described; block diagram of complete control system is shown along with some control waveforms; design features; continuous path system was designed to automate small quanity production work where conventional mass production techniques are not applicable for economic reasons; applications indicated.

Numerical Control of Machine Tools, D. F. WALKER. J Instn Elec Engrs v9 Feb 1963 p 61–5. Discussion of numerical control as system particularly suitable for small quantity production; error checking and correcting, and measuring systems; future trends.

Pneumatic Contactless Instrument for Automatic Control in the Course of Machining, E. I. PED', A. V. FEDOTOV. Meas Techns 1962 n8 Feb 1963 p 639–40 3 figs 1 ref. Translated from Izmer Tekh n8 Aug 1962 p 16–7. Describes an automatic pneumatic instrument for production control which is equipped with a liquid manometer as an indicating device.

Survey of Techniques Evolved for Measurement of Position in Numerically Controlled Machine Tools, R. BELL. Radio & Electronic Engr v25 n3 Mar 1963 p 207–24 64 refs. Techniques employed in numerical control of machine tools are reviewed; they are classified into basic groupings of analog and digital, and then according to mode of operation of transducer; inherent sources of error are discussed.

Big Tables Ride N/C "Cushion" for Accurate Positioning. Iron Age v191 n10 Mar 7 1963 p 140–1. Numerical positioning control system guides table along horizontal and vertical planes; it has already been applied to 30 ton Wiedemann press, where it positions large steel panels for turret punching; system designed by Cutler-Hammer, Long Island, N.Y., moves 2-ton table mass from "dead still" to speed of 600 ipm in only $\frac{1}{10}$ sec; it places workpiece under right punch with positioning accuracy of 0.006 in.; punched tape controls all machine operations in automatic, or normal mode.

Instrument for Automatic Control of Dimensions of Articles with Discontinuous Surfaces, B. N. MARKOV, E. I. PED'. Meas Techns 1962 n9 Apr 1963 p 722–5 1 ref. Translated from Izmer Tekh n9 Sept 1962 p 9–11. Contactless pneumatic instrument with large measuring range developed by Moscow Machine Tool Inst for automatic control of parts during machining at low speeds.

Magneto-Optic Positioning, R. J. MELTZER. IEEE Trans Indus Electronics vIE–10 n1 May 1963 p 46–56 27 figs 4 refs. For accurate production of scales and grids it was necessary to develop device which would locate lines with precision better than 1μin.; system is described that accomplishes this by forming image of line with polarized light, whose angle of polarization varies with position of line.

Inside Mark Century Numerical Controls, J. T. EVANS, L. U. C. KELLING. Control Eng v10 n5 May 1963 p 112–17. Design of Gen Elec Co positioning and contouring numerical control system that uses binary-coded-decimal

computation throughout; controls obtain high feed speeds (up to 500 in./min) with increments of 0.0001 in.; absolute coordinates are used for positioning, and departure coordinates for contouring.

Effect of Servomechanism Characteristics on Accuracy of Contouring Around Corner, H. E. VIGOUR. IEEE Trans on Applications & Indus v82 n66 May 1963 p 120–4. Servomechanism errors in 2-dimensional contouring system are analyzed to determine position error of tool center negotiating corner formed by 2 straight lines; results establish feed rate which will permit specified tolerance on path error to be met; transient response information from analog computer tests is summarized in nomographic form to permit convenient consideration of maximum tool center path error during design of servomechanisms. Paper 62–250.

Application of the Television Computing Technique in Automatic Control of Dimensions, V. S. VIKHMAN. Meas Techns 1962 n11 June 1963 p 904–6 figs. Translated from Izmer Tekh n11 Nov 1962 p 9–14. Describes a system which amounts to the automation of known production control methods. Tests have shown that the system operates with stability and very few adjustments during operation.

Technological Requirements of Machine Tool Manufacturing System, R. R. WEBER. Int Prod Eng Res Conf Proc Sept 9–12 1963 p 556–60. Published by ASME. Design, control, machining and part acceptance are considered as necessary parts of fully integrated and automatic system; role of numerical control in element of design is discussed; some problems in area of control are considered where applications can be made of current knowledge and where additional research is necessary to complete evolution of machine tool manufacturing system.

Measurements and Control, V. Y. KNELLER. Meas Techns 1963 n3 Sept 1963 p 181–4 11 refs. Translated from Izmer Tekh n3 Mar 1963 p 1–4. Conclusions derived are that measurement and control (and correspondingly automatic measurement and automatic control) are different processes distinguished by their objective and final results, and representing as a whole different forms of information transformation. The suggested definitions of measurement and control reflect these characteristics. Measurement can form part of an intermediate transformation in a control process. A clear conception of each of these processes, together with an understanding of their common features, will help to systematize the accumulated practical data, to understand the trends of development in automatic measurements and control, and to determine the tasks of further research.

Television Methods of Controlling Dimensions, O. D. BYCHKOV. Meas Techns 1963 n5 Nov 1963 p 372–5 2 figs 21 refs. Translated from Izmer Tekh n5 May 1963 p 6–9. An article reviewing various methods.

DIG, a Long-Travel Ultraprecise Absolute Reading Digital Linear Measuring Instrument. Bausch and Lomb, Rochester, N.Y. 1964 8 p 4 figs. See abstract under 1.2.1.

The Use of Encoders in Machine Tool Control Systems, F. J. ROBINSON. Machy (London) v104 n2668 Jan 1 1964 p 12–9 7 figs. Discusses types of control systems, methods of feedback, the Baldwin encoder, coding, and position control system using encoders.

Measurement for Control, N. ANDERSON. Instrum Control Syst (USA) v37 n8 Aug 1964 p 103–12. A review of the most common types of transducers that have an output suitable for use in control systems.

Controlling Workpiece Accuracy, R. TILLEN, NPL. Sept 1964 19 p 15 figs 24 refs in 2 parts. Part 1 is a review of known commercial and experimental techniques, including direct in-process measurement of diameter, indirect in-process measurement, and comparison of direct and indirect in-process measurement. Part 2 is a first report on work at NPL on measurements during turning, including design considerations applied to NPL proto-

type turning gage, experimental results obtained with such gage, and conclusions.

Air and Electronic Gaging, J. J. DWYER, JR. Am Mach Special Rept n558 Oct 12 1964 16 p. Discusses the basics of air gaging; typical manual air-gaging applications; electronic gaging, automatic size control, gaging, and sorting.

12.4. Grinding

Continuous Reading Grinder Caliper, H. K. SPENCER. Am Mach v25 Oct 5 1911 p636–8 6 figs. An amplifying gage of which the table of a rotary surface grinder is the work support. The rotary work table carries the pieces, which are being ground, alternately under the wheel and the measuring contact, so that each piece is measured after evey pass under the wheel.

Die Grundlagen des Schleifens (Principles of Grinding), C. KRUG. VDI Zeit v71 Aug 6 1927 p 1109–16 36 figs. Classification of types of grinding, from rough to finest; physics and technology of grinding process studied with aid of microscope; structure and design of grinding wheel; analytic and experimental study of details of grinding; list of technical problems requiring study.

Precision Surface Grinding, E. C. LARKE, F. C. SMITH. Machy (London) v31 Dec 8 22 29 1927 Jan 26 Feb 2 23 1928 p 308–12 391–4 422–3 545–7 579–81 673–5 48 figs; also v32 Apr 26 May 31 June 7 1928 p 105–7, 265–7 294–5 25 figs. Precision surface grinding dependent upon skill of operator, accuracy of machine, and correct composition of grinding wheel; fundamental rules governing choice of wheels; grades of wheels; form of wheels; mounting of wheels; hollowing and cornering; wheel speeds; feeds, preparation for lapping; swiveling angle plate; magnetic chucks; producing accurate angles on wheels.

Precision Cylindrical Grinding, R. E. W. HARRISON. Machine-Shop Prac (ASME Trans) v51 n24 Sept–Dec 1929 p 133–7 8 figs. Process of evolution through which precision cylindrical grinding has passed during last eight years; production dependent upon horsepower capacity of tool; consequently its structure has been strengthened; work handled on 5-hp. machines in 1921, today being produced in proportionately reduced time on 20-hp. machines; still considerable work to be done; comparative methods of metal removal; production possibilities on controlled center-type machine.

Alignment Tolerances on Precision Grinding Machines. Machy (London) v35 n890 Oct 31 1929 p 141–2 7 figs. Description of range of special alignment test developed by Churchill Machine Tool Co., Manchester, for all classes of precision grinding machines; method of checking perpendicularity of wheelhead slideway vee; checking alignment of table as it travels along ways; checking alignment of wheelhead spindles with bed slideways in both vertical and horizontal directions; tolerances met on Churchill Cincinnati grinding machines.

Technique of Size Control in Precision Grinding Operations, R. E. W. HARRISON. ASME Advance Paper meeting Oct 3 1932 16 p 2 supp plates; Am Mach v76 Oct 12 1932 p 1065–7; Iron Age v130 Oct 13 1932 p 570–1 16 18 20; Machy (London) v41 Oct 6 1932 p 11–4 Oct p 37–9; Abrasive Indus v13 Nov 1932 p 13–5 and Dec p 14–7 v14 Jan 1933 p 15–7 22; Western Machy & Steel World v24 12 Jan 1933 p 10–7; Indus Standardization v3 n12 Dec 1932 p 299–305 and v4 n1 Jan 1933 p 10–7. Use of limit system as major key to cheap manufacture; functions of precision grinding machine and design factors which make for ease of size control.

Profile Grinding Machine for Tools and Gages, O. P. VAN STEEWEN. Machy (N.Y.) v39 n6 Feb 1933 p 411–3. Operating characteristics of grinding machines developed by Loewe Gesfuerel of Berlin, Germany, with particular regard to accuracy obtained by profile-copying system using pantograph with ratio of 50 to 1.

Electric Sizing in Grinding, A. V. MERSHON. Mech Wld v93 n2414 Apr 7 1933 p 335–6. Automatic sizing control developed by Gen Elec Co., Schenectady, which has been adopted by sections of American machine-tool industry; single electric gage head has pair of coils which are used to produce deflection on indicating instrument while workpiece is being ground to size.

Precision Profile-Grinding Machine. Eng v139 n3601 Jan 18 1935 p 58–9 supp plate. Machine made by Loewe Gesfuerel, Berlin, it is claimed, reduces time required to form complicated profile on tool or gage to fraction of that required by usual methods; principle is that of employing pantograph with tracing point on its long arm and microscope, with cross lines in its field, on its short one.

