NATIONAL BUREAU OF STANDARDS REPORT

2442

Semiannual Progress Report
of the
Office of Basic Instrumentation

For the Period Ending

December 31, 1952

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE

Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS

A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity. Resistance Measurements. Inductance and Capacitance. Electrical Instruments. Magnetic Measurements. Applied Electricity. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Gage.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenics. Engines and Lubrication. Engine Fuels. Cryogenic Engineering.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Measurements. Infrared Spectroscopy. Nuclear Physics. Radioactivity. X-Rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. Atomic Energy Commission Instruments Branch.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Aerodynamics. Engineering Mechanics. Hydraulics. Mass. Capacity, Density, and Fluid Meters.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure. Chemistry of Mineral Products.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Machine Development.

Electronics. Engineering Electronics. Electron Tubes. Electronic Computers. Electronic Instrumentation.

Radio Propagation. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Frequency Utilization Research. Tropospheric Propagation Research. High Frequency Standards. Microwave Standards.

Ordnance Development.
Electromechanical Ordnance.
Ordnance Electronics.
These three divisions are engaged in a broad program of research and development in advanced ordnance. Activities include basic and applied research, engineering, pilot production, field testing, and evaluation of a wide variety of ordnance matériel. Special skills and facilities of other NBS divisions also contribute to this program. The activity is sponsored by the Department of Defense.

Missile Development. Missile research and development: engineering, dynamics, intelligence, instrumentation, evaluation. Combustion in jet engines. These activities are sponsored by the Department of Defense.

- Office of Basic Instrumentation
- Office of Weights and Measures.

NATIONAL BUREAU OF STANDARDS REPORT

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Office of Basic Instrumentation

SEMI-ANNUAL PROGRESS REPORT

July 1, 1952 to Dec. 31, 1952

The Basic Instrumentation Program at the National Bureau of Standards is co-operatively sponsored by the Office of Naval Research, Office of Air Research, and the Atomic Energy Commission, and is an extension and continuation of a limited program undertaken in 1948, sponsored by the Office of Naval Research.

The Basic Instrumentation Program is a program designed to realize the benefits in instrumentation research that accrue from co-ordinated planning of such research from the standpoint of instrumentation as a science in itself, common to the "primary" technical fields. The program is intended to help fulfill the needs of the sponsoring agencies by providing a background common to the several primary sciences from which problems in instrumentation may be more effectively attacked.

This report contains progress reports on projects started during the present fiscal year as well as reports on continuing projects. For convenience, the project reports have been grouped according to the technical division of the Bureau in which the work is conducted.

W. A. Wildhack, Chief
Office of Basic Instrumentation

A. V. Astin
Director

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Survey of Millimicrosecond Oscillography - NBS Project 2018, Electrical Instruments Section, J. H. Park

Objective: To prepare a critical survey containing comprehensive information on the present status of oscillographic methods and instruments for the recording of high-speed transient voltages in the time intervals below one microsecond, and an evaluation of their theoretical and practical capabilities.

Background: Recent developments in radar, television, atomic physics, telemetering, etc., have greatly increased the need for oscillographic measurements in the time range below one microsecond. As a result, new and faster oscillographs have been and are being developed. Such instruments will also find applications in the study of electrical breakdown under steeply rising voltage surges (a subject of growing importance in the field of insulation testing), and in the general development of high-voltage surge-testing techniques. Experiences gained by work on the CRO-beam intensification project (2006) will be helpful in evaluating the high-speed recording instruments available. A survey in this field will be useful in the planning and conduct of new research and development on high speed oscillography as well as in guidance in instrumentation problems concerned with recording of high-speed transient voltages.

Progress: This project was started during the reporting period. Letters of inquiry were sent to manufacturers of high-speed oscillographs and some replies have been received. A bibliography of pertinent technical articles and reports is being assembled and reviewed.

Future Activity: The present bibliography is to be extended and individual articles reviewed and summarized. Summaries or tabulations will be prepared containing data on mechanical and electrical characteristics of high-speed oscillographs, writing speeds obtainable under various conditions, and accuracy of displayed wave forms as affected by amplifier characteristics, electron beam transit time, and type and arrangement of deflecting systems. Work will be started on a portion of the report on theoretical considerations concerned with design techniques and operating limitations of high-speed oscillographs.

Determination of Temperature With the Noise Thermometer
NBS Project 0301-31-2637, Temperature Measurements Section,
E. W. Hogue

General Objective: To evaluate the capabilities of the noise thermometer as an instrument for measuring temperatures on the thermodynamic scale and to investigate the suitability of the device for other temperature measurement and control applications.

Specific Objectives: To determine the principal limiting factors on the sensitivity, precision, and accuracy of temperature measurements made in this way.

Background: The limiting sensitivity of electrical measuring circuits has been of interest to designers of equipment as well as scientists for many years. Even if no electric field is applied, electrons, moving in conductors as a result of thermal energy, may have at any particular instant an unsymmetrical distribution along the conductor. As a result, there is at that time a difference of potential between the ends of the conductor. Over a long period of time, these differences in potential average to zero. The frequency distribution of the fluctuations is given by the equation of Nyquist.

$$\bar{V}^2 = 4k\tau \, Re(Z) T \Delta f$$

where $\bar{V}^2$ is the mean-square fluctuation in voltage in a band of frequencies of width, f

k is Boltzmann's constant

Re(Z) is the real part of the impedance of the passive network

T is the thermodynamic temperature of the resistor.

The fluctuation in potential described by the above equation is commonly termed Johnson noise.

Although this effect is generally considered harmful since it limits the ultimate sensitivity of circuits, it does provide a method for measuring the thermodynamic temperature. Kelvin, in 1854, first proposed a method of defining a temperature scale which is independent of the properties of thermometric substances. Temperatures on this scale are of primary importance to thermodynamicists concerned with the relation between properties of matter and temperature. In the past, a gas thermometer has been used to determine temperatures on this scale. Precise measurements require elaborate equipment, available in only a very few research laboratories in the world, and a large investment of time. The noise thermometer provides a possible substitute for a gas thermometer.

Recognizing this possibility, Drs. J. B. Garrison and A. W. Lawson of the University of Chicago developed a noise thermometer with which they measured ratios of temperatures. The equipment which they used has been set up at the National Bureau of Standards where it has been extensively modified, greatly increasing its sensitivity and stability. If an accuracy of 0.1% can be obtained at temperatures above the gold point (1063°C), the measurement of temperatures in this range will be improved considerably and a determination of the temperature of the gold point, which is one of the fundamental points on this scale, could be made. The value used for this temperature is based on gas thermometer measurements made approximately 40 years ago.

Preliminary results obtained in earlier work indicate that the modified instrument can be balanced with a precision of approximately 0.1°C. On this basis, it appears possible that temperature measurements equivalent to those made with a gas thermometer can be made.

Summary of Project Activity: Two experimental noise thermometers were acquired from the University of Chicago Institute for the Study of Metals where they were designed and built by J. B. Garrison and A. W. Lawson.

One of these models had not been developed sufficiently for use in temperature measurements, but the other had been used by them to make measurements at around 1000°K, and the results together with a description of the thermometer have been published in their article "An Absolute Noise Thermometer for High Temperature and High Pressures", Rev. Sci. Instru. Vol. 20, No. 11, 785-794, November 1949. An accuracy of 0.1% is claimed.

When the noise thermometer was received it was at first assembled on the bench. Little test equipment was available at this stage for work on it. No complete circuit diagram was available. Much of the circuit was then traced. Preliminary attempts to make a noise balance showed some unbalance sensitivity, but very little. The thermometer could just distinguish between an input resistance of 10,000 ohms and short circuit. Further circuit tracing and adjustment of the synchronous switches increased the sensitivity, but nothing approximating a true balance could be obtained. Much of this trouble was finally traced to interference from the signal of a television station about a mile away.

Study and experimentation was carried out to devise a better way to amplify and integrate the unbalance signal. Several schemes were tried out in breadboard form. The feedback integrating circuit used in analogue computers seemed most promising, and several ways of constructing one were tried out. To get more sensitivity, more gain and more bandwidth reduction (longer averaging or integrating time) were both necessary. The analogue integrator accomplishes both amplification and bandwidth reduction simultaneously.

While the new circuit devised proved to be much more dependable and convenient than the other, unbalance sensitivity remained far from the theoretical. Further checks of the amplifiers in the thermometer revealed noisy components in the electronic filter; the high gain amplifier, and the preamplifier. High level electrical signals from an induction heating generator and from numerous but unlocatable machines in the vicinity had been almost completely screened out by the newly acquired screen room. When many of the internal sources of noise (faulty components) had finally been cleared up, balances were obtainable to a few degrees, or about 1%, as of January 1952.

Using a calibrated mercury-in-glass thermometer to indicate the temperature of the reference resistor of the noise thermometer, determinations of the ice point and steam point were made. The noise thermometer element was placed in a steam hypsometer for the steam point, and a noise balance was carefully made using both the low and high frequency amplifiers.

A value of 99.8°C was obtained. The actual steam point, taking into account the atmospheric pressure at the time, was between 99.5°C and 100°C.

When these measurements were made, the thermometer circuit was up to full sensitivity. In subsequent checks the thermometer failed to maintain this sensitivity consistently enough to make further temperature measurements. It is felt that the trouble is chiefly due to faulty components in the preamplifier, and possibly in the electronic filter following it. As is well known, even though the noise level of a sensitive amplifier may be calculated on the assumption of ideal components, large departures from theory will occur in actual amplifiers depending upon the choice of tubes and other components used. The existing noise-thermometer amplifier was not at all adapted to the easy substitution of parts to allow a systematic search for quiet components, so the design of a new preamplifier chassis has been started. This design, when completed, will allow quick interchange of components and easy circuit re-design.

Progress: At the beginning of this period the noise thermometer consisted of the original amplifier units (built at the University of Chicago) to which had been added the new high-gain integrator-detector circuit. Although the old components had been "de-bugged" to a considerable extent, they failed to maintain high sensitivity at all consistently. Erratic disturbances (bursts of high level noise) and microphonism were bad, and the electronic filter was found not to have a sufficiently sharp cut-off.

During the last two quarters the old preamplifier unit has been replaced by a much quieter, more stable and less microphonic one; and a new filter-amplifier using a passive filter having a sharp upper cut-off has been substituted for the original one. Unbalance sensitivity of the new circuit was then of the order of 0.4%. Unbalance sensitivity measurements giving .05% made earlier, on the old equipment have since been found to be in error. Because of the uncertain behavior of the old equipment, good sensitivity measurements were extremely difficult to get.

A serious source of interference and systematic error has been traced to circuits carrying the electrical power used to drive the synchronous switches. Small arcs in connections and switches in these circuits greatly increased the overall noise level because they were repetitive at the synchronous frequency. Also, a large and steady error, or false balance, could be eliminated only by completely disconnecting the chassis carrying the preamplifier from all possible connection with the synchronous power.

The resolving power of the first detector remained insufficient to give 0.1% detectability despite the fact that its dynamic range had been increased by the use of a crystal rectifier and higher plate voltages. It is felt that the chief limitation on unbalance sensitivity lies in the detector. Measurements on the other components of the circuit indicate that they are capable of detecting sufficiently small differences in noise level to give 0.1% detectability.

Future Activity: It is hoped that a suitable set of mechanically driven synchronous switches can be found to replace the electrically driven ones.

A study will be made to try to find what the resolving power of the present diode linear detector is, and what can be done to improve it if it turns out to be the principal obstacle to the attainment of greater unbalance sensitivity.

A final report on the work under OBI sponsorship will be prepared during the coming quarter.

Electron Interferometer - NBS Project 0405-30-2929,
Electron Physics Section, Dr. L. Marton

General Objective: The experimental and theoretical investigation of the design and performance of an electron interferometer.

Specific Objectives: To design, construct and develop an interferometer using electron beams in place of light beams of the optical interferometer and to use the instrument to demonstrate the formation of interference fringes. This requires the development of electron beam splitters, the theoretical design of the interferometer system, design and construction of the instrument mechanism, the assembly and fine adjustment to demonstrate interference, and the carrying out of test measurements on the completed instrument.

Background: Ever since the first experimental evidence of the wave nature of the electron was reported in 1927, a large volume of work with electron diffraction has confirmed the interference of electrons. The gap between such naturally occurring interference phenomena in crystals or electron microscope observations and controlled achievement of electron interference has not been bridged. Preliminary calculations show that it should be perfectly feasible to bridge this gap with an electron interferometer of a type reminiscent of the 'Mach-Zehnder', but using diffraction from lamellar crystals as beam splitters and deflectors. Such an instrument could be used to extend the interferometric measurement of length and angle to new lower limits now set by the wave length of visible light. It should also be useful in the measurements of weak magnetic or electric fields in a manner analogous to measurement of the refractive index in optical interferometry. A number of important theoretical questions on the nature of the electron would also be open to direct measurement.

Summary of Project Activity: During the previous year calculations showed that it should indeed be possible to build such an interferometer. It was also shown experimentally that the necessary crystals could be grown by evaporation on a suitable substrate, i.e. by the process of epitaxy, and a light optical analogue was constructed and tested. A design was prepared meeting all the required criteria and a first model built. At the end of the last year the instrument was installed on a modified electron microscope and the search for adjustment to give fringes was commenced.

Progress: The past six-month period has been spent in an attempt to achieve the initial alignment of the instrument. It has been found that with the thinnest crystals maintaining the necessary mechanical strength (100 A annealed copper), contrary to our hopes the alignment must be done photographically for lack of sufficient intensity for visual observations. In a series of attempts to increase the intensity the intercrystal distances were reduced from their initial design values and the illuminating system of the microscope improved. Although, the intensity is much better it has to date still proved insufficient for visual observations with any beam density that avoids immediate thermal destruction of the crystals.

In the alignment process therefore approximately one thousand exposures were made and studied for fringes. The first of these showed a lack of resolution which was progressively overcome by increasing the magnetic shielding, the mechanical rigidity of the instrument, and by lowering the interferometer with respect to the viewing system (to allow the use of short focus optics). These improvements give a demonstrated least resolved distance in the region of interest of less than 100 A.

To insure that the crystals were indeed as thin as the evaporation geometry implies, a Tolansky type optical interferometer was set up to measure the crystal thickness. No significant deviation from calculated thickness was found.

In view of the difficulty of alignment experienced, the optical analogue, using diffraction grating replicas, was again set up and a series of experiments performed. In the course of these experiments it was found that this instrument belongs to a class of interferometer partially studied by Carl Barus forty years ago and since almost forgotten. The instruments have the peculiar property that the number of clear fringes is almost independent of the spectral purity of the source and in this sense the fringes are "achromatic". However, since the field of view is colored the fringes are not the achromatic fringes of Rayleigh but a form of "channeled spectrum".

As far as the main problem is concerned the results so far are inconclusive. The experiments were tried with a number of grating replicas, with a number of intergrating spacings and a number of different light sources and conditions of illumination. In every case it was possible to obtain fringes of varying contrasts and spacings. A series of quantitative experiments was attempted to check the alignment criteria developed in the early phases of the project. In every case it was shown that these criteria were not over-optimistic. Some experiments using unmounted gratings were attempted but in this case the fringes were inferior in contrast and stability. Some of the difficulty was in the movement of the gratings in the air current of the room and part to the wrinkled surface of the gratings. These observations give a suggestion as to the cause of some of the difficulty experienced, since optical inspection of the crystals show that they are not flat. It is difficult, however, to draw any valid conclusions due to the enormous difference in scale involved.

Future Activity: In the remaining half year the following activity will be pursued. Further attempts will be made to align the instrument with crystals of the present quality. Attempts will be made to increase the perfection of the crystals and their mounting. Some special cases of the theory of the instrument will be developed in a search for clues to the difficulty experienced. A full report will be prepared of the status at the end of the project.

Mass Spectrometer for the Study of Solids - NBS Project 0406 - 10 - 2930, Atomic Physics Section, Robert Lewis, J. A. Hipple

General Objective: Development of a magnetic type mass spectrometer suitable for the analysis of solids.

Specific Objectives: To devise an analytical system which will combine the advantages of the spark source with the advantages of electrometric detection. The basic new idea to make this possible is the incorporation of a monitor system at the first focus of a double focusing mass spectrometer to give continuous determination of the ratio of any given mass to the whole sample.

Successful development and test of this principle particularly for those analyses not adequately treated by other methods are aims of the project.

Secondary objectives are: The investigation of the factors involved in the attainment of rapid analyses by presentation of the data on a pen-and-ink recorder; the development of techniques for different types of solids and the extension of the range to very small concentration primarily through the use of electron multipliers. Purely engineering refinements are left to subsequent commercial development.

Background: The features which have led to the rapid acceptance of the mass spectrometer during the past ten years as an essential instrument in laboratories concerned with gas and vapor analysis indicate that it might be modified for rapid and accurate analysis of solid samples.

Highly developed spectro-chemical methods do already provide a means of solids analysis, quite rapid compared to wet chemistry, and, for trace determination, considerably more accurate. However, this same accuracy is sometimes not sufficient for the determination of major constituents (i.e. chromium in the control of 18-8 stainless steels) where the more tedious techniques of wet chemistry must be employed. Often this is also necessary for even small concentrations of non-conductors such as phosphorus and sulphur. Moreover the presence of certain elements sometimes interferes with an optical analysis.

The more direct measurements possible with mass spectrometric techniques may be able to supplement other methods in these regions of difficulty and perhaps provide a simpler measurement for many other problems. This application has been slow in developing. The ion sources that are sufficiently stable to provide a source of constant intensity are very limited in their application. On the other hand, the high frequency spark would be applicable to a much wider class of analyses, but its erratic nature makes it unsuitable for the conventional mass spectrometers presently available commercially. The spark source has been used previously with photographic detection to integrate the wild fluctuations. While the photographic method solves the problem of the source fluctuations, problems of limited range, non-linearity, calibration, speed and convenience limit its usefulness. Combination of the advantages of the spark source and electrometric detection would form a useful analytical system.

Summary of Project Activity: A monitoring system was developed to permit measurement to be made in spite of the severe fluctuations of the spark source. The monitor consists of an electrode placed at the entrance to the magnetic field to sample the total ion beam. As the various ions are scanned across the exit slit, the ratio of current passing the exit slit to that received by the monitor is recorded. Since these two collectors receive current from the same source, the fluctuations of this source are effectively nullified. Calibration was found to be linear over the range 1% - 25% in analyzing for nickel and chromium in stainless steel.

A description of the successful analysis of six stainless steel samples for nickel, chromium and iron appeared in Analytical Chemistry[1]. Additional details of this work were reported at a Physical Society meeting[2]. Application of this method to measurement of the isotopic ratios for nickel, copper, and magnesium was reported at a later meeting of the American Physical Society[3].

Following these preliminary results studies were conducted to improve and refine the operation of the system. Automatic recording methods were introduced. Results with automatic recording did not match the results previously obtained with manual methods.

Preparation and tests have been made for using electron multipliers as sensitive ion detectors.

In order to improve the monitoring action, the performance of the monitor was studied with a steady source of ions whose output was subject to better control than the spark source. The output of this "steady" source could now be modulated to determine the effectiveness of the monitoring system at various frequencies. This study revealed several necessary modifications to the mass spectrometer and amplifying system which were subsequently made. The monitor collector was split to assist in centering the beam on the magnet entry slit (adjustment of the beam position axially in the direction of the magnetic field). Auxiliary deflectors were installed between the electrostatic and magnetic fields for control of the ion beam in the direction of the magnetic field.

Progress: Using the new auxiliary deflecting plates the beam distribution across the monitor was studied and adjusted for optimum performance. By sweeping the electrostatic analyzer voltage the beam distribution in the other direction was studied and found to be poorly defined in the vicinity of the monitor. This was corrected by adding further collimation above the magnet entry slit to suppress reflections. (Illustrations with the previous report - June, 1952 - include a schematic of the monitor system).

Other modifications in the ion optics brought the resolution to the theoretical limit, but, although the stability was increased, further improvement was necessary. Centering the beam in the magnet gap with the axial deflectors improves the operation and reduces the noise on the mass peaks. The evidence was clear that the walls of the magnetic analyzer were a contributing cause of the fluctuations; because it is a major job to clean these surfaces, the decision was made to tolerate this disturbance for the short time remaining on this project.