Measurement During Machining and Automatic Sizing, H. C. TOWN. Eng v139 n3603 3606 Feb 1 1935 p 107–8 and Feb 22 p 189–90. Feb. 1: Details of automatic measuring device introduced few years ago by H. W. Kearns and Co, known as Insulater dial traverse indicator; with increasing accuracy demanded, Kearns now prefer to fit vernier scales on high precision Chesterman rules accurate to within 0.0005 in. in 4 ft. of length. Feb 22: Pneumatic micrometer developed by Solex Ltd.

Precision Grinding Machine for Small Cylindrical Parts. Eng v140 n3627 July 19 1935 p 62–3. Machine made by Loewe-Gesfuerel A–G, Berlin, intended for work ranging from 0.02 in. to 1.18 in. in diam only; proportioned and constructed that within these limits, very high degree of accuracy of 0.00039 in. in error can be consistently obtained.

Five Theorems for a Mechanical Surfacer, C. DEVE. Rev Opt v15 June–July p 201–14 and Aug 1936 p 241–57. A machine for grinding surfaces is described and its mechanism provides means for realizing new parameters and gives uniform use for the optical manufacturer. The theory of the instrument is explained in a series of five theorems and their principal applications are set out.

Extreme Precision is Required in Gage Grinding. Abrasives v18 Sept 1937 p 9. Illustrated description of a few of the grinding operations at tool making plant of Taft-Pierce Mfg. Co. giving the size, kind, and grade of grinding wheel, and its speed for grinding a typical thread gage.

Size Controlling Device for Internal Grinding Machines, H. A. DUDGEON. Machy (London) v60 n1537 Mar 26 1942 p 238–9. Description of device having light control wheel, attached to spindle running freely in bearings, which is placed in position close to end of work piece so that periphery of grinding wheel touches periphery of control wheel exactly when grinding wheel is in position for finishing hole; contact between grinding and control

wheels causes latter to revolve, thus opening or closing electric circuits which perform pre-arranged function.

How to Secure Fine Surfaces by Grinding, H. J. WILLS, H. J. INGRAM. Machy (N.Y.) v50 n5 6 7 8 9 10 11 Jan 1944 p 173–5, Feb p 167–70, Mar p 211–13, Apr 159–60, May p 181–2, June p 173–5, July p 208–9; Machy (London) v64 n1640 Mar 16 1944 p 294–6, v65 n1661 1663 Aug 10 1944 p149–52 Aug 24 p 210–2. Jan: Balancing grinding wheels; conditions responsible for chatter marks; methods and equipment employed to balance wheels; arbors equipped with balancing weights. Feb: Functions of coolants used in grinding; properties of different types of coolants and method for securing their most effective use. Mar: Fundamentals of lapping. Apr: Machine lapping operations. May: Details of lapping operations in tool room. June: Production lapping of ground internal and external cylindrical surfaces. July: Lapping operations as applied to production of gears and worms.

Accurate Grinding Depends Upon Correct Location of Surfaces, S. H. NEADY. Am Mach v88 n21 Oct 21 1944 p 110–12. Difficulty in securing correct lateral dimensions or correct relationship on ground parts is frequently due to incorrect use of multiple locating points; article gives specific case examples and illustrations showing methods of locating surfaces correctly.

Surface Grinder Attachment Generates Involute Gears. Iron Age July 31 1952 p 87 1 fig. Describes a new universal involute gear generator for attachment on surface grinders. Only standard grinding wheels are required. A wheel dressing unit is part of the attachment.

Basic Gear Grinding Methods Compared, D. W. BOTSTIBER. Iron Age v170 Aug 7 1952 p 118–21 6 figs. Grinding can correct gear tooth form and spacing errors. It is particularly useful after hardening. Each of the three basic methods—form, line, and point grinding, has advantages and limitations. Hardened and ground gears can make transmissions 50 percent lighter, 40 percent smaller, and cheaper than unground gears of equal capacity.

How to Calculate Exact Wheel Profiles for Form Grinding Helical-Gear Teeth, O. SAARI. Am Mach v98 n19 Sept 13 1954 p 172–5 3 figs 3 refs. In form-grinding helical gear teeth the exact wheel profile is not reproduced anywhere on the work. The article shows how the correct wheel profile and its radius of curvature at any point can be calculated by an exact mathematical method. Formulas are derived for computing the coordinates, pressure angle, and radius of curvature of the cutter form. A numerical example shows how to use the computed data in establishing the settings of the radius-dressing fixture.

Grinding Round Within Millionths, R. LEGRAND. Am Mach/Metalworking Mfg v106 n26 Dec 24 1962 p 51–3 5 figs. New Highs in grinding accuracy—grinding round within ten millionths on a revolving spindle headstock— are now possible with the hydrostatic bearing, a development which has been around since 1907, but which has come into its own as a metalworking tool relatively recently. Hydrostatic bearings, which support the headstock spindle by floating it on opposed pads of high-pressure oil, attain extremely high grinding accuracy through counter-balancing of oil pressures. The slightest off-axis movement of the spindle builds up pressure in one pocket and reduces it in the opposed pocket. This fact buildup of force limits the off-axis movement of the spindle to millionths of an inch. That is why, with the hydrostatic bearings, it is possible to produce OD, ID and face dimensions that are round, concentric and square within plus or minus 10 millionths—or even less. At the moment, such superfine grinding is more or less limited to manufacture of missile servos, gyroscopes, gimbals, gages and the like. Here the idea is to attain the correct geometry and an ultrasmooth finish to closer limits and at a lower cost through the use of hydrostatic bearings. But by now enough field experience has been racked up with these bearings that their future potential in the fine grinding field can be evaluated.

Automatic Instrument for Combined Grinding, A. V. VYSOTSKII. Meas Techns 1962 n11 June 1963 p 909–11 2 figs 2 refs. Translated from Izmer Tekh n11 Nov 1962 p 14–5. Embodies a differential pneumatic pressure gage, one branch of which measures the diameter of a shaft during machining while the other branch is connected to a device for measuring the diameter of a hole to which the shaft is to be matched.

12.5. Lapping

Laps and Lapping, W. A. KNIGHT, A. A. CASE. Trans ASME v37 June 1915 p 297–338. An investigation of the cutting properties of abrasives when used with different laps and different lubricants. Comment, Aug 1915 p 976.

Accurate Lapping, L. J. VORHEES. Am Mach v53 Aug 5 1920 p 263–5 3 figs. Instructions for gage lapping and for making laps. Material for laps, work speeds, lapping screw threads, plain plugs, and flat surfaces.

Modern Lapping Practice. Machy (N.Y.) v27 Nov 1920 p 209–17 19 figs; Machy (London) v17 Nov 4 1920 p 129– 37 19 figs. Developments in lapping practice, including abrasives used in lap-charging methods, lapping thread gages, snap gages, measuring wires, flat surfaces, ring gages, die-casting dies and T-slots.

Hand and Machine-Lapped Surfaces as Seen through a Microscope. Machy (N.Y.) v28 Apr 1922 p 638–9 6 figs. Illustrated study by Pratt and Whitney Co. of the characteristics of different surfaces, as obtained by various methods of lapping.

Machining and Lapping Very Deep Holes, J. B. ROSE. Mech Engr v44 Dec 1922 p 807–12. Discussion of shop operations in the forming of very accurate and highly finished cylindrical holes.

Precision Lapping, W. E. HOKE. Machy (N.Y.) v31 Apr 1925 p 593–6 1 fig; Machy (London) v26 1925 p 4. Lapping abrasives and methods, and use of double type of lap for plane parallel surfaces.

Precise Cylindrical Lapping, P. M. MUELLER. Mech Eng v47 Sept 1925 p 701–4 11 figs; Machy (London) v27 1925 p 16; Am Mach v62 1925 p 749 and v63 1925 p 439. Method of production; preparation before lapping; preparation of laps; lobing; measurement, international tests. See also abstract in Machy (N.Y.) v32 Sept 1925 p 60–2 3 figs.

Moline Automatic Cylinder Lapping Machine. Machy (N.Y.) v33 Dec 1926 p 305–6 3 figs. Latest automobile-cylinder lapping machine developed by Moline Tool Co. with view to making operation as nearly automatic as possible.

Maintaining Precision in Production Lapping, S. PLAYER. Machy (N.Y.) v36 May 1930 p 686–8 4 figs; Iron Age v125 Mar 27 1930 p 943; Abrasive Indus v11 May 1930 p 23–6 4 figs; Automotive Indus v63 Dec 20 1930 p 906–8 5 figs; Machine Shop Practice (ASME Trans) v52 n24 Sept–Dec 1930 p 167–70 4 figs. Description of equipment and processes; flat or cylindrical parts are lapped by machine to tolerance of 0.00002 in.; 500 piston pins per hour being lapped; limits of 0.0001 in. for straightness and round-

ness; stock removed during roughing 0.0002 to 0.0004 in.; for finishing from 0 to 0.0002 in. over high limit of finished piece.

Progression of Commercial Accuracy—Turning, Grinding, Lapping. Grits and Grinds v22 n2 Feb 1931 p 1–8 9 figs. Origin and development; fields for use; advantages; methods.

Zur Kenntnis des Schleif- und Polier-Vorganges (Study of grinding and polishing process), L. HAMBURGER. Zeit Metallkunde v25 n2 Feb 1933 p 29–32 Mar p 58–62. Attention is called to deceptive appearance of polished surface; comparison of grinding and polishing processes; deformations as result of polishing and grinding; theoretical principles of polishing; factors influencing process; change in properties of surface layers due to grinding and polishing. Bibliography.

Production of Optical Flats. Machy (London) v56 n1454 Aug 22 1940 p 625–8; Eng v150 n3905 Nov 15 1940 p385–6 and 390 supp plate. Methods employed at factory of Optical Measuring Tools Ltd; primarily, optical flats are designed for gaging differences too small to be detected by standard micrometer; in practice it is possible to detect with ease differences of 0.00001 in. directly, or from 0.00001 in to 0.000005 in. by estimation; preliminary operations on quartz crystal; finish grinding.

Optical Flats by Mass Production, L. P. JACKSON. Iron Age v148 n9 Aug 28 1941 p 42–4. Elimination of hand lapping operations in making optical flats has effected considerable savings in their production time and cost, thus making manufacture of these surface gages practical for general industrial production.

Lapping Center Holes for Accurate Grinding, R. N. CLARK. Grits & Grinds v34 n6 June 1943 p 8–10. Description of lapping machine for grinding center holes, which handles work up to 36 in. long and 10 in. diam, with spindle speeds varying from 665 to 4300 rpm; machine operates similar to drill press, with work resting on vertically adjustable center, while spindle which carries lapping stone is brought down by hand lever; entire movable spindle assembly is counterweighted to provide sensitivity to lapping pressure.