Initial tests with the filament source following the above adjustments indicated that the ratios measured with the monitor method varied less than 1 percent of the variation in the number of ions emitted by the source.

A dummy circuit was constructed to simulate the action of the amplifiers feeding their signals into the recorder. The time constants of the circuits feeding the signals to the slide wire and chopper of the recorder were made variable. It was thus possible to observe the distortion in the recorded ratio as a function of mismatch of the two input circuits. The square wave signal was obtained from a fast relay driven by an audio oscillator. The frequency range was one to 130 cps. To balance out the fluctuations it was necessary to match the time constants within 10 percent at 0.1 second.

The time constants of the two amplifiers were studied by modulating the electrostatic analyzer voltage with the square wave generator mentioned above. This produced a 100 percent modulation in the beam intensity at the monitor and collector. By varying the capacitances across the input resistors, the time constants were adjusted to balance out the variation produced in the ratio as a result of the modulation. Difficulty was experienced in maintaining this balance more than a few hours apparently because of varying characteristics in the first stage of the amplifiers.

Experiments were conducted with the high frequency spark on ions obtained from a finely powdered glass pressed into a matrix of silver. The ions detected were those expected from the type of glass that was used.

Electronic Coating Thickness Gage - NBS Project 0506-31-3224, Electrodeposition Section, Abner Brenner.

General Objective: To develop a thickness gage for measuring the thickness of metallic coatings which differ from the basis metal in electrical resistivity or in magnetic properties.

Specific Objectives: To develop an inexpensive, portable, direct-reading instrument for nondestructively measuring the local thickness of those combinations of coatings and basis metal which are not susceptible to measurement by magnetic thickness gages.

Background: Numerous magnetic devices are available for measuring the thickness of metallic coatings which differ from the basis metal in magnetic properties, but no convenient device is at present available for nondestructively measuring the thickness of other combinations of coatings and basis metals such as silver on brass. An X-ray method has been developed for tin coatings on steel, but the instrument is extremely expensive and not portable. A beta-ray back scattering device has been developed for measuring the thickness of films, but it requires an area about three inches in diameter and therefore yields the average thickness rather than the local thickness of the coating. Devices based on inducing eddy currents in a metal surface are now available for measuring the thickness of non-conducting coatings upon metals, but they cannot be used for measuring the thickness of a metal coating upon a metallic base.

An exploratory study made several years ago in this laboratory indicated that the thickness of a metal coating on another metal of different electrical conductivity could be determined by using high frequency current to induce an eddy current in the coating. By virtue of the skin effect it was expected that the induced current could be restricted mainly to the coating. Preliminary experiments with a variable frequency oscillator and a primary and secondary coil indicated that the current should have a frequency above 50 kilocycles. Experiments were subsequently made with a circuit similar to that used in the Naval Research Laboratory thickness gage and evidence was obtained that the presence of a silver coating on nickel brass could be detected.

Summary of Project Activity: Experiments with a simple resonant bridge circuit were made, in which the active test probe was a small coil of fine wire wrapped on a thin plastic rod. When operated at a frequency of about two megacycles the inductance of the test probe when placed in contact with the plated surface was sufficiently sensitive to variations in thickness of the plating, when differing in conductivity with the basis metal, that fairly accurate determinations of plating thickness could be made.

For localizing the area of measurement small probe coils were made with diameter of .05 to .01 inch. Sensitivity of the simple bridge circuit was such that a change in reading of approximately 100 microamperes was obtained when the probe was placed on copper and then on brass.

Improvements were then made in the circuitry following a method proposed by Mr. Maurice L. Greenough of the Electronic Instrument Section which approximately doubled the sensitivity of the instrument. Further improvements were made by use of precision components and use of germanium dials instead of vacuum tube dials.

Progress: The sensitivity has been further improved to 300 microamperes with a current of 14 milliamperes in the probe winding.

(Studies in calibrations have been made to determine the effect of the thickness of the probe on the sensitivity). A sharp decrease in sensitivity occurred with increase in probe-tip thickness. For a tip thickness of 0.015 inch the sensitivity was 100 microamperes, but when this thickness was increased to 0.024 inch the sensitivity was decreased to 50 microamperes.

Experiments are now being conducted to observe the effects of using various size coils on the operation of the instrument at various frequencies, using appropriate values for resistance and capacitance. The 1/16 inch probe has practically zero sensitivity at all of the lower (50 KC - 1200 KC) frequencies, but the largest probe (1/4 inch) has good sensitivity (180 μa) at 50 KC and very good sensitivity (300 μa) at 500 KC as compared to only 20 microamperes at 2 megacycles.

The advantage in operating at lower frequencies is that the depth of eddy current penetration is greater, therefore, enabling the measurement of thicker platings. By using sheets of metal of various thicknesses the approximate depth of penetration of the eddy currents can be determined with this instrument.

A study is now being conducted to determine the effects of geometry of the specimen on the sensitivity of the instrument. At present it appears that the sensitivity doesn't change with shape of specimen, but the actual meter readings are shifted.

Some experiments have been performed using mu metal and permalloy for the core (bobbin) of the probe. These probes, when properly annealed, proved to be a great aid in increasing this sensitivity of the instrument at lower frequencies (2-500 KC), therefore permitting operation at lower frequencies than previously. The sensitivity at 50 KC was 400 μa.

Future Activity: A final report on this project will be forthcoming at a later date. The practical details of the instrument are now being worked out on a grant from the Bureau of Engraving and Printing.

Carbon Dioxide Hyspometer - NBS Project 0602-34-3524, Mechanical Instruments Section, W. G. Brombacher

General Objective: To develop apparatus and technique for measuring pressure-altitude at high altitudes by measuring the temperature of subliming carbon dioxide snow.

Background: There appears to be considerable promise in a "hypsometer" utilizing the temperature of subliming, solid carbon dioxide in equilibrium with its vapor at ambient pressure as a measure of pressure in upper air research. An electrical output from the sensing element is peculiarly desirable. The carbon dioxide hypsometer would function similarly as a hypsometer using measurements of the boiling point of water to determine ambient air pressure or pressure altitude. The chief advantage of an instrument on this basis is the fact that both the measured temperature and the pressure altitude vary approximately with the logarithm of the ambient pressure and thus the sensitivity on a pressure altitude basis is practically constant. A change of 1°C is equivalent to a change in pressure altitude of 2172 feet from sea level to 60,000 feet and 5875 feet from 175,000 to 300,000 feet.

Previous work on hypsometers for this purpose included investigation of the utility of water and carbon disulphide. Pressure altitudes not over about 112,000 feet can be obtained with water, and carbon disulphide is unpleasant to work with.

The temperature to be measured is that of the solid carbon dioxide which is formed by expanding liquid carbon dioxide through a porous plug. The experiments are chiefly directed to obtaining a suitable porous plug, refinements to reduce the size of the instrument to a vacuum, and the development of suitable temperature probes.

Summary of Project Activity: On the basis of theoretical studies and preliminary experiments a variety of porous plugs was constructed of fine copper powder compressed under high pressure which would permit the flow of carbon dioxide from a 1000 psi tank at rates of 1/2 to 10 litres per minute. A standard size for the plugs was 2 inches in length by 1/2 inch OD by 1/4 inch ID. It was found that at flows below 2 litres per minute carbon dioxide flow could not be reliabily formed. The effect of the shape and length of the tube, in which the thermocouple junction was placed for determining the temperature of the subliming carbon dioxide, was investigated to find an arrangement which would reliably deposit solid CO_2 on the thermocouple junction. In some arrangements it was found that the CO_2 would form a solid plug which would then be forcibly blown out, breaking the thermocouple. It was found that flows of two to three litres per minute appeared to give the best performance.

Progress: A number of hypsometer models were constructed and tested at reduced pressures in an altitude chamber. The most promising models were tested to pressures corresponding to altitude of 105,000 feet.

Further theoretical study was made of the factors determining the sensitivity of various possible vaporizing substances for use in high altitude hypsometers and of the conditions required for initial temperature of the expanded CO_2. A final report on the project is being prepared.

Absolute Measurement of Vibration Amplitudes - NBS Project 0601-31-3528, Sound Section, Walter Koidan

General Objective: To develop and precisely calibrate a vibration generator in the range from 100 to 10,000 cycles per second; to develop and calibrate a vibration detector on the basis of the known motion of the vibration generator; to use the detector for vibration measurements and for calibrating other vibration pickups.

Specific Objectives:

(a) To develop a barium titanate shaker which will vibrate at an approximately constant amplitude for a given input voltage in the range from 100 to 10,000 cycles per second.

(b) To calibrate the shaker over this range by an acoustic method.

(c) To develop an electrostatic detector which can be calibrated against the known motion of the driver and which can be transferred to other vibration generators for determining their motion.

(d) To design one electrostatic pickup with high sensitivity and another detector for practical applications.

(e) To devise and develop methods for calibrating the electrostatic detector independent of the acoustic method.

Background: An important link between vibrations and acoustics is provided by the pistonphone, which is a device for developing an alternating pressure in a closed cavity by means of a vibrating piston. This instrument was first built so that a known motion could be imparted to the piston. By a simple expression which relates the motion and the pressure, the pressure in the cavity can be calculated:

$$p = \frac{A p_o d \gamma}{V}$$

p = peak pressure
A = Area of piston
p_o = ambient pressure
d = peak amplitude of piston motion
γ = ratio of specific heats (1.4)
V = volume of cavity

A microphone acoustically coupled to the cavity can thus be calibrated. Development of this technique for use up to 200 cps. has been accomplished. 1,2.

1. Wente, "Absolute Measurement of Sound Intensity", Phys. Rev. 10, p. 48 (1917).
2. Ballantine, "Technique of Microphone Calibration", JASA 3-3, p. 338 (1932).

With the development of the reciprocity calibration of condenser microphones,[3] the use of the pistonphone for calibrating microphones became somewhat outmoded. However, it was suggested[4] that the pistonphone procedure be reversed, that is, to determine the amplitude of motion of the piston on the basis of being able to accurately measure the pressure in the cavity. At the same time, the method could be extended to include higher frequencies.

In this connection, the need arises for a method of transferring the acoustic calibration to other vibration generators for purposes of comparison or for calibration of vibration pickups. This can be done by means of a capacitance pickup, whose sensitivity and frequency response has been obtained by means of the acoustic calibration. Use of a circuit after Van Zelst[5] was contemplated because of its simplicity and its adaptability as an electrostatic detector.

In order to have a check on these measurements, it was planned to investigate other methods of calibrating the electrostatic detector, namely by electronic means and by direct microscope measurements.

Summary of Project Activities: The first instrument built makes use of an electromagnetic driver arranged to vibrate a piston projecting into a cavity. The diaphragm of a condenser microphone, previously calibrated by a reciprocity technique, is acoustically coupled to the cavity. The pressure change in the cavity resulting from the motion of the piston is detected by the microphone and the amplitude of motion of the piston computed from the observed sound pressure.

The electrostatic pickup associated with this device is a parallel plate capacitor used as one componant in the series resonant arm of a low impedance bridge circuit. A 1.6 mc signal is injected, which is modulated by the motion of the piston. The carrier is then combined with the modulated signal to produce an amplitude modulated wave. The audo signal corresponding to the vibration of the piston is extracted by demodulation in an infinite impedance detector.

The best accuracy which could be obtained with this instrument was about 10% up to a frequency of 2500 cps. The peak amplitude range extended from 6×10^{-9} to 6×10^{-4} cm. After some experimentation, the reasons for the limitations in accuracy, frequency response and amplitude became apparent and plans were made for developing a new instrument to overcome these difficulties.

3. R. K. Cook, "Absolute Pressure Calibration of Microphones" JASA 12-3, p. 415 (1941)
4. A. London, Discussion, J. App. Mech. 15-4, p. 391 (1948).
5. J. J. Zaalberg van Zelst, "Circuit for Condenser Microphones with Low Noise Level" Philips Tech. Rev. 9, p.357 (1947/8).

The driver for the new device is a hollow, cylindrical barium titanate crystal, designed to vibrate at approximately 10^{-5} cm peak amplitude up to 10,000 cps for an input voltage of 50 volts. The cavity is a reproduction of the 19.5 cc. cavity used in the Sound Section of the Bureau of Standards for the reciprocity calibration of condenser microphones. Measurements without theoretical corrections are possible up to 3,000 cps using air in the cavity. Provision is made for introducing hydrogen to eliminate the effects of standing waves between 3,000 and 10,000 cps and permit calibration in this range. A capacitance monitor pickup is included to yield an output at the same time that the microphone is in use, so that the calibration of the shaker need not be depended upon.

Calibration of a capacitance probe vibration detector is accomplished adjacent to the same vibrating surface that is used to generate the pressure in the cavity. The capacitance and its series resonant inductance are arranged as a probe in a shielded enclosure to eliminate possible effects of stray capacitance. Thus, transfer from the calibrating instrument to other shakers is made possible without changing the sensitivity of the pickup. The design permits measurement of the average amplitude of vibration of a flat surface, 3/4 inch in diameter. For larger surfaces, the variations in surface motion can be measured.

Two probes were built, one for high sensitivity, operating at a spacing of about 0.15 mm and one for practical use, operating at 0.45 mm. The former probe has approximately 10 times the sensitivity of the latter.

A method for calibrating the electrostatic detector at low frequencies independently of the acoustic calibration was also investigated. In this procedure, a known direct displacement is imparted to the probe and the output of a null detector noted. After retuning to a null, an alternating motion is given the piston, yielding an increase in the null reading. The two readings of the null detector can be related mathematically and the motion of the piston calculated. Use of this method has given results comparable with the accuracy of the measurement of the direct displacement, which is at present the limiting factor. The measurements generally agree within 10%.

A third method consists of illuminating a vibrating surface by an alternating light source. When the frequency of this source is slightly different from the vibration frequency, the vibration can be observed in slow motion through a microscope and accurate measurements made.

In the first attempts at an acoustic calibration, direct mechanical coupling between the driver and pickups presented the greatest difficulty. It had been planned to mount the driver on vibration mounts in order to minimize this effect.

However, another factor intervened. The rubbing of the piston against the cavity walls is also a strong enough coupling element to develop wave motion in the main structure of the instrument. Clearance between the piston and the cavity enclosure is necessary to eliminate this difficulty. With vibration mounts, the driver mechanism tilted sufficiently to result in rubbing, despite a provision for clearance. The mounts were therefore temporarily abandoned in favor of solid clamping of the driver to the main structure. Although direct coupling still existed, the resistance factor was at least eliminated. The clearance is about .004" and is sealed with vaseline to prevent leakage of air. With this arrangement, acoustic calibrations were obtained from 100 to 2500 cps with an estimated accuracy of 3%. Above 2500 cps the results were too erratic to have any meaning.

It was found that the probe pickup can be tilted up to about 5 degrees compared to the flat vibrating surface without any noticeable change in the output.

The output noise level of the detecting circuit in a 20 cps band is 50 microvolts. This corresponds to a displacement of 10^{-10} cm peak amplitude when referred to the calibration of the more sensitive probe.

The possibility of extending the frequency range was investigated further and a method devised to support the driver mechanism by vibration mounts and still maintain the .004" clearance. With the mechanical coupling thus reduced, preliminary acoustic calibrations were made from 100 to 10,000 cps.

Progress: The frequency response of the detecting circuit was measured by disconnecting the bridge circuit and substituting an amplitude modulated wave input. Close agreement with the response determined by the acoustic calibrations was obtained from 100 to 10,000 cps.

On the basis of the electronically measured frequency response and the microscope measurements at low frequencies, the accuracy of the average of four acoustic calibrations performed is estimated as follows:

Frequency Range, cps	Accuracy
100 to 2,000	3%
3,000 to 5,000	4%
6,000 to 10,000	5%

The general trend of the response curve of the capacitance vibration detector is regular except at 5,000 cps, where a 0.1 db dip in sensitivity exists. This anomaly is attributed to the small amount of mechanical coupling remaining between the driver and the main structure. At 10,000 cps, the response falls off slightly more than 1 db.

Several barium titanate accelerometers were calibrated up to 10,000 cps by comparison with the capacitance probe.

Future Activity: The objectives of this project having been attained, a terminal report was prepared which is in the process of approval.

Ultrasonic Velocimeter for Liquids - NBS Project 0601-31-3531, Sound Section, Martin Greenspan

General Objective: To investigate the feasibility of applying the "sing-around" and the "time-of-flight" pulse methods to a fixed path acoustic delay line so as to provide a direct-reading instrument for measurement of the speed of sound in (and hence the compressibility of) liquids.

Specific Objectives: To determine which of the fixed path pulse systems ("sing-around" or "time-of-flight") is the more accurate and reliable. To investigate the possibility of making an absolute indicating instrument, or if this is not possible, to determine the extent and nature of the corrections which must be applied.

Background: The adiabatic compressibility is a quantity of fundamental importance in studies of the liquid state. Together with isothermal compressibility (from static measurements) it determines the ratio of specific heats. This instrument would facilitate, for example, the study of ionic equilibria in liquids. Sound-velocity measurements could be used in the laboratory and in industry for process control and for analysis much as index of refraction measurements are used. It may be possible to apply the results of this work to the development of a device to measure continuously the velocity of sound in sea water for sonar and other underwater sound applications.

Of the hitherto existing instruments for measurement of the speed of sound in liquids the variable-path interferometer is the most accurate and among the simplest. Operation of an interferometer is tedious and requires skilled personnel; further, a run requires an hour or so, so that the instrument is not satisfactory for use with liquids of which the temperature or composition is changing, and very precise temperature and frequency control is required in any case. Most other methods, of which there are a great many, are suitable for use in the laboratory only, and are less accurate than the interferometer method. An instrument, even of somewhat complex structure, but nevertheless reliable and capable of operation by non-professional personnel, and approaching the accuracy of the interferometer, would make it practicable to utilize sound-velocity measurement in laboratories other than sound laboratories, and perhaps in industry and in the field.

Summary of Project Activity: The apparatus is essentially an acoustic delay line. The line now in use is a tank about 10 cm long of which the ends are quartz-crystal transducers. A high voltage pulse is applied to the "sender" crystal; a corresponding pulse of sound travels down the sample liquid and is received and converted to a voltage pulse by the "receiver" crystal.

The pulse is distorted by transmission through the liquid because the high-frequency components are attenuated more than the low-frequency components. The sent and received pulses are thus of different shapes, and precise specification of the location in time of the pulse can be made only by consideration of the instant at which the signal begins to rise from the noise. Therefore a rapidly rising pulse is essential and a pulse-modulated carrier has no advantage over a video pulse.

Initially the "sing-around" system was investigated, as it appeared to be simpler. In this system the received pulse after suitable amplification and reshaping is again applied to the sender; thus the device regenerates and the pulse repetition frequency depends on the velocity of sound in the sample. In this "sing-around" system considerable difficulty was encountered with multiple reflections. Those echoes which arise from a single primary pulse are self-synchronous, but they are not synchronous with any other set because of time delay in the amplifier and trigger circuits. Effort was made to eliminate these troublesome reflections by putting absorbers in front of the crystals, backing the crystals with tapered lead blocks, reducing cross-section of the path, etc. All of these methods tend to obscure the initial rise, thus introducing an additional delay, but what is more important, the proper adjustment and also the amount of delay depend on the sound attenuating properties of the particular liquid. The sound-attenuation coefficient varies enormously from liquid to liquid. For these reasons the sing-around scheme was abondoned for general use, at least temporarily; nevertheless it is felt that it holds great promise for the measurement of small variations in the speed of sound among liquids of nearly the same attenuation; an important example is sea-water in which it is important to detect the effects of variations in temperature, pressure and salinity.

Experiments were conducted using many variations of the time-of-flight method and finally a system was devised which reduces the measurement to one of frequency and has great inherent precision.