Flatness and Parallelism in Quartz Plates, C. M. THURSTON. Bell Lab Rec v22 n10 11 June 1944 p 435–9 July p 452–3. June: Description of lapping machine used for surfacing crystals. July: Design of hand lapper and outline of new technique which gives much improved results.

Superfinishing by Lapping, F. M. BURT. Mill & Factory v36 n3 Mar 1945 p 96–100 306 310. In superfinishing measurements are made in millionths of inch; incredibly fine tolerances of this magnitude are generally produced by precision lapping methods and measurements are made by light bands; superfinishing processes as performed by company with experience in this field, are explained.

Closer Dimensional Control, G. E. STEDMAN. Machine Tool Blue Book v42 n1 Jan 1946 p 149–50 152 154 156. Developments in precision and dimensional control as applied in manufacture of precision instruments and machines; detailed description of micrometer lapping machines and precision thread lead finder developed and employed at N. A. Woodworth Co. Ferndale, Mich; construction, operation, application and performance discussed.

How Russians Lap Carbides. Am Mach v90 n7 Mar 28 1946 p 138. Details of machine and methods developed for lapping brazing face surface of cemented carbide inserts for cutting tools; machine operates on optical shop method principles and batch grinds inserts by oscillated motion

of disks on eccentric driven swing frame; machine construction and operation illustrated.

Investigation of Lapping Process, F. EUGENE. Indus Diamond Rev v7 n75 76 Feb 1947 p 35–40, Mar p 67–71; Engrs' Digest (Am Ed) v4 n9 Sept 1947 p 403–8. Tests to determine: influence of period of testing; influence of hardness of metal tested; comparison between abrasives; influence of load and speed on abrasion; abrasive properties of lap in relation to time and usage; wear of laps; behavior of lap with reference to holding of abrasive; comparison between smooth and grooved laps. From Travaux et Memoirs du Laboratoire Central des Industries Mecaniques 1945 p 9–33.

Precision Lapping Centerless Method, P. L. SOMMER, JR. Tool Engr v18 n3 Apr 1947 p 33–4 5 figs. Data concerning typical, complete unit cabinet type lapping machine, built by Size Control Co, Chicago; simple but positive operating principle produces uniform precision finish to less than 2 microinches; advantages of centerless over previously used ring lapping.

New Lapping Technique is Economical, Accurate . . . Increases Lapping Production by 55%, W. F. SCHLEICHER. Machine & Tool Blue Book v44 n8 Aug 1948 p 141–6. Features of process developed, by Crane Packing Co., Chicago, for superfinishing of faces of mechanical seals and closures, including design and operating details of Lapmaster used in process; machine eliminates grinding operations between machining and lapping.

Laeppen, die Grundlagen und ihre praktische Awendung (Lapping, the Fundamentals and their Practical Application), W. LAETZIG. Carl Hanser Verlag, Munich 1950 185 p illus, diagrs, charts, tables. Book deals with process of lapping all metallic materials with exception of cutting tools; it covers lapping material and media, hand and machine lapping, lapping time and defects, kinematics of lapping and other allied aspects; recommendations and examples are generally based on practical experiences and only in few cases on scientific research. Bibliography. Eng Soc Library, NY.

Lapping Technique; To Improve Image Quality of Electron Microscope Lenses, F. A. HAMM. J App Phys v12 n4 Apr 1950 p 271–8. Magnetic asymmetry or astigmatism in objective lens is often due to imperfect machining, localized defects or impurities in iron, or grain anisotropics; lapping technique is described which effectively reduces effect of imperfect machining or misalignment of components; electron micrographs illustrating value of lapping procedure.

Machine Lapping With Continuously Fed Free Abrasives, F. L. WHITE. Am Mach v95 n12 June 11 1951 p 161–3. Important factors in machine lapping of flat surfaces to close tolerances for flatness and surface quality; good results obtained in short predetermined time controlled lapping cycles; lapping machines arranged with wear rings providing continuous conditioning during lapping cycle; pressure on work; recommended abrasives; stock removal rates indicated.

Moderne Verfahren der mechanischen Feinbearbeitung von Metallen (Modern methods for fine mechanical finishing of metals), H. H. FINKELNBURG. Metall v8 n11–12 June 1954 p 459–62. Honing and lapping; barrel grinding; lapping with compressed air pistol; immersion lapping.

Machine for Lapping Centre Holes. Eng v178 n4621 Aug 20 1954 p 249. Pillar mounted machine introduced by A. A. Jones and Shipman, designed for lapping centers, drilled in ends of shafts and other pieces, which have suffered slight distortion at time of cutting or by subsequent hardening.

Ultrafinishing—New High-Precision Lapping Process, T. C. LEWIS, JR. ASME Trans v79 n7 Oct 1957 p 1699–1706. Innovations which permit use of lapping for production of exceptionally smooth metal surfaces with precise geometrical control; technique includes necessary variations in velocity to permit lapping of soft homogeneous and hard heterogeneous metals; process can yield 0.3 to 0.5-micron. finish rms with overall geometry control equal to or better than any commercial finishing method.

Finishing Surfaces by Vibration, R. C. HITCHCOCK, J. P. MORAN. Tool Engr v40 n4 Apr 1958 p 127–30. Production type vibratory lapping machines generate surface finishes as smooth as three microin.; flatness is held to within three helium light bands; productivity is high as compared to manual lapping; application of new technique to bronze and stainless steel rings for mechanical shaft seals described.

Whitworth Was Only Partly Right, R. J. RAHN. Am Mach v103 n8 Apr 20 1959 p 112–13. 119 yr old three-plate matching system of Sir Joseph Whitworth for producing flat surfaces considered incomplete; how this established method, if followed literally, might easily produce sections of spirals instead of flats; best modern method is to check with ten-millionths indicator.

Investigating the Efficiency of Plane-Parallel Lapping of Gauges, A. M. VEDMIDSKII. Meas Techns 1961 n9 Feb 1962 p 642–4 1 fig 1 ref. Based on experimental data an empirical formula is developed giving the mean amount of metal removed per unit in plane-parallel mechanical lapping of gage blocks. However, at the beginning of lapping a more intensive removal of metal occurs.

Plastic-Fabric Lapping Discs for Diamond Compounds. S African Min & Eng J v73 n3602 Feb 16 1962 p 367. Self-adhesive chemico-textile polishing disk, known as Hyprocel, introduced as improved vehicle for diamond and other abrasive compounds used in lapping or polishing of soft, hard and very hard materials; introduction represents major advance over other lapping cloths; Hyprocel is foam/fabric material composed of more than 50% chemicals; it is said to have excellent abrasive and lubricant retaining power.

Centerless Lapping Smooths Its Wrinkles, R. G. PIERCE. Grinding & Finishing v8 n3 Mar 1962 p 42–4. Recent developments which helped to improve Centerless Lapper; it can provide finish of 0.5 μ in. rms and tolerances down to 0.000005 in.; recommended abrasives for centerless lapping; 7 tips for improving quality of lapped work.

Preliminary Study of Lapping Process, G. A. ALLAN, K. H. SUTHERLAND. Prod Engr v41 n4 Apr 1962 p 195–202. Experiments on flat lapping carried out on 4 workpiece materials; 60/40 brass, fully heat-treated aluminum alloy HE 30 WP, and two annealed carbon steels EN 9 and EN 24b were tested in order to ascertain effect of load on workpiece and speed of lap on stock removal rate and surface finish of workpiece; hardness of materials was obtained in order to see if this value correlated with any of results; 36 in. Lapmaster machine was used for tests.

Contribution Relating to Metallographic Study of Disturbed Metal Caused by Abrasion and Polishing, R. H. ATKINSON. Plating v49 n5 May 1962 p 485–9. Study of surface of brass, steel, nickel and palladium, polished with abrasives such as diamond, chromic oxide, alumina and rouge has revealed presence, hitherto unsuspected, of characteristic lines of very small "dots" which were found to be tears; formation of tears can be avoided by hand polishing; dark field illumination, which is particularly advantageous for detection of polishing tears with optical microscope, also enables much clearer pictures to be obtained of microstructures produced in disturbed metal by abrasion.

Machining to 0.0000005 in. Steel v153 n2 July 8 1963 p 58. Inside diameters are machined to half millionth surface finish at Taylor Devices, North Tonawanda, N.Y.; job in question concerns finishing cylindrical parts for liquid springs to be used in space programs of General Dynamics/Astronautics; after honing and polishing operations critical, 2 stage lapping process on specially designed machine is carried out with patented, thin Teflon lap covered with diamond particles; lap, moving linearly, expands uniformly from hydrostatic pressure within, to provide surface finish of 0.0000005 in.

Fine Art of Flat Lapping, C. STEAD. Am Mach/Metalworking Mfg v107 n16 Aug 5 1963 p 78–80. Recommendations for obtaining maximum results in flat lapping on semiautomatic machine; importance of close control over such variables as size, shape, weight and required surface finish is emphasized.

12.6. Manufacture of Precision Measuring Tools and Components

12.6.1. General

The Manufacture of Standard Thread Measuring Wires, F. R. DANIELS. Mach (N.Y.) v25 Mar 1919 p 606–7 4 figs. Table of values used for determining error in thread angle by the three-wire system. Also describes method of manufacture used by B. Seaboldt Corp.

Gage Design and Gage-Making, E. OBERG, F. D. JONES. Industrial Press, N.Y. 1920 310 p 235 figs. Contents: Developing a gaging system; snap and plug gages; contour or profile gages; flush-pin, sliding-bar, and hole gages; thread gages and their production; making Whitworth thread gages; grinding and lapping thread gages; lead and diameter measurements on thread gages; microscopic measuring machines for testing accuracy of contour and thread gages; projection method of testing gage threads; general gage-making practice.

Making the Almond Micrometer, E. VIALL. Am Mach v53 n14 Sept 30 1920 p 605–11 24 figs. Illustrates the mechanical processes of making the parts and discusses the extreme care and workmanship required.

Accurate Tool Work, C. L. GOODRICH, F. A. STANLEY. McGraw-Hill Book Co., Inc. N.Y. 1923 29 chapters 300 p 327 figs. Also pub. as Tool and Gage Work, 1922. Contains chapters on making: master plates, accurate tapers, accurate index dials, thread gages, plug and ring gages, flat gages, and accurate squares.