Two fast pulses are produced, the time interval being adjustable and accurately known. The first is applied to the sending crystal and the second is set in coincidence with the output of the acoustic line. The repetition rate for this cycle is long enough for the echoes to have died away before the next pulse is applied. The pulses are derived from a variable-frequency, sine-wave oscillator. Those pulses other than the two desired are eliminated by means of two series of binary dividers operated in parallel but one pulse apart in phase. Provision is made for equalizing the delays of the two pulses. This system, which is applicable to various time-measurement problems in radar and elsewhere will be described in a forthcoming issue of the RSI under the title, "An Accurate Time-Modulated Pulse Circuit", by

Carroll Tschiegg and Martin Greenspan. This system (and any other) requires an amplifier to restore to the received pulse the fast rise lost in passage of the sound pulse through the tank. A fast amplifier which saturates almost immediately after the signal rises from the noise, but not on the noise itself was developed and is in use. It is important to note that the very beginning of the received signal is obscured in the noise resulting, unavoidably, in a fictive delay which must be held to a very small, or a known, value.

The coincidence measurement referred to above is made on an oscilloscope screen. For good resolution without excessive sweep speed it is necessary to have markers of fast rise and short duration. A pulse transformer based on a ferrite core was developed which makes it possible to build a small blocking oscillator which delivers a pulse having a rise time of less than 0.02 microsecond and a duration of about 0.1 microsecond. This development is described in the May, 1952 issue of the Technical News Bulletin (NBS) under the title, "New Pulse Transformer Gives Faster Response".

This fast blocking oscillator was found to be a more suitable input pulse for the transmitting crystal. The fast pulse tends to improve the initial signal intensity at the receiving crystal. More important, it was found that this shorter pulse (about 0.1 microsecond) does not excite the transmitting crystal's radial mode of vibration which is thought to send a small amount of sound through the walls of the tank. With this improvement, it is not necessary to slot the walls of the tank to produce an acoustic labyrinth as was previously necessary.

A precision liquids interferometer of conventional type has been constructed for use in calibration of the velocimeter. It was used to measure the velocity of sound in six different liquids (glycerine, ethylene glycol, water, benzene, methanol, and carbon tetrachloride). These liquids vary greatly in attenuation and velocity. For comparison, those same liquids were checked in the velocimeter. A nearly constant delay of 0.45 to 0.50 microsecond was found for all liquids. This suggests that a cycle of the crystal frequency (2Mc/s) is lost in the noise. However, this error may have other causes as it does not change with very large changes in attenuation. Crystals of twice and half the frequency of the ones now in use are on order. With these new crystals it should be possible to pin down this source of error, or determine if this delay is related to the crystal frequency.

A simple sing-around circuit was built consisting of a fast blocking oscillator, delay tank, and a high gain, pulse shaping amplifier. The troublesome reflections were eliminated by tilting and receiving crystal slightly, and also by increasing the attenuation by using smaller diameter crystals. With proper adjustment it is possible to eliminate all reflections and still be left with enough signal to saturate the amplifier for one pulse only. This procedure results in the loss of several cycles at the beginning of the pulse, thus increasing the delay and apparent time of flight. It is felt that this loss is not important because the amplifier and trigger circuit have delays that cannot be eliminated. If these over-all delays can be made constant over a narrow range, such as encountered in sea water, this instrument can be calibrated to give a direct reading of the velocity. The breadboard model, (still lacking many refinements) is very stable and sensitive to changes in velocity. With proper measuring devices a change in velocity of one part in 10^6 can be detected.

Progress:

(a) Time-of-flight type. New delay tanks of fused quartz were obtained. These have optically flat open ends and it should be possible to assemble them with polished quartz transducers so that no cement is needed. Three sets of crystals of different thicknesses are being polished. These will be used in an experiment to determine the source of the 0.45 - 0.50 microsecond delay.

(b) Sing-around type. The sing-around model velocimeter was calibrated in artificial sea water against a precision liquids interferometer over the temperature range 13° to 43°C, corresponding to a speed-of-sound range of about 1510 to 1570 meters/sec. Over this range the electrical delay is constant at 1.55 microseconds except that near the high end it gradually increases to 1.60 microseconds. The calibration is reproducible.

The stability of the model was checked using a zero temperature coefficient liquid. It was found that a stability of 1 part in 10^5 over a 24 hour period could be achieved if proper attention was paid to the selection of stable components and to power supply voltage regulation.

It is indicated that this device could be made to operate over a 10% range in any particular liquid except excessively attenuating ones such as glycerine. The adjustments and calibration would need to be made for each liquid independently.

An automatic recording model of this instrument for field use in the sea is being constructed for the ONR. Work on this project will be suspended until the sea-water model for the ONR is completed.

Future Activity:

(a) Time-of-flight type. The direction of future activity depends on the nature of the 0.45 - 0.50 microsecond delay. The determination of this is the next item on the program.

(b) Sing-around type. The development of this model is complete except for construction details and adaptation to specific use. A final report is in preparation.

Acoustic Viscometer for Gases - NBS Project 0601-31-3533
Sound Section, Martin Greenspan

General Objective: To develop an instrument based on acoustical principles for measurement of the viscosity of gases and gas mixtures over as wide a range of temperature and pressure as is practicable.

Specific Objectives: To determine whether or not it is possible and practicable to deduce the viscosity coefficient of a gas from resonance measurements on a modified Helmholtz resonator. To study and develop the necessary instrumentation, especially as regards suitable transducers (microphones).

An additional specific objective, adopted since the last report, is to determine the feasability of using a non-resonance technique for the same purpose. The principle involved is the reduction of phase velocity of a low-frequency sound wave by the high damping in a small capillary tube.

Background: The absolute measurement of viscosity coefficient of gases is of importance in determining the physical properties of sound-absorbent acoustical materials. Besides the application to acoustics, viscosity coefficients are important in applying the principles of gas dynamics to combustion problems, and to flow problems encountered in wind tunnels and in flight of aircraft.

Nearly all of the available data on the viscosity coefficients of gases were apparently obtained by static flow methods. In one of these methods, a steady uni-directional flow of gas through a capillary is maintained by a steady pressure difference between the two ends of the capillary. The distribution of gas velocities within the capillary tube is assumed to follow Hagen-Poiseuille's Law.

We propose to deduce the viscosity coefficient through measurements of the "Q" and natural frequency of a Helmholtz resonator formed by a capillary joining two volumes of gas. A preliminary analysis reveals the remarkable fact that the measurement of viscosity coefficient can be made to depend only on measurements of the resonant frequency, the "Q" of the resonant frequency, the square of the diameter of the capillary, and the density of the gas. The static flow method, however, gives a result which is dependent on the fourth power of the diameter of the capillary, and in addition requires the measurement of a pressure difference, length of the capillary, rate of flow through the capillary, and the density of the gas.

It is not expected that an acoustic method will be as accurate as the static flow methods, but it is felt that greater compactness and greater speed and ease of operation will be achieved. For example a capillary tube used in a static flow method may be more than fifteen feet long and its associated equipment may fill a large room. The acoustic resonator will be on the order of one foot long and the associated electrical circuits will occupy a relatively small space. Temperature and pressure regulating equipment also are expected to be less complicated. Another advantage of the proposed acoustic technique is that flow measurements will be made for extremely small pressure gradients. Existing acoustic techniques are readily available for measuring pressure differences as small as 10^{-7} atmospheres.

The results of measurements thus far made on the resonators are not very promising. For this reason it may be desirable to concentrate for the time being on the other technique mentioned above, which does not involve resonance methods.

Summary of Project Activity: A typical resonator consists of two equal volumes connected by a capillary tube, the whole filled with the gas under investigation. Upon excitation the gas in the capillary may be thought of as a mass vibrating between the two springs formed by the relatively large volumes of compressible gas. If all of the dimensions are small compared to a wavelength of sound at the frequencies of interest, then practically, all of the pressure variation during an oscillation takes place in the volumes, and all of the velocity variation in the capillary, so that the gas in the capillary acts as if it were incompressible. The walls of the resonator are very rigid so that no energy is lost by radiation. The gas in the capillary remains practically at constant pressure and therefore at constant temperature; thus there is negligible energy loss due to heat conduction to the walls of the capillary. The temperature variations occur in the volumes; however calculation shows that for the dimensions and frequencies involved, the heat conduction loss is negligible. Thus the losses are determined principally by viscous effects in the capillary and these are readily calculated on the assumption of Poiseuille flow.

The technique, then, is to produce by means of a transducer a sound in one volume and measure either the sound pressure in the other volume or the particle velocity in the capillary; from the response of the system as a function of frequency, the "Q", and finally the viscosity coefficient is calculated.

Five brass resonators were constructed. These were designed to have the same natural frequency (about 150 cycles per second for air) and volumes (30 ml ea.), but the capillaries vary from 0.4 cm in diameter and 11 cm in length to 0.1 cm in diameter and 0.6 cm in length.

After preliminary experiments with various types of transducers such as carbon, crystal and condenser microphones, thermophones and hot wire microphones, it was decided to concentrate for the time being on the hot wire instruments. These seem more applicable to use at elevated temperatures and pressures than do the others.

The thermophones tentatively in use consist of about 20 inches of 0.001 inch dia. platinum wire wound in a spiral around insulated posts. The hot wire microphone is similar to those used in wind tunnel experiments and consists of a 0.0001 inch dia. platinum wire stretched across the points of two ordinary sewing needles suitably mounted. The frequency response characteristics of several thermophones were measured using a condenser microphone standard.

The electrical circuits for the biasing of the hot wire instruments were designed and built. A suitable signal source for exciting the thermophone and amplifiers for the hot wire microphone were assembled. Circuits for shielding and filtering the output of the hot wire microphone are being developed. It is to be noted that due to the small signal developed by the microphone, the filtering and shielding requirements are quite exacting.

Preliminary results showed that it is difficult to realize Poiseuille flow in a resonator of convenient dimensions. A more general expression which gives the velocity distribution in terms of Bessel functions, with Poiseuille flow as a limiting case was calculated. The "Q" is a complicated function of the parameter $(\omega_0/\mu^1)^{1/2}$ where ω_0 is angular resonant frequency

$\mu' = \mu/\rho$, the kinematic viscosity,

r = radius of the capillary.

In the region of the parameter under investigation, a first approximation of the form $Q = .71\,(\omega_0/\mu^1)^{1/2}\, r-.56$ can be used. The experiments on air in brass resonators gave results for viscosity which are too high and therefore were repeated with the hot wire transducers replaced by condenser microphones, whose properties are better known. Indications are that excess loss amounting to about 15% is involved.

For use in experiments designed for tracking down the excess loss a simpler, although less accurate method of measuring the "Q" of the resonator was adopted. A transient is produced by firing a spark plug in one volume and the response of the resonator is obtained by photographing an oscillogram of the output of a condenser microphone in the other volume. The decrement, and hence the "Q" of the response is obtained by measurement of the oscillogram using a travelling microscope. These transient-response measurements are in essential agreement with the steady-state response measurements.

The theory of alternating flow in a tube was re-examined during the quarter. The general theory, due to Kirchhoff, shows that sound propagation in a tube depends in a complicated way, not capable of explicit expression, on a parameter $z = (\omega/\gamma^1)^{1/2} r$ where ω is the angular frequency, r is the radius of the tube, and γ^1 is a constant of the gas depending on the viscosity, heat conductivity, ratio of specific heats, and density. For large values of z Kirchhoff was able to find the form of γ^1 and obtain a solution which many investigators have verified experimentally within 15% and one (Lawley, 1952) within 5%. For these large values of z the Q is too great to permit accurate measurement by the resonance technique and in any case the losses depend as much on heat conductivity as on viscosity.

The equations for intermediate values of z have been hitherto intractable unless the effect of heat conductivity is ignored, in which case there is a solution due to Crandall (1926) adapted to computation by us during the preceeding quarter. The assumption that the heat conductivity has a negligible effect was regarded as plausible on physical grounds and the resonators were designed around values of z which give suitable values of Q. During the quarter an approximation was developed which allows the Kirchhoff equations to be solved with good accuracy for all except very small values of z.

In the limiting case of small values of z Rayleigh showed that the propagation of sound in the tube becomes diffusive in nature and independent of heat conductivity, and that the velocity distribution across the cross section becomes that of Poiseuille. These conditions correspond to small tube diameters and low frequencies, that is they approach static conditions for which the theory for low z is accurate. During the quarter a study was made of the possibility of doing experimental work in this range. The principle involved is the reduction of phase velocity by high damping. The measurement of pressure difference and flow velocity in the static method is replaced by that of phase difference between the particle velocities between the ends of the capillary in the present method. In principle this measurement can be made to high accuracy. The result (for viscosity) depends on a knowledge of the density and gas constant of the sample, and on the first power (rather than the fourth, as in the static method) of the radius of the capillary.

Progress: The theory was elaborated and instruments were designed and built to measure the phase shift across a tube about 0.5 mm in diameter and 85 cm long at 10 c/s. Under these conditions the phase shift is about 29° for air if the tube is short-circuited at each end. The tube was terminated at each end by a relatively large volume either of which can be driven by a loudspeaker. A hot-wire microphone of diameter 2.5 microns was used as a transducer at each end of the capillary.

Another technique involves the measurement of the phase difference between the input impedance of the capillary open at the far end and that for the closed condition (about 53° for air). In both cases preliminary measurements give the viscosity of air at room conditions within about 4%.

The phase shifts were measured using a phase shifter constructed from a resolver with an oscilloscope as a null detector.

Future Activity: More precise methods of measuring phase shift will be tried. Precision-bore tubing of smaller diameter will be procured and the frequency increased somewhat. Gases other than air will be measured.

Microwave Hygrometer - NBS Project 0502-30-3540, Mechanical Instruments Section, W. G. Brombacher

General Objective: To investigate the possibilities of using the microwave refractometer as a humidity standard.

Specific Objectives: To redesign the microwave refractometer of Birnbaum and to develop associated electronic equipment so that the instrument may be used to continuously record the water vapor content of air with high accuracy, low time lag and over a wide ambient temperature range.

Background: Birnbaum of the Central Radio Propagation Laboratory (NBS) developed a recording microwave refractometer (Rev. Sci. Inst. 21, 169, 1950) of high sensitivity that can continuously sample and record the dielectric constant of a stream of air or gas. Since the dielectric constant varies with the water-vapor content, this instrument is inherently capable of being used as a recording hygrometer. The refractometer operates by comparing two identical cavity resonators. Into one of these cavities, the test sample is introduced. The resulting differences in resonance frequency between the reference and test cavities is then a measure of the dielectric constant of the test sample. The basic virtues of this refractometer for use in measuring humidity are its high sensitivity, high speed of response and capacity for high accuracy. In view of these considerations, it appears feasible to adapt the microwave refractometer into a standard hygrometer for use over a wide moisture and ambient temperature range.

The relation between the index of refraction and the dielectric constant of air is given by

$$\varepsilon = n^2$$

where n = index of refraction

ε = dielectric constant

and the relation between index of refraction and moisture content of air is given by the empirical equation (Radiation Lab. Report No. 551, dated April 6, 1945)

$$(n-1)10^6 = \frac{79}{T} P + \frac{4800e}{T}$$

where T = absolute temperature, °K

P = barometric pressure in millibars

e = partial pressure of the water vapor in the air

The refractometer determines index of refraction, n, which, when inserted into the above formula with values of absolute temperature and barometric pressure, yields the water vapor content in terms of its vapor pressure. If $N = (n-1)10^6$, then over a temperature range of +50° to -40°, the number of N units of saturated air is as follows:

t, °C	50	40	30	20	10	0	-10	-20	-30	-40
N units	437	277	172	102	58	30	15	6.1	2.37	.79

Summary of Project Activity: A critical review was made of the factors affecting the performance of the refractometer when utilized as a humidity measuring device. In addition, a microwave refractometer was borrowed from the CRPL for laboratory study. As a result of this, it was concluded that a refractometer could be constructed with a sensitivity of 0.05 N units, but that in order to fully realize the potentialities of this sensitivity certain modifications and new features would have to be incorporated into the basic design. Some of these are as follows:

1) To operate the refractometer as a null-balancing instrument. A servo system is required to drive a plunger into one of the test cavities so as to bring it back to the resonant frequency of the reference cavity. This type of operation will aid in reducing instrument dependence on klystron noise and frequency drift and possibly lead to greater sensitivity.

2) To use two cavities, both operating at the same barometric pressure, one containing dry air (the reference cavity) and the other the test sample. Operating both cavities at the same barometric pressure serves to cancel out this term from the equation and eliminates the necessity of making a precision pressure measurement.

3) To maintain the klystron, cavities and gas to be measured at some fixed temperature. Fixed temperature operation will help in reducing the noise level and permit ready control and precision measurement of the temperature. Maintaining both cavities at the same fixed temperature will eliminate the need for making the cavities from invar. Frequency drift of the klystron due to temperature fluctuations, will be reduced.

4) To develop pulsing circuitry for operating at the peak of the resonance curve of the cavities. Again, this is desirable so as to reduce noise level. With the temperature fixed the number of N units is proportional to the water vapor pressure.

5) To provide means for checking instrument drift at frequent intervals. It is proposed to incorporate means for introducing either dry air or the moist air sample into both cavities.

An initial model of a servo-system for balancing the two cavities by operating plunger was completed and tested. Satisfactory performance was obtained although some improvements appear desirable to obtain optimum performance. A preliminary model of a temperature controller for maintaining and controlling the temperature of the gas sample, cavities and klystron was completed. This unit is based on a modulated pulse width type heat input that is proportional to the departure from the control temperature. Preliminary experiments on a water bath operating at +40°C indicated that the controller was able to maintain a fixed temperature to better than 0.03°C for several hours duration. Design of other circuitry was started.

Several modifications have been made on the temperature controller in order to improve its performance. The basic principle has been retained. On subsequent tests the controller was able to maintain the temperature of a varsol bath at +40°C ± .01°C for a period of 24 hours.

Progress: A new method is being developed for measuring the frequency difference between the cavities which eliminates the need for frequency modulating the klystron and the development of suitable amplifiers and pulsing circuits as originally used in Birnbaum's instrument. This proposed system reduces the complexities of the development, construction, and maintenance of the equipment.

The method consists of using a carrier wave signal from the klystron whose frequency is set at approximately the half power point of the cavities. The difference in d-c output of the crystals will be zero if the cavities are at the same frequency. If the resonant frequency of the measuring cavity changes, the output voltage will be either positive or negative, depending on the resonant frequency shift, and will have a magnitude approximately proportional to this shift. This d-c output is applied directly to a Brown converter-amplifier unit which drives a servo-motor. The servo-motor drives the cavity micrometer plunger in such a direction as to rebalance the frequency shift.

Preliminary experiments have indicated that this method is quite feasible and that the sensitivity of the Brown converter amplifier is sufficient to rebalance the system to within several hundred cycles (approximately 0.02 N units).

Future Activity: One of the factors to be determined is the noise and stability of the crystal rectifiers in the d-c range.

A preliminary model in which the microwave equipment will be maintained at a fixed temperature is being constructed so that further tests may be carried out to determine stability, sensitivity, and noise level of the overall system.

Survey of Dynamic Pressure Instrumentation - NBS Project 0602-50-3555, Mechanical Instruments Section, W. G. Brombacher

General Objective: To make available in the form of a critical survey, comprehensive information on the current status of development of instruments for measuring dynamic fluid pressures, including an evaluation of their theoretical and practical limitations, useful in the planning and conduct of research and development on such devices and useful for provision of general guidance in instrumentation problems concerned with measurement of dynamic fluid pressures.

Background: A critical, comprehensive survey on instrumentation for measuring dynamic fluid pressures would be useful - a) in planning research and development on such instrumentation and b) as a guide to the selection of the most suitable type of instrument for particular applications. Recent and fast growing needs, particularly in aeronautic and ordnance research, for making dynamic fluid pressure measurements and relative inaccessibility and non-critical nature of much of the technical information now available indicates that a survey is a practical necessity both for those interested in application and in development.

Progress: A bibliography of about 250 books, articles, and reports of various government research laboratories, covering a period from 1920 to the present has been assembled. This will be enlarged from time to time. In addition, about 45 manufacturers in the U. S. and Great Britain, listed as manufacturers of dynamic pressure gages, were contacted, of whom 28 supplied catalogs describing their products.

Twenty-six of the articles in the bibliography have been reviewed and summaries prepared. These include information on the basic pressure-pickup; the transducer, if any; the pressure and frequency range; the sensitivity; and performance data, where available. A broad outline has been prepared to guide the investigation of the literature.

Future Activity: The present bibliography is to be extended and individual articles reviewed and summarized. The manufacturers' literature will be reviewed and some attempt made to evaluate the accuracy where performance data are available. The survey will be prepared from the above data.