Manufacturing a Precision Tool, E. SHELDON. Am Mach v59 n25 Dec 20 1923 p 903–7 12 figs. Describes manufacture of micrometer caliper, including preparatory operations on frames and sleeve as one piece, threading the main and adjusting nuts, rigid inspection methods.

Der Laeppvorgang bei der Herstellung von Messwerkzeugen (The Lapping Process in the Manufacture of Measuring Tools), C. BUETTNER. Werkstattstechnik v25 Mar 1931 p 113–6. Fundamental relations of various factors in lapping necessary for obtaining measuring surfaces of high quality; relationship between tool and workpiece with particular regard to action of abrasive and lubricant.

Balls for Bearings Are Last Word in Precision, H. T. MORTON. Metal Progr v35 n2 Feb 1939 p 149–55. Historical review of evolution of present day ball bearing, tracing materials used, lowered tolerances in last 25 yr

for balls 2 in. and under, improvement of ball surfaces, and various stages in production of 3 in. steel balls for Grade I ball bearings.

Manufacture of Precision Measuring Tools, A. E. MOR-RISON. Machy (London) v60 n1531 Feb 12 1942 p 81–4. Notes on state of precision tool industry in England; discussion on manufacturing methods, tolerances required, inspection and checking of micrometers, try squares, straight edges, etc; improvements in micrometer design.

Mechanical Problems in Setting of Spirit Levels, F. GROVER. Instn Prod Engrs J v21 n3 Mar 1942 p 123–36. Author undertook investigation of problems involved in construction of levels in general, and attempted to evolve simple technique for setting instruments of special form described; review of fundamental principles and their application to specific case.

Precision Hole Location, J. R. MOORE. The Moore Special Tool Co. 1946 448 p 309 figs. Discusses hole location and early practices relating thereto, development of the jig borer with accurate lead screws, jig boring practices, hole grinding, and interchangeability in toolmaking.

Notes on Gauge Making and Measuring, Metrology Division, NPL. His Majesty's Stationery Office, London 2d ed. May 1946 73 p 38 figs, 4 parts 2 appendices. Part 2 on gagemaking. Covers selection of steel, machining the blanks, hardening, stabilizing, grinding, and special workshop methods.

On Sharpening of Microtone Knives for Ultra-Thin Sectioning. J. HILLIER. Rev Sci Instrum v22 n3 Mar 1951 p 185–8. Conventional methods of sharpening involve extensive grinding primarily for removal of large nicks but which serves additional purpose of fitting knife to sharpening means; since large nicks rarely occur in ultra-thin microtomy, grinding would become unnecessary if fitting of knife to sharpening means could be made permanent: how this may be done.

A Precision X-ray Diffraction Spectrometer Ring, D. C. BARNES, C. WAINWRIGHT, NPL, Machy (London) v84 n2149 Jan 22 1954 p 189–92. 5 figs 1 ref. The rotatable member carries a scale divided into degree and half-degree intervals. The scale is subdivided by a graduated drum mounted on a worm drive-shaft. Overall accuracy of angular setting is ±20″ at any position of the rotatable member throughout 360° The design and construction are described.

Cam Design on a Visual Computer, W. HOFFMAN. Indus Mathematics v9 1958 p 21–6 4 figs. The problem to be solved is the determination of the master cam outline for the production of a cam having previously determined lift characteristics on a cam grinding attachment.

Anwendungsmoeglichkeiten von Lagerungen höher Praezision (Possible Applications for High Precision Bearings), H. BECKER. VDI Zeit v100 n29 Oct 11 1958 p 1398–1405. Increased accuracy required of modern instruments leads to new combinations of structural parts by designer; some examples are discussed and illustrated, e.g., optical dividing head, micromanipulator, microtome for ultrafine sections, etc.

Determination and Correlation of Fundamental Instrument Bearing Parameters, T. P. BARNARD. R. S. GUY-ETTE. Lubrication Eng v16 n2 Feb 1960 p 61–8. Paper shows why measurement and evaluation of dimensional, geometrical and performance qualities of miniature instrument ball bearings requires use of ultra-precise instruments; development of Running Torque Tester, torque analyzer, and roundness comparator; use of supporting instrumentation in determination and correlation of bearing, geometry, retainer, and surface finish analysis; dirt and lubrication analysis.

The Effect of Mandrel Eccentricity on the Accuracy of Edge Cams, A. V. RUMYANTSEV. Meas Techns 1960 n5 Jan 1961 p 384–7 3 figs 6 refs. Translated from Izmer Tekh n5 May 1960 p 11–4. Present a mathematical analysis which shows that the effect of mandrel eccentricity on the accuracy of machining the working surface of a conoid amounts to a considerable and unavoidable quantity which must be taken into account when the cams are made.

High-Speed Master Cams Generated Mechanically, R. E. CHENEY. Machy (N.Y.) v68 n2 Oct 1961 p 93–9, 148. Description of three-phase program by IBM Endicott, NY Development Lab, to investigate and implement cam design and cutting techniques; new short run procedure enables hardened master cams for data processing machines to be generated and finished to radial accuracies of four decimal places; computers provide design capabilities for establishing as many control points as needed to obtain necessary four-place accuracy in cam master model; procedure adopted as standard method for cutting master cams.

Manufacture of Integral Ball Bearing Raceways, H. H. SHERRILL, Jr. Western Elec Engr v7 n4 Oct 1963 p 31–5. Method is presented for precision grinding and lapping in manufacture of bearing raceways for Nike Hercules guidance gyroscopes, to obtain design advantages of integral ball bearings; roundness checking instrument and electronic vibration analyzer used for precision grinding are described, along with lapping and grinding process, and evaluation of raceway curvature, geometry and waviness.

Spheres Turned to Millionths. Iron Age v192 n16 Oct 17 1963 p 90–1; Am Mach/Metalworking Mfg v107 n18 Sept 2 1963 p 80–1. Machine developed by Brown & Sharpe especially for customer in atomic energy field, produces spheres up to 18 in. in diam within roundness tolerance of plus or minus 25 millionths; surface finish is very smooth; spheres are sized with part-to-part repeatability of 0.0001 in.; hydrostatic bearings used permit accurate positioning of workpiece and cutting tool and provide very stiff support for machine elements while in motion; machine is reliable and very fast, turning out finished sphere in few hours.

High-Accuracy Screws. Production Technology v1 n8 Nov 1963 p 296–304. Procedures used in manufacture of recirculating ball-screws by Rotax Ltd for use in aircraft undercarriage mechanisms, and in machine-tools where low power servo motor drives for numerical control and high resolution positioning are essential; assembly comprises shaft with semicircular helical groove, nut of corresponding threadform and steel balls; deflector plates in nuts, located between each complete revolution of threadform cause free rolling balls at end of turn to return to start of thread, thereby providing recirculating path for each row of threadform in nut; thread whirling, hardening and thread grinding operations applied; equipment used and method of inspection.

Unusual-Precision Bearings, H. HANAU, L. BURGMEIER. Machine Design v36 n5 Feb 27 1964 p 148–53. Ball bearing systems are being produced that maintain erratic angular deviation within 1 arc sec and predictable angular deviation within 1.5 arc sec; however, specifications of airborne guidance devices and optical systems demand limiting these deviations to less than 0.1 and 1.0 arc sec, respectively; new production and assembly techniques for such highest precision bearings are discussed.

New Instrument for Generating Angles to High Accuracy over 5-deg. Range, L. W. NICKOLS. Machy (Lond) v104 n2677 Mar 4 1964 p 554–8. To overcome limitations of instrument described previously, new instrument utilizing same principle was developed at National Physical Laboratory, which enables angles up to 5° to be set out in increments of few seconds of arc; diagram of kinematic pivot arrangement for small-angle generator is

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shown; effect of errors on accuracy of angular measurement; performance tests on instrument; simplified method of calculating values of x required to set out angle α.

Making of Spacers for Fabry-Perot Etalons, F. M. PHELPS III. J Opt Soc Am v55 n3 Mar 1965 p 293–5. The Fabry-Perot etalon is a versatile device but it is not widely used because of the high cost of its components if purchased from a commercial supplier. The author has developed a method of making spacers of excellent quality for a large diameter (60 mm) etalon for less than 10% of the typical price quoted by specialty houses which make them to order. While the spacers described here were made for use with the finest quality flats obtainable, the fact that 25.4 mm diam, 1/20 wavelength, optical flats are available for less than $100.00 per pair, means that a Fabry-Perot etalon is now within the reach of even the most impecunious physics department. Such an etalon can always be up-graded by purchasing better-quality flats; no additional work on the spacers would be required.

12.6.2. Scales and Gratings

See also subsection 4.1.

Automatic Circular Dividing Engine, W. R. STAMPER, E. R. HALL. Phys Rev v3 Apr 1910 p 492–505. Illustrated description of the apparatus and of the method of calibration employed.

Precision in Instrument Making. Am Mach v33–2 July 7 1910 p 25–8. Illustrates and describes methods of extreme accuracy in measurement and division used in the manufacture of standard scientific instruments.

Building a Machine which Splits Millionths, D. M. LIDDELL. Am Mach v40 June 4 1914 p 969–73. A detailed description of the methods of making the screw, straight ways, and divided head of the Rowland dividing engine, with its maximum allowable error of two-millionths of an inch.

The Circular Dividing Engine of Edward Troughton, 1793, D. BAXANDALL. Opt Soc Trans v25 1923–4 p 135–9. History of development and description of construction. Bibliography, 8 refs from 1768 to 1923.

Ruling 15000 Lines per Inch, F. A. STANLEY. Am Mach v60 1924 p 161–6. Prepared by committee whose chairman was Dr. Ames. A description of the dividing engines designed by Prof Rowland. Physical Papers of Rowland collected by Johns Hopkins Univ p 691. 3 machines, no. of teeth in the ratchet such that they rule 14,438, 15,020, and 20,000 lines in an inch. The 3 machines are kept in the sub-basement of the Physical Laboratory of Johns Hopkins University.

Untersuchungen an einer Kreisteilmaschine (Investigations of a Circular Dividing Machine), L. FRITZ. Zeit Instrumkde v46 June 1926 p 289–320 11 figs. Describes dividing machine of Geodetic Institute of Technical High School at Hannover; illumination, microscopes, axial rotation, formation of rosettes, improvement in diameter, systematic and accidental errors.

Accurate Graduating in Mount Wilson Shop, J. HOMEWOOD. Machy (NY) v34 Mar 1928 p 540–1 1 fig. Machine for ruling diffraction gratings having 15,240 equidistant lines per inch; how diamond graduating tool is held and traversed; obtaining indexing movement of 1/15,240 in.; cross-slide which floats in mercury; special thrust bearings and other constructional features.

A Machine That Rules Fourteen Thousand Lines per Inch, E. F. BARKER. Michigan Technic v41 Mar 1928 p 17–8 25 2 figs. Machine to rule optical gratings; distances marked off by parallel grooves of certain selected shape and depth with error of less than one millionth of inch; machine resembles ordinary shaper; two carriages; tests of butt bearing and of screw thread; optical tests of gratings; preparation of diamond ruling points; experimental gratings adapted for measurement of spectra.

The Rowland Ruling Machine. Mech Eng v50 Apr 1928 p 294–8 3 figs. Details regarding mechanism and working of this historic precision dividing engine devised for engraving lines of diffraction gratings; machine can be compared structurally to simple reciprocating steam engine; it has flywheel, two-bearing crankshaft, connecting rod, crosshead, and slide which correspond in location to piston; both technique of making mirrors and design of ruling machines have been somewhat modified and improved of late.

The Manufacture of Steel Measuring Tape, F. W. HOBBS. Metal Indus (N.Y.) v26 Sept 1928 p 399–400. Manufacture of steel measuring tape is transfer and etching process, and consists briefly in filling etched surface of standard plate with acid-resisting paste, transferring it to etching tissue, and thence to blank steel line after which line is immersed in acid bath which eats away exposed parts having figures and lines in relief; detailed description of equipment and process is given.

Graduating Machine for Special Rules and Gages, R. B. LOVELAND. Am Mach v73 Nov 20 1930 p 822 2 figs Hand-operated graduating machine and its operation.

Machine for Dividing Scales of Varying Increment, B. M. DAVIES. J Sci Instrum v10 n10 Oct 1933 p 314–8. Dividing machine incorporating special device for dividing thermometer and other scales of unequal increment; employs flexible metal strip which can be set in given curve according to calibration of thermometer; curve of strip adjusts exact position of dividing tool in relation to work; details of operation; typical scale is shown.

Machines for Ruling Diffraction Gratings. W. STONE, J Sci Instrum v14 1937 p 209–11. The design of a type of machine is described which will reduce to a minimum the displacement of the lines being ruled, due to changes of temperature of the machine and of the plate on which the rulings are being made. Some suggestions for improvements in the design and construction of machines for ruling diffraction gratings were made by the author in an earlier paper. Further improvements, particularly as regards expansion of the parts due to changes of temperature, are suggested.

Grayson Micro-Ruling Machine, W. STONE. J Sci Instrum v14 Jan 1937 p 8–14. The principles involved in the design of micro-ruling machines are stated and it is shown how these principles were applied by Grayson in the design and construction of the machine which he made and used in ruling test plates with as many as 120,000 lines to the inch. The machine is described in detail.

Rapid Calibration and Correction of Comparator Screws and Photographic Production of Scales, G. R. HARRISON. Rev Sci Instrum v9 Jan 1938 p 15–8. An automatic recording and computing comparator has been adapted to the rapid construction of uniform and non-uniform scales on glass by photography. With such a scale, the recording attachment of the comparator can be used to determine the correction curve for a screw in a few minutes. A three dimensional correcting cam may then be shaped to correct the errors found, and fairly cheap screws can thus be made to serve for precision measurements. Details of a method of mounting the screw and the comparator carriage so as to reduce friction are given.

Dividing and Ruling Scales, R. P. ABRAHAMS. J Sci Instrum v16 July 1939 p 205–9. A general outline is given of modern methods of producing ruled scales, either singly

or in quantity, on metal, glass, wood, or celluloid. The important elements of a dividing machine are discussed together with the provisions necessary to reduce or compensate for errors. Reference is also made to those scales, reproduced on glass by photographic means which are now commonly employed as graticules in optical instruments.

Graticule Ruling in Australia, M. SHAW. Instn Mech Engrs Proc v160 n2 1949 p 145–52 (discussion) 152–3. Production of graticules or reticles for range finders, predictors, gun sights, telescopes, etc. under conditions prevailing in Dominion; methods used in reproducing pattern, particularly ruling and etching process; design of high precision machines which were made for ruling glass disks preparatory to etching pattern into glass; machine accuracy tests.

The Graduation of Precision Circles, B. L. PAGE, NBS. Surveying and Mapping v13 n2 Apr–June 1953 p 149–61. See abstract in subsection 6.4.

The Production of Accurate Linear Scales by Means of the Merton Nut, L. A. SAYCE. J. Sci Instrum v32 n1 Jan 1955 p 11–2. A dividing engine is described for making linear scales of unusual accuracy. The scale is engraved photographically upon a plate carried by a Merton integrating nut riding upon a cylinder bearing a very fine screw thread. The cylinder is carried by bearings in which it is restrained from longitudinal movement by applying the principle of the Merton nut to a "thread" of zero lead.

Interferometric Control of Grating Ruling with Continuous Carriage Advance, G. R. HARRISON, G. W. STROKE. J Opt Soc Am v45 n2 Feb 1955 p 112–21 10 figs 4 refs. See abstract in subsection 2.4.2.

On Preparing Plastic Copies of Diffraction Gratings; Extension to Merton-NPL Process, G. D. DEW. J Sci Instrum v33 n9 Sept 1956 p 348–53. Process whereby number of glass based plastic copies may be prepared from gelatine backing grating; these copies, considerably more stable than gelatine replicas, may be employed as transmission gratings or aluminized and used by reflection; by using plate glass blanks it is possible to reduce production costs while obtaining optical quality almost indistinguishable from that of parent replica.

Ruling of Large Diffraction Gratings with Interferometric Control, G. R. HARRISON, N. STURGIS, S. C. BAKER, G. W. STROKE. J Opt Soc Am v47 n1 Jan 1957 p 15–22 12 figs 14 refs. Describes mechanical features by which high accuracy has been attained.

Precision Circular Scales. Nat Eng Lab, East Kilbride, Scotland June 1958 2 p. Extension of the moiré fringe technique to automatic angular control has shown the requirement for circular scales having very large numbers of lines. Automatic machine installed is capable of ruling scales accurate to 1 sec of arc.

Controlled Ruling of Diffraction Gratings, G. R. HARRISON. Am Phil Soc Proc v102 n5 Oct 20 1958 p 483–91. How, by using light waves to control diamond tool while it engraves grooves on aluminum coated mirror to produce diffraction grating, quality of resulting grating can be improved and, if desired, its size increased; half dozen gratings of high quality, 10 in. in ruled width, have been produced on such engine; resolving power of several of these gratings is found to equal that theoretically expected, in all orders up to and including highest obtainable with visible light.

Interferometrically Controlled Ruling of Ten-inch Diffraction Gratings, G. R. HARRISON, N. STUYGIS, S. P. DAVIS, Y. YAMADA. J Opt Soc Am v49 n3 Mar 1959 p 205–11 10 figs 14 refs. Seven plane gratings of high quality, having ruled widths of more than 10 in., have been

produced on the MIT servo controlled ruling engine, monitored with interference fringes. Discusses wavefront shapes, ghost and satellite intensities, etc.

Attainment of High-Resolution Gratings by Ruling under Interferometric Control, G. W. STROKE. J Opt Soc Am v51 n12 Dec 1961 p 1321–39 83 refs. Theory of grating improvements necessary for reduction of spectral-line imperfections in gratings made on MIT ruling engine; improvements made in interferometric control of grating ruling give better performance by factor of 4 to 9 over 10-in. gratings described by G. R. Harrison and G. W. Stroke; precision replicas permit high-resolution spectrometer studies.

Multi-section Gratings for Linear Measurement, G. D. DEW, NPL J Sci Instrum v39 1962 p 141–4 6 figs 2 refs. Describes recent improvements in the techniques of preparing multi-sectional gratings for moiré-fringe measuring application. The system enables adjacent sections to be phased with accuracy of 5–10 μin. and is applicable to gratings of the finest pitch employed in this work. A method of evaluating the phasing errors at the junctions is also described.

Graticules and Fine Scales: Their Production and Application in Modern Measuring Systems, E. BOVEY. J Sci Instrum (GB) v39 n8 Aug 1962 p 405–13. See abstract under subsection 5.1.

Ruling, Testing and Use of Optical Gratings for High-Resolution Spectroscopy, G. W. STROKE. Progress in Optics v2 North-Holland Publishing Co, Amsterdam, 1963 p 1–72 115 refs. Quality of gratings required for high-resolution spectroscopy, and means for obtaining such gratings by ruling under interferometric control are discussed; high-resolution grating spectrometers and spectrographs are described; contemporary methods for obtaining plastic replicas of gratings are briefly examined; further improvements in quality and blaze of diffraction gratings, as well as in speed of ruling, are being made using electron microscopy and other control methods.

Some New Advances in Grating Ruling, Replication, and Testing, R. F. JARRELL and G. W. STROKE. App Optics (USA) v3 n11 Nov 1964 p 1251–62. A report on some significant recent advances in the art of grating ruling, blazing, replication, and testing, with a more detailed description of the construction and performance of a newly completed interferometrically controlled ruling engine recently put into operation.

Ruling Engine with Hydraulic Drive, W. R. HORSFIELD. App Optics (USA) v4 n2 Feb 1965 p 189–94. The carriage of a ruling engine is driven by a hydraulic system servo-controlled by an optical interferometer, so that the position of the carriage is determined in terms of the wavelength of light. The arrangement is free from the errors of the conventional lead-screw system and is far cheaper to construct.

A Method for Making Very Accurate Line Patterns for Photographic Reproduction, U. PICK. J Sci Instrum (GB) v42 n2 Feb 1965 p 120–1. A method is described for cutting a parallel line pattern in very thin metal films. The width of the cut lines is constant to less than 4×10^{-4} cm and the edge definition is better than 2×10^{-4} cm. Photographic negatives of similar accuracy can be produced by contact printing from the cut film.

12.6.3. Worms and Power Screws, Including Lead Screws (Leading Screws, Guide Screws [Leitspindeln], and Feed Screws)

On a Practical Solution of the Perfect Screw Problem, W. A. ROGERS. Trans ASME v5 Paper n146 1885 44p v12 Paper n446 p 725–8. Discusses three classes of errors to

which screws are subject; a survey of the accuracy that had been attained; and a new method of cutting screws.

Das Fräsen von Schraubengewinden (The Milling of Screw Threads), E. STUEBLER. Zeit für Mathematik und Physik v57 1909 p 271–9 2 figs. Develops the geometric theory of producing a screw thread of a given form by means of a milling cutter.