Vacuum Tube Accelerometer - NBS Project 0604-30-3557, Engineering Mechanics Section, S. Levy, J. B. Woodson

General Objective: To design and construct improved models of the Ramberg Vacuum Tube Accelerometer.

Specific Objectives: To develop models of the Vacuum Tube Accelerometer covering a series of acceleration and natural frequency ranges; to utilize high-strength steels in the plate support rods so as to give increased performance; to improve the overload stops; and to develop a mechanical damper.

Background: The Vacuum Tube Accelerometer invented by Dr. Ramberg of the National Bureau of Standards is essentially a double diode with elastically supported plates on either side of the common cathode. Acceleration of the base in the sensitive direction causes a relative displacement between the elastically supported plates and the fixed cathode. The two diode plate-to-cathode resistances have been reduced so that the relative change in resistance per unit deflection of the plate is quite large. For example, the 10g capacity tube having an undamped natural frequency of 160 cycles per second, when connected into the customary Wheatstone bridge, gives an output of the order of 3 milliamperes for an acceleration of 1g.

Summary of Project Activity: Improved tubes of other acceleration ranges have been designed and are being manufactured by Sylvania Electric Products, Inc. The new tubes have high-speed steel plate-support rods, improved stops which will limit the plate motion, and a stiffened structure attaching the plates to the base. An improved manufacturing technique using brazing instead of spot welding has been perfected which permits more accurate adjustment of the plate to cathode spacing. Two 10 g tubes, six 100 g tubes, and one 500 g tube have been submitted by Sylvania and have been tested to determine the effectiveness of the improvements. A specially designed Kelvin double bridge was used for testing these tubes, in order to minimize the effect of changes of contact resistance in the tube socket. The 10 g and 100 g tubes were generally satisfactory, while the 500 g tube was unsatisfactory because of having too limited a range of linear operation.

A part of the work during the past year has been toward the development of a mechanical damper to reduce the natural frequency response of the tube. Although electrical filters have been successfully used to suppress the natural-frequency output, many advantages would be gained by the use of a mechanical filter. The theoretical work on the design of a mechanical damper indicated that a damper having the desired characteristics is possible. Response and optimum values of the parameters which control the characteristics were computed using SEAC. The mechanical damper designed in accordance with these calculations has been completed and tests to determine its effectiveness have been made. To date the behavior of the damper has not been entirely satisfactory.

Progress: The paper entitled "Damping of Elastically Supported Element in a Vaccum Tube" was presented by Samuel Levy at the Eighth International Congress of Theoretical and Applied Mechanics, and has been printed as NBS Report No. 1707. This report shows the method of obtaining the optimum values of the damper parameters. It also presents experimental evidence of the damper's effectiveness in the case of a suddenly applied acceleration.

The following measurements were made on one 500 g accelerometer; response to static acceleration, zero drift, zero shift following high acceleration, natural frequency, and response to side acceleration. The range of linear response was not satisfactory for this tube.

Reduction of the data obtained previously on two 10 g and five 100 g accelerometers was completed, and a report presenting the results was prepared in rough draft. The performance of these tubes was generally satisfactory.

Sylvania Electric Products, Inc., reported that a good method of centering the overload stops during assembly has been worked out by the use of an improved type of jig. They also reported some progress toward developing a method for better control of plate to cathode spacing.

In view of the fact that the first 500 g tube received at NBS had too low a range of linear operation, Sylvania has increased the stop hole diameters of these tubes from .010" to .014". They also reported making 100 g tube plate assemblies with a better controlled siderod to crossbar joint, achieved by plating only the extreme ends of the side rods, in order to bring about more nearly equal natural frequencies for the two plates. A final shipment of twenty-eight accelerometer tubes completing delivery of tubes on order from Sylvania Electric Products, Inc., was received. Not all of these tubes were operable. A Kelvin double bridge was constructed and used in testing the vacuum-tube accelerometers, to render the accelerometer output insensitive to contact resistance changes in the tube socket.

Future Activity: The testing of the accelerometer tubes will be completed and the results will be included in the report, now in preparation.

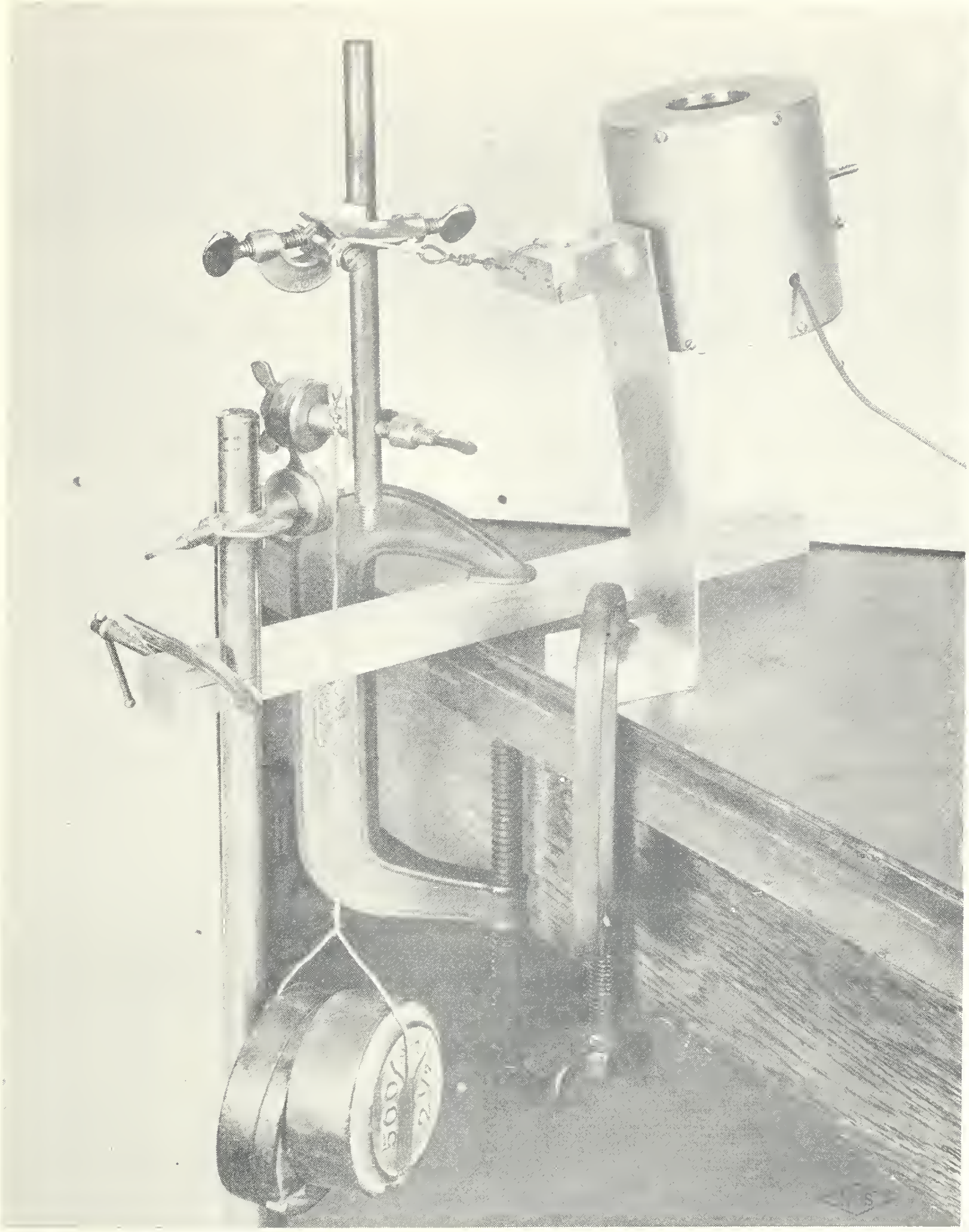

FIGURE 1 ACCELEROMETER TUBE AND DAMPER (BOTH ENCLOSED IN CASING) MOUNTED ON CANTILEVER BEAM PRIOR TO RELEASE. (A SUDDEN ACCELERATION WAS APPLIED TO THE TUBE IN THIS MANNER, WITH AND WITHOUT THE DAMPER ACTING, TO EVALUATE THE EFFECTIVENESS OF THE DAMPER.)