Screw, H. A. ROWLAND. Encyclopedia Britannica 11th ed v24 1911 p 477–82 10 figs. With reference to lead screws the article contains sections on testing screws, errors of screws, and mounting of screws. Describes Rowland's machine for ruling gratings. Refers to Holtzapffel's "Turning and Mechanical Manipulation" for early history of manufacture of screws.

Cutter Shapes for Milled and Ground Threads, E. WILDHABER. Am Mach v60 n18 May 1, 1924 p 645–9 4 figs 1 ref. Presents an analysis of the relationships between the cutter and the thread which is important for worms and long-lead screws. Presents table of formulas for curvature radii for various threads and cutters.

Cutting a Lead-screw of Unusual Accuracy, WM. GAERTNER. Machy (N.Y.) v31 June 1925 p 808–10 5 figs. Methods used in producing precision screw about 4 ft. long with lead accurate within 0.00004 in. in entire length.

Die analytische Berechnung des Gewinde-Drehstahlprofils für steilgängige Schrauben und Schnecken mit geradem Achsenschnitt (The Analytical Calculation of the Thread Lathe Tool for Long-Lead Screws and Worms with Straight-Line Axial Section), W. F. VOGEL. Werkstattstechnik v27 n14 July 15, 1933 p 275–9. Classical equations proved to be only approximate; data on exact profile equations; results of analysis; relation between principal dimensions of thread and of cutting profile.

Analytische Berechnung des Fingerfräserprofils für steilgängige Schrauben und Schnecken mit geradem Achsenschnitt (The Analytical Calculation of End-Mill Profile for Long-Lead Screws and Worms having Straight-Line Axial Section), W. F. VOGEL. Zeit VDI v78 n5 Feb 3 1934 p 156–8 and discussion Oct 20 p 1222; Betrieb v13 n9/10 May 1934 p 252 2 figs 3 refs. Error indicated in usual method for graphical determination of profile and correct method pointed out; exemplification.

Konstruction eines Fräsers der eine gegebene Gegenflanke erzeugt (Construction of a Milling Cutter which Generates a Given Counterflank) O. BAIER. Zeit für angew Mathematik und Mechanik v14 n3 Aug 1934 p 248–50 4 figs. Presents the principle of construction and a practical explanation of the construction; also the procedure of the construction of the milling cutter by an example.

Der Geradflanken-Drehstahl für steilgängige Schrauben und Schnecken mit geradem Achsenschnitt (The Straightsided Lathe Tool for Long-Lead Screws and Worms with Straight Line Axial Section), W. F. VOGEL. Werkstatts technik und Werksleiter v29 n6 Mar 15 1935 p 121–6 n7 Apr 1 p 135–40. Practical mathematical analysis for design and making of tools; limits of application.

Gesetze und Berechnung der Mutterdrehstähle und Schlagmesser für steilgängige Schrauben und Schnecken mit geradem Achsenschnitt (Rules and Calculation of Internal Lathe Tool and Fly Cutter for Long-Lead Screws and Worms with Straight-Line Axial Section), W. F. VOGEL. Werkstattstechnik und Werksleiter v29 n20 Oct 15 1935 p 399–400. Theoretical design analysis and exemplification.

Berechnung der Schneidflanken von Gewindedrehstählen für steilgängige Schrauben und Schnecken mit geradem Achsenschnitt (Calculation of the Cutting Flanks of

Thread Lathe Tools for Long-Lead Screws and Worms of Straight Line Axial Section), W. F. VOGEL. Zeit VDI v79 n45 Nov 9 1935 p 1370–2 7 figs 7 refs. Consolidated report. Discusses lathe tools and impact tools with crooked cutting flanks; the plane straight-sided tool; the cross tool.

Gewindedrehstähle und Schlagmesser für Schnecken und steilgängige Schrauben mit geradem Achsenschnitt. Ermittlung und Verlauf der Schneidflanken. (Thread Lathe Tools and Fly Cutters for Worms and Long-Lead Screws with Sraight Line Axial Section. Calculation and Analysis of the Shape of Cutting Edges), W. F. VOGEL. Maschinenbau — Der Betrieb v15 n1/2 Jan 1936 p 27–30 13 figs 11 refs. Consolidated summary of the author's four pertinent papers. Se abstracts above, in 1933 and 1935.

On Cutting and Hobbing Worms and Gears, D. W. DUDLEY, H. PORITSKY. ASME Trans (J Appl Mechanics) v10 n3 Sept 1943 p A139–46, 197–201. Two problems are treated in this paper: (1) given the shape of a milling cutter tooth or of a hob tooth, to find out what is the resulting shape of worm or gear surface; (2) given the desired shape of a worm or gear tooth, what shape of milling or hobbing tooth will produce it. Discusses four common types of worms: straight-sided axial section; that produced by cutter or grinding wheel of straight-sided axial section; straight-sided normal section; involute helicoidal worm.

Grinding Lead Screws, J. R. MOORE. Iron Age v153 n22 June 1 1944 p 42–6 June 8 p 66–70. Description of elaborate techniques worked out by Moore Special Tool Co, Bridgeport, Conn, over period of years to achieve ultimate in accuracy in manufacture of micrometer screws for small jig borer; highlights of method is use of electronic thermostat to maintain temperature of coolant and hence work at constant differential with respect to master lead screw of thread grinder; unusual methods of checking product are illustrated.

Interferometric Calibration of Precision Screws and Control of Ruling Engines, G. R. HARRISON, J. E. ARCHER. J Opt Soc Am v41 n8 Aug 1951 p 495–503 12 figs 14 refs. A new device is described with which screws of any length can be calibrated rapidly for both periodic and cumulative errors in terms of interference fringes. It can also be used to plot correction cams to remove fixed errors of translation or rotation, and to monitor the operation of an engine while ruling diffraction gratings or scales, correcting by automatic feedback differences between the actual carriage position and its proper position as shown by an optical interference field. This so-called "Commensurator," whose name arises from its function of overcoming the incommensurability of the wavelength of the light used for calibration and the lead of a screw, consists principally of a screw drive system, eight-figure dials, and a generator, geared together in ratios that can be controlled to one part in 10^8. Fringes produced by a Michelson interferometer mounted on the ruling engine (or having one mirror moved by the nut of the screw being calibrated) are changed photoelectrically to a wave train that measures translation to within 0.1 microinch. A second wave train of almost identical average frequency is produced by the Commensurator generator to measure screw rotation, and the two trains are continuously compared by means of a phase-sensitive amplifier and motor to within 1/100 cycle or fringe. Any error in carriage translation appears as a lag or lead which produces a torque in the motor until synchronism is re-established by a relative shift of the two wave trains, and thus makes possible automatic plotting of the screw error curve on a moving chart.

Precision Screw Thread Corrector Lathe. Eng v196 n5099 Oct 16 1953 p 489–90; Engr v176 n4578 Oct 23 1953 p 524–5. Essential element for accurate operation of gear hobbing

machines is hob slide feed screw; new high precision lathe for finishing of such screws as developed by Craven Brothers (Manchester); on this machine screw thread can be accurately measured in position after cutting and corrector mechanism can be directly adjusted to precision gage readings as required.

Craven Precision Screw Thread Corrector Lathe. Machy (London) v83 n2142 Dec 4 1953 p 1111–3. Lathe especially constructed for correcting gear hobbing machine hob slide feed screws, after they have first been cut by normal methods; special measuring head mounted on top of tool post carries single stylus point and spigot type dial gage reading to 0.00005 in.

Method of Recording the Pitch Errors of Screw Cutting Lathes, F. H. ROLT, NPL. Eng Dimensional Metrology, Proc of Symposium held at NPL, 2 vols, Her Majesty's Stationery Office (London) 1955. Paper n19 p 323–8 3 figs. Describes equipment by which lathes can be tested in the works and an autographic record obtained showing the complete periodic and progressive errors over any length of traverse required. Discussion.

Special Lathe at the National Physical Laboratory for Cutting and Forming Fine-Pitch Screw Threads, V. W. STANLEY, NPL. Eng Dimensional Metrology Symposium held at NPL, 2 vols, Her Majesty's Stationery Office (London) 1955. Paper n20 p 329–45 10 figs 3 refs. A high precision lathe is described capable of producing fine-pitch screws ranging from about 100 to 30,000 threads per inch. Reference is made to the application of these fine screws to the production of diffraction gratings for use in spectrochemical analysis and for measurement of linear displacement.

Precision Lead-Screws Ground from Solid, M. C. SU-LANDER, W. F. SPIERLING. Machy (N.Y.) v62 n9 May 1956 p 146–9; Machy (London) v89 n2285 Aug 31 1956 p 505–6. Lead screws produced by Precision Thread & Gear Corp, Chicago, have variation in thread pitch diameter not exceeding 0.0002 in., and max lead error between any two vees at 1-in. intervals of 0.0003 in.; importance of material selection, with good results obtained with Sparta, Universal Cyclops air hardening tool steel; ultra-precise thread grinding operations described; continuous inspection of threads.

10,000 Threads to Inch, J. F. BELL. Am Mach v100 n16 July 30 1956 p 112–3. Modification of 50 yr old Rivett lathe at Johns Hopkins University has made it possible to make very accurate screws of 10,000 threads to inch; thread is used as diffraction grating and is also of value for very accurate measurement of lineal displacement through relatively large distances; methods of making screw.

Mechanical Engineering Research Laboratory: Work of the Mechanisms, Engineering Metrology and Noise Control Division, C. TIMMS, Nat. Eng. Lab. Trans Instn Engrs and Shipbuilders in Scotland 1958 p 317–68. On p 334 is described and illustrated the master-screw correcting lathe recently transferred from NPL which has a history dating back to 1900. Screws to 10 ft. in length may now be corrected. Reference is made to "Standard Leading Screws for Screw-Cutting Lathes" 1905 (Stationery Office, London).

A Comparison between Different Tooth Forms on Ground Worm Gears, G. ZEISE. Klingelnberg News, W. Ferd. Klingelnberg Söhne, Remscheid Dec 1961 5 p 5 figs. Toothforms are designated in DIN 3975 as A, N, and E in which the generatrix of the toothflank is a straight line and as K when the straight line generatrix is on the tool itself. The paper shows the difference of the various profiles, particularly the results obtained in relation to grinding wheel parameters.

Finishing Worm Profiles on Universal Thread-Grinding Machine, B. SMITH. Machy (London) v102 n2621 Feb 6 1963 p 304–8. Setup for fly-cutting teeth in worm wheel on hobbing machine; description of Matrix generating dresser for forming wheel on universal thread grinding machine; Matrix dresser eliminates need for time-consuming calculations and greatly facilitates dressing required form; example of calculating, producing and checking involute helicoid worm; grinding fly-cutter for machining worm-wheel teeth; development of dressers. See also H. KALUZKA subsection 9.2, 1963, p. 205.

12.6.4. Screw Thread Gages

Making Thread Gages, A. L. MONRAD. Machy (N.Y.) v14 Feb 1908 p 387. A thorough description of the manufacture of thread gages; tables of ball diameters to be used in determining angle of thread for V, USS, Briggs Standard, and Whitworth threads.

The Production of Screw Thread Gages, W. RICHARDS. Mech Wld v59 1915 p 134–5 146 158–9. Methods of turning on lathe; measurement by three-wire method.

The Manufacture of Screw Gages, J. E. SEARS, NPL. Eng v103 Feb 9 1917 p 137. Various developments and refinements in the measuring of screw threads at NPL.

Producing British Screw Gages, I. W. CHUBB. Am Mach v46 n14 Apr 5 1917 p 593–4 3 figs. Gives brief description of screw thread plug and ring gages, methods of manufacture, accuracy, composition of material, and method of hardening. Measurement of pitch diameter.

Making Precision Thread Gages, E. A. SUVERKROP. Am Mach v47 Aug 16 1917 p 265. Describes manufacture. Comment by J. BOLKOVAC, v47 Nov 1917 p 938.

The Manufacture of Hardened Thread Gages, G. DOORAKKERS. Eng v124 n3222 Sept 28 1917 Oct 5 12 26 Nov 2 p 263 290 308 354 390. Gives details of manufacture of master tool, thread cutting tool, checks for thread plug gages, laps.

Making Whitworth Thread Gages, W. D. WOODWORTH, H. W. BENDER. Machy (N.Y.) v24 n6 Feb 1918 p 483–93 17 figs. Reviews practice of a successful manufacturer.

Making Whitworth Thread Gages. Machy (London) v11 Mar 14 1918 p 645–9, Mar 21 p 676–81. Elements of Whitworth thread; machining gage blanks; preliminary annealing process; rough machining thread; carburizing; finishing-machining; hardening; advantages of grinding thread before lapping; special grinding machine; use of wires for measuring pitch diameter; measuring core diameter; heat treatment to prevent future distortion; finish grinding operations; timing lapping periods; lead and angle checking gage.

Gage Making in a Shell Plant, F. D. JONES. Machy (London) v13 Sept 21 1918 p 197–202. Practice used for gaging of 75 mm shell; materials used for thread gages; thread gage cutting, grinding, and lapping; testing accuracy of thread gages.

Making Thread Gages, T. H. FENNER. Can Machy v20 Nov 7 1918 p 529–32 7 figs. Description of plant and methods of a Canadian firm.

Present Practice in Thread Gage Making, F. O. WELLS. Trans ASME v40 paper n1666 1918 p 809–25; Am Mach v50 Jan 23 1919 p 153–8. Manufacturing difficulties; lead errors in lathes; approved methods of thread lapping, grinding, and testing; gage tolerances.

Advance of Thread Gage Making during the War, C. B. COLE. Machy (N.Y.) v25 Aug 1919 p 1153–4. Practices used during the war in thread gage making; difficulties

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experienced in cutting Whitworth threads; choice of material; annealing and pack-hardening; laps; checking ring gages using four check plugs.

Thread Gage Standards, J. E. COLLINS, Machy (N.Y.) v26 Jan 1920 p 427. A complete system of thread plug and ring gages; tolerances and their application, three-wire method of measurement, effects of heat treatment, lapping, and shadow projection method of measuring threads.

Making Whitworth Thread Gages, C. E. ALLEN. Machy (N.Y.) v26 Aug 1920 p 1157–60 5 figs; Machy (London) v14 July 1919 p 504. Method which utilizes disintegration of grinding wheel during grinding operation to produce final thread form.

Hardening Screw Gages with Least Distortion in Pitch, W. J. LINEHAM. Am Mech v53 Sept 1920 p 547; Mech Wld v67 May 7 1920 p 291, May 14 p 307, May 28 p 339; Engr v129 Apr 30 1920 p 443. Report of the procedure used at Goldsmith's College, London, to give least distortion. Discusses cutting, measurement, and heat treatment.

The Manufacture of Hardened Screw Gages. Engr v130 Sept 24 1920 p 310–1 5 figs. Manufacturing process followed at plant of Coventry Gauge & Tool Co., Coventry, England.

The Manufacture of British Association Screw-Thread Gauges, T. F. DAVEY. J Inst Mech Engrs Apr 1921 p 191–6. Design, methods, and apparatus used in measurement, compensation and correction for errors in lathe, cutting tools, lapping, and heat treatment.

Some Notes on Hardening Various Screw Gauges, F. A. LIVERMORE. Can Machy v28 July 13 1922 p 26–7. Results of experimental work; effort to obtain process that will eliminate warpage and change of shape; methods of heat treating and quenching; expansion and contraction.

Heat Treatment of Screw Gauges. Eng Prod v5 Aug 10 1922 p 138. Résumé of experimental work conducted over period of nine months with view to determining best conditions for production of hardened screw gages to satisfy stringent tests of NPL.

Special Apparatus for Tapering Thread, W. O. RUSSEL. Am Mach v60 Mar 1924 p 480. Description of apparatus used in place of taper attachment for cutting taper thread gages.

Die Herstellungsgenauigkeit der Gewindelehren und ihre messtechnische Erfüllung (The Production Accuracy of Thread Gages and their Metrological Performance), G. BERNDT. Werkstattstechnik v22 n5 Mar 1 1928 p 131–6 5 figs. Describes special microscopes, gages, and measuring devices; methods used in making thread gages in accordance with German DIN standards.

Nitriding Oil Tool Gages, F. W. CURTIS. Am Mach v70 n22 May 30 1929 p 863–4 5 figs. Description of nitriding process for large thread gages which eliminates difficult grinding operation; and produces hard surface free from scale; tool joint made by Doheny Stone Drill Co. is discussed; case hardening by nitriding process can be done by small shop with inexpensive equipment.

Tools for Hartometer Production, C. R. RANNEY. Am Mach v71 n25 Dec 19 1929 p 1001–2 6 figs. Discussion of how problems of aligning multiple starting points for threads of different pitch and diameter in Hartometer screw-thread gage are solved.

Herstellung und Prüfung von Normal-Gewindelehren (Manufacture and Inspection of Standard Thread Gages), O. KESSLER. Werkzeugmaschine v38 Jan 1934 p 3–6. Detailed description of machines, instruments, and methods used. Illustration of special microscope.

Typical Operations on Ford Gages, C. O. HERB. Machy (N.Y.) v43 July 1937 p 706; Machy (London) v50 Sept 16 1937 p 749. Grinding and thread-lapping accurate thread gages and methods of checking and measurement. Plating of gages.

Aus der Fertigung von Gewindedorn und Lehrringen (On the Manufacture of Thread Plug and Ring Gages), F. MATTHEES. Werkstattstechnik v33 May 1939 p 262. Discussion of the methods with particular reference to lapping.

12.6.5. Other Gages

See also subsection 3.1.

Making Spherical End Gages, C. W. WRIGHT. Am Mach v26 Aug 13 1903 p 1148–9. Illustrates and describes inventions of the writer for grinding spherical end gages and a lapping rig for gages.

The Making of a Knife Edge Square, T. MILLER. Machy (N.Y.) v17 Mar 1911 p 519 5 figs. Detailed description with line drawings.

Gage Making and Lapping. Machy's (N.Y.) Reference Book No. 64. Principles of gage making, the manufacture of gages, lapping flat work and gages, the rotary lap, miscellaneous lapping.

The Manufacture of Gages at the L. C. C. Paddington Technical Institute, A. G. COOKE, W. J. GOW, W. G. TUNICLIFFE. Proc Inst Mech Engrs Jan Feb Mar 1917 p 45–108; Eng v103 Jan 26 1917 p 89–91 5 figs; Mech Wld v61 Jan 26 1917 p 46; Feb 2 p 57–8. Discusses work of Institute on standardization of Gages. Discusses accuracy and the tolerances on limit gages, position gages, screw gages. Discusses instruments devised there for measuring pitch and diameters of screw gages and an optical apparatus by which screw cutting tools could be shaped and the sections of screw threads examined. Gives results of some of tests in form of curves; the optical apparatus consisted of a light source giving a parallel beam of light freed from heat rays by passage through saturated solution of alum, a rigid optical adjustable bench carrying tool or gage and projecting lenses, a screen at a distance of about 16 feet. In final projection of screw thread in silhouette a careful examination for symmetry is made. Magnification up to 400 diameters was obtained. Discussion which followed paper took up more in detail such points as pitch errors in lathe, the optical apparatus used, lenses used for magnification, method of lapping (much in detail) the importance of an accurate lead screw, materials, methods of hardening quenching and annealing of gages, the alum bath used, sequence of operations in manufacture of case-hardened mild-steel gages, method of inspection of gage, pitch measurement, etc.

Grinding Accurate Profile Gages by Means of Master Plates, H. M. DARLING. Am Mach v50 Jan 16 1919 p 105–6 3 figs. Description of operation.

Making Some Difficult Duplicate Gages, E. A. DIXIE. Am Mach v50 Jan 23 1919 p 162. Describes method of making a special taper plug gage. Discussion by A. MOSES on p 706.

Manufacture of Hoke Precision Gages at the Bureau of Standards, H. L. VAN KEUREN. Am Mach v50 Apr 3 1919 p 625–30 6 figs; Mech Eng v41 Mar 1919 p 289–90. Gage blocks are being produced at the Bureau with an accuracy limit of a few millionths of an inch. Apparatus used in testing flatness and parallelism to one millionth of an inch. Development of process for their commercial manufacture has taken place within period of six months. Special reference is made to light-wave interference method for determining accuracy.

Angular Plug-Gage Making, H. PUSEP. Am Mach v50 Apr 3 1919 p 635–40 15 figs. Lays emphasis on elimination

of errors in preliminary operation, in order to prevent their accumulation and the appearance of serious defects which will be difficult to eliminate in later operations.

How Precision Gage Blocks are Made, F. D. JONES. Machy (N.Y.) v26 Apr 1920 p 697–708 27 figs; Machy (London) v16 June 3 1920 p 253–63 27 figs. Practice of Pratt & Whitney Co., Hartford, Conn.

Generating Precision Tools, W. E. HOKE. Machy (N.Y.) v31 Feb 1925 p 421–5 7 figs; Machy (London) v25 1925 p 613. Fundamental or natural methods of obtaining precision in toolmaking, gagemaking, etc. by application of generating principle.

Lapping Micrometers, H. L. VAN KEUREN. Am Mach v64 June 3 1926 p 871. Describes procedure for reconditioning micrometer calipers to high degree of accuracy.

Manufacture of Wickman Gages. Machy (London) v33 Nov 29 Dec 27 1928 p 257–62 397–402 24 figs. Methods employed by Coventry Gauge and Tool Co. Ltd, in manufacture of adjustable limit plain and thread snap gages. Wickman gage details; operations on frame; drilling holes for anvils; seasoning process; sizing anvil holes; operations on anvil; hobbing threads; grinding operation by which finished form of thread is generated; checking finished anvils; method of assembly; tests for alignment of teeth as between two opposing anvils.

Der Laeppvorgang bei der Herstellung von Messwerkzeugen (Lapping Procedure in Manufacture of Gages). C. BUETTNER. Werkstattstechnik v25 n5 Mar 1 1931 p 113–6 10 figs. Fundamental relations of various factors in lapping necessary for obtaining measuring surfaces of high quality; relationship between tool and work piece with particular regard to action of abrasive and lubricant.

Anleitung zur Herstellung einer Praezisions-Rachenlehren-Schleifmaschine (Design of Special Grinding Machines for Precision Grinding of External Gages), O. LICH. Maschinen Konstrukteur v65 Mar 5 1932 p 29–31.

Production of Dial Indicators. Machy (London) v41 Oct 6 1932 p 6–9. Machining operations and equipment used by T. and F. Mercer, St. Albans, in manufacture of dial indicators giving readings up to 0.0001 in.

Heat Treatment of Gage Steel, F. A. W. LIVERMORE. Mech Wld v92 Oct 21 1932 p 381–3. Ideal conditions would be realized if it were possible to transmit simultaneously to each molecule of steel given amount of heat in given time; in efforts to approach as nearly as possible this ideal, certain phenomena in connection with mass occur; in heat treatment of steel for gages, these alternations are of great importance; results obtained; construction of special furnace.

How to Make Accurate Multi-Spline Gage, W. C. BETZ. Machy (N.Y.) v40 n1 Sept 1933 p 22–3; Machy (London) v43 n1103 Nov 30 1933 p 245–6. Difficulties in obtaining precision spacing of blade slots are overcome by simple and ingenious method; simple ring gage used for precision spacing; equipment used for making final inspection of slots in gage body.

Facts to Know in Gage Grinding, H. J. CHAMBERLAND. Abrasive Indus v17 n4 Apr 1936 p 8–10. Form of physical adjustment which steel must undergo, between heat treating and finish grind, which is known as seasoning period; procedure to be followed; gages ground to size.

Typical Operations in Making Ford Gages, C. O. HERB. Machy (N.Y.) v43 n11 July 1937 p 706–8; Machy (London) v50 n1301 Sept 16 1937 p 749–51. Commentary on some of grinding and thread lapping operations carried out in gage plant of Ford Motor Co.

Extreme Precision is Demanded in Gage Grinding. Abrasives v18 n9 Sept 1937 p 9–11 62–3. Brief illustrated description of few of grinding operations carried out at toolmaking plant of Taft-Peirce Manufacturing Co. Woonsocket, R.I.

Production of Dial Gauges. Machy (London) v74 n1896 Feb 22 1949 p 227–32. Methods employed by British Indicators, Ltd. St. Albans, for making "John Bull" gages; punching, boring and plating; machining operations are few; production of gear train components; assembly.

Zur Frage des Feinschleifens und Laeppens von Lehren (Fine Grinding and Lapping of Gages), O. RICHTER. Werkstatt und Betrieb v82 n5 May 1949 p 160–1. Conclusions based on replies to circular letter sent to gage manufacturing firms; problems discussed include: accuracy of gages, their uses, costs, and manufacturing problems.

How Gage Blocks Are Made, R. GIERLICH. Am Mach v94 n1 Jan 9 1950 p 85–9. Importance of surface finish; wear on gage block surfaces; manufacture of gage blocks; lapping procedure and importance of interchanging blocks during lapping; inspection of finished gages including calibrating for exact size and inspection for flatness.

Producing Gage-Blocks To "Millionths", R. A. GIERLICH. Machy (N.Y.) v59 n6 Feb 1953 p 147–56; Machy (London) v83 n2121 July 10 1953 p 59–67. Techniques employed in Savage, Minn, plant of Continental Machines, Inc. for manufacturing DoAll gage blocks; 131 sizes of gage blocks, ranging from 0.010 to 20 in. in length produced; grinding, heating and inspection operations; lapping of gage blocks.

Lapping Anvils of Micrometer Calipers, H. M. BUCK. Machy (London) v88 n2251 Jan 6 1956 p 14–5. Description of apparatus and techniques which were applied successfully for generating accurately flat and parallel measuring faces on micrometer calipers; method involves first rectification of measuring face of micrometer spindle, after which anvil face is lapped in fixture.

"C.E.J." + "B. & S." = Precision Gaging. Machy (N.Y.) v64 n8 Apr 1958 p 132–5. Manufacture of "Jo" (after Carl Edward Johansson) gage blocks at Brown & Sharpe Mfg Co, Providence, R.I.; details of making "Thrift" blocks which is new class of blocks produced to better than Class B accuracy; lapping operations indicated.

Gage Inspection in Millionths—Not Guesswork, G. ASH-MEAD. Machy (N.Y.) v70 n5 Jan 1964 p 104–6. Deltronic Corp, Costa Mesa, Calif manufactures Class "X" cylindrical plug gages exclusively in over 6000 sizes; with each plug gage certificate is supplied which unconditionally guarantees that gage is within size tolerance of plus 0.000,040 in. minus 0.000,000 in. and that it has surface finish of approximately one μin; manufacturing methods described and illustrated.

Addendum to Section 12.

12.6.2. Scales and Gratings, Manufacture of

Preliminary Notice of the Results Accomplished in the Manufacture and Theory of Gratings for Optical Purposes, H. A. ROWLAND. Phil Mag ser5 v13 1882 p 469–74. Refers to previous work of Rutherford in making gratings. Describes progress in making a highly accurate screw; the ruling of 160,000 lines on a surface or 29,000 per inch, and the making of concave gratings.

12.6.5. Other Gages, Manufacture of

Addendum to Section 2 (continued from page 90)

flection within a plane-parallel plate, by means of which interferences can be investigated for much larger path differences than previously. Green rays from a mercury lamp pass into a glass plate 6 cm thick through a slit in the opaque silvering which covers the face of the plate. The opposite face is half-silvered, and the rays which emerge pass into a telescope focused at infinity. A movable shutter at the eyepiece can cut off the rays in succession, and the change observed on cutting off the ninth reflected ray shows that the latter is still in a condition to interfere. The corresponding path-difference is 2,600,000 wavelengths,—a limit which could be extended by the use of a thicker plate.

Über cine Kadmiumamalgamlampe aus Quartz (Regarding a Cadmium Amalgam Lamp of Quartz), O. LUMMER, E. GEHRKE. Zeits InstrumKde v24 n 10 Oct 1904 p 296–8 6 refs. Lamp produces eight strong visible Cd and Hg lines from 644 to $436\mu\mu$. Construction is described.

2.4.1. Length and Diameter Measurements —General

Méthode pour Mesurer en Longueurs d'Onde de Petites Épaisseurs (Methods of Measuring Small Thicknesses in Wavelengths), J. M. De LÉPINAY. Ann Chim Phys ser6 v10 1887 p 68–85. The method adopted was based on the use of Talbot fringes, the advantages of which were set forth by Mascart. Presents numerical data; corrections for temperature and pressure; description of apparatus; preliminary experiments and calculations; conclusion.

Mesures Optiques D'Etalons D'Épaisseurs (Measurement of the Thickness of Optical Standards), J. M. De LÉPINAY. Ann Chim Phys ser7 v5 May–Aug 1895 p 210–55 10 figs. Contents: measurement of index; measurement of thickness; determination of the equal-thickness curves.

2.4.2. Fringe Count Interferometers and Dilatometers

Measuring Device Employing Light Interference Fringes, E. ROOT III. U.S. Patent 2 604 004 July 22 1952 8p 20 refs. Provides an apparatus for making absolute measurement of an article of any size by an actual count of the succession of interference fringes.

Reversible Interference Fringe Counter with a Small Measurement Range, L. Ya. KVASKOV. Meas Techns n8 Mar 1965 p 675–8 4 figs 3 refs. Translated from Izmer Tekh n8 p 16–9 Aug 1964. Describes a Michelson interferometer, photocells, and an electronic unit consisting of a photo multiplier, a dc two-channel amplifier, a reversing stage, and a counter. The apparatus has a range of 50 fringes and a precision of one interference fringe.

2.4.4. Interference Comparators

New Interferometer for Measuring Block Gauges. V. P. GOLUBKOVA, V. P. KORONKEVICH, E. I. FINKEL' SHTEIN. Meas Techns n8 Mar 1965 p 672–4 3 figs 4 refs. Translated from Izmer Tekh n8 p 14–6 Aug 1964. Describes a new interference comparator for measuring the lengths of gage blocks from 3 to 100 mm without wringing them to auxiliary surfaces.

2.4.5. Measurement of Long Lengths (by Interferometry)

Sur les Phénomène des Interférences entre deux Rayons de Lumière dans le cas de Grandes Différences de Marche (Regarding the Phenomenon of Interference of Two Rays of Light in the Case of a Large Path Difference), H. FIZEAU, L. FOUCAULT, CR Acad Sci v21 1845 p 1155–8; Ann Chim Phys ser3 v26 1849 p 138–48, v30 1850 p 146–59. Discusses interferences produced by an array of mirrors, by reflection on thin plates, and by means of double refraction.

2.4.6. Measurement of Line Standards (by Interferometry)

Automatisches Vermessen und Protokollieren von Präzisionmasstäben durch fotoelektrisches Interferometer und fotoelektrisches Mikroskop (Automatic Measurement and Programming of Precision Measurement Standards by Means of the Photoelectric Interferometer and Photoelectric Microscope), F. HOCK, K. HEINECKE. Maschinenmarkt v71 n37 May 7 1965 p 27–37 25 figs 14 refs. Describes apparatus for fast, completely automatic length measurements of line standard intervals in relation to the wavelength definition of the meter, millimeter graduations are calibrated to 0.1μ as the result of many years of development work. Graduation lines are scanned photoelectrically by an oscillating light beam, and a punched tape is used for recording.

AUTHOR INDEX

NOTE. References showing names of firms or organizations, but not naming authors, are indexed in italics.

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THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its three Institutes and their organizational units.

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