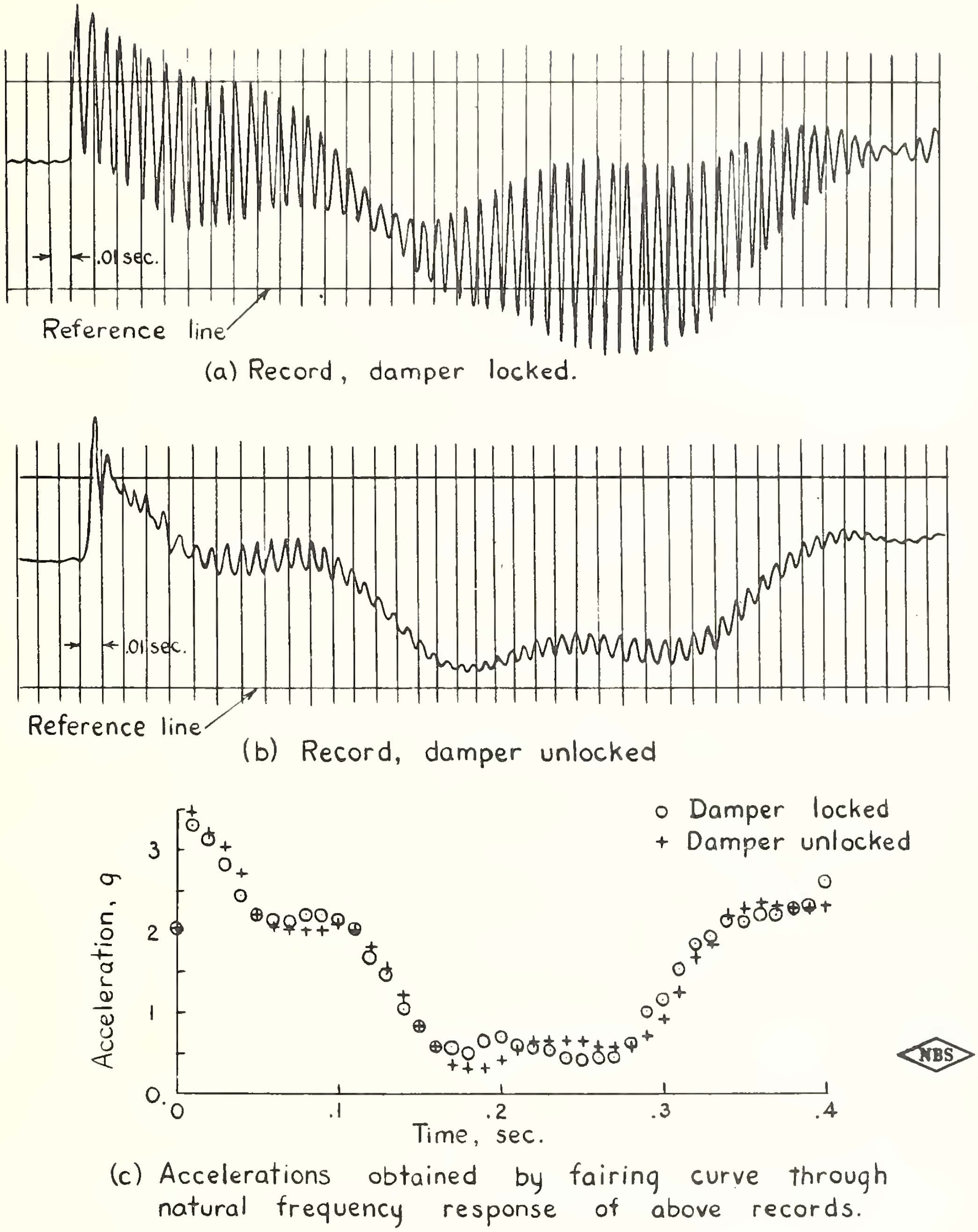

FIGURE 2 RESPONSE OF VACUUM-TUBE ACCELEROMETER TO A SUDDEN ACCELERATION, WITH AND WITHOUT THE DAMPER ACTING. (IT IS SEEN FROM (c) THAT THE APPLIED ACCELERATION HAD APPROXIMATELY THE SAME TIME HISTORY IN EACH CASE.)

Survey of Strain Recorders - NBS Project 0604-30-3558, Engineering Mechanics Section, D. R. Tate, R. R. Bouche

General Objective: To survey and test equipment currently available for producing autographic stress-strain records of tensile test specimens.

Specific Objectives:

1. To write to manufacturers of recording equipment and testing machines requesting information to ascertain: (a) whether or not they manufacture equipment capable of attachment to a standard testing machine to record stress and strain simultaneously and, (b) what the operating principles, accuracy, and special features of such equipment are.

2. To conduct tests on some of the basic stress-strain recording instruments most commonly used in materials testing laboratories for tensile testing. These tests will evaluate the accuracy of the devices under calibration and will also exemplify diagrams obtainable under service conditions.

3. To compile a report giving a brief history of the development of stress-strain recording, a summary of the survey of manufacturers, a listing of the equipment available for stress-strain recording and the results of actual tests of some of the most commonly used equipment.

Background: The use of recorders for drawing autographic stress-strain curves for tension specimens of metals and other structural materials has become a standard practice in most materials testing laboratories for acceptance as well as comparison tests. Recorders for this purpose are supplied by manufacturers of testing equipment in a variety of forms. There is, however, little in the open literature other than advertising folders to guide the user in the selection of equipment. There is even less information regarding the accuracy of recorders and strain gages. Recorders of two different makes were obtained during fiscal year 1952 for the tests.

Progress: Plans were laid during the period for conducting the survey. A systematic review was made of the files of the Engineering Mechanics Section extending back over the past twenty years and conferences were held with members of the Section whose experience in testing dates back over approximately the same period. A complete review of the Proceedings at the American Society for Testing Materials was conducted and summarized.

Letters were written to thirty-five manufacturers of recording instruments and testing equipment in an effort to obtain descriptive literature on stress-strain recorders. The many replies received were processed and that material was selected which was pertinent to the project. Principles of operation, etc. were discussed with representatives of the leading manufacturers of stress-strain recorders used for metals testing.

A systematic search of the literature was launched by making use of the facilities of the Library of Congress and the NBS Library. Plans for conducting tests on the most common stress-strain recorders used in metals testing were initiated.

Future Activity: The extensive review of the literature will be concluded with a careful coverage of the abstracting services relating to materials testing. A better sampling of the foreign made recorders will be attempted by writing letters to some of the foreign manufacturers of testing equipment. Performance tests are expected to be made on representative stress-strain recorders. The project will be concluded by a report on the survey of stress-strain recorders.

Resistance Strain Gages - NBS Project 0604-30-3559, Engineering Mechanics Section, W. R. Campbell

General Objective: To determine fundamental performance characteristics of two new types of resistance strain gages, namely, the temperature compensated gage and the post yield gage.

Specific Objectives:

1. Completion of report on the study of SR-4 and G-H post yield resistance strain gages. Laboratory work on this phase of the project has been completed.

2. Development of a test procedure for calibrating resistance strain gages at temperatures up to 300°F. Tests will be made on SR-4 gages temperature compensated for aluminum alloy and on gages compensated for mild steel. Linearity of gage output with strain will be determined for several temperatures in the range 75° to 300°F. Calibrations will also be made under varying temperatures to determine the effectiveness of gage compensation. Temperature sensitivity of representative gages will be studied to determine the degree of uniformity between gages. A report will be prepared.

Background: The application of the resistance strain gage to the measurement of large plastic strains, such as those produced in structures in underwater explosion studies, and its application to the measurement of strains in rockets and missiles which are subjected to rapid changes in temperature has fostered the development of post yield and temperature compensated gages for such measurements.

Post yield strain gages are bonded resistance wire strain gages intended for measurement of strains in the plastic region. Ordinary bonded resistance wire gages are suitable for strains up to two or three percent but by the use of special base papers, plasticized bonding media and dual lead gage construction these special gages will function at strains up to fifteen or twenty percent. Gages of this type have been marketed in the United States by the Baldwin-Lima-Hamilton Corporation (SR-4 type PA-3) and in Sweden by the Gustafsson-Huggenberger interests (G-H gages).

Temperature compensated gages developed by the Baldwin-Lima-Hamilton Corporation are of considerable interest at this time as a single compensated gage can discriminate between the expansion of a structure caused by a temperature rise and actual strains in the structure caused by stresses. In the field tests of high speed aircraft or rocket missiles where telemetering methods must be used these gages are a valuable addition to existing equipment.

The investigation of bonded wire strain gages requires special techniques. Unlike mechanical and optical strain which may be calibrated by attaching one gage point to the frame of a comparator and the other to a movable bit, these bonded resistance wire strain gages must be calibrated by mounting them on a test specimen, straining it, and measuring the strain with a specially designed, calibrated, mechanical strain gage.

During fiscal year 1952 G-H type A820S post yield resistance strain gages were obtained from the Aeronautical Research Institute of Sweden and a supply of SR-4 type PA-3 gages was obtained from the Baldwin-Lima-Hamilton Corporation. A special lever transfer was designed for use with a Tuckerman optical strain gage to measure calibrating strains up to 14 percent. This device after calibration on an interferometer comparator was used as an intermediary standard to measure the actual strains in test bars to which the resistance strain gages were attached. Laboratory tests were completed on the post yield gages and the preparation of a report was started.

Summary of Project Activity: A procedure for calibrating post yield resistance strain gages was developed, and tensile calibrations of SR-4 and G-H gages were completed. It was found that the error in strains indicated by the SR-4 type PA-3 gages did not exceed 4 percent of the applied strain for strains up to 0.14. Similar results were obtained with G-H type A820S gages except that numerous gage failures were encountered at strains in the range 0.06 to 0.12. A report describing this work was begun.

In preparation for tests of wire strain gages at elevated temperatures, calibrations of two special Tuckerman strain gages were carried out at room temperature and also at approximately 370°F. The results indicated that the calibration of the gages at high temperature is probably not affected by any factors other than the expansion of the stellite lozenge. This effect is compensated in part by expansion of the gage body.

A transite oven was designed and constructed for use in maintaining calibration bars at temperatures ranging from room temperature to 300°F. Nichrome wire was used in the heating elements and a Vycor glass window was provided to facilitate reading Tuckerman strain gages.

Progress: Laboratory tests were completed on gages compensated for aluminum alloy. Stress-free gages bonded to aluminum plates were subjected to temperatures ranging from 25° to 275°F. Changes in gage resistance, which represented apparent strains, were recorded for each of ten gages during the temperature cycle. Results indicated a high degree of uniformity between different gages, and apparent strains due to lack of perfect temperature compensation did not exceed 60×10^{-6}. Calibration curves of resistance change vs. strain were determined for five gages at temperatures ranging from 125° to 250°F. Results of these tests showed that calibration factors for the gages tested were in excellent agreement with values given by the manufacturer, and non-linearities in gage output were less than 2 percent. The performance of these gages compared favorably with cellulose bonded gages which are usually used only at room temperature.

Work has continued on preparation of the report on the post-yield gages.

Future Activity: It is expected that laboratory tests will be completed. Tests are to be conducted on gages compensated for mild steel, and a report describing the test and results on temperature compensated gages is to be prepared.

The report on the post-yield gages will be completed.

Application of Feedback Around Image Scanning Systems - NBS Project 1204-21-5552, Electronic Instrumentation Section, H. M. Joseph

General Objective: To investigate the application of two-dimensional, linear and non-linear feedback in optical-electronic systems.

Specific Objectives:

1. To assemble an optical-electronic apparatus useful for studying the possible application of feedback around such a system.

(a) Build equipment incorporating feedback around a flying-spot scanning system similar to the one described in "Background".

(b) Build a constant-velocity scanning generator to obtain a signal that can readily be modified.

2. Study the results obtainable with the system and determine the techniques for applying the method:

(a) Operate upon the signal by incorporating differentiating and other networks in the feedback path and/or between the system and the "slave" oscilloscope, and study the image outlining and other effects that will occur.

(b) Explore the techniques necessary for using the system as an analogue computer for partial differential equations.

(c) Manipulative techniques for determining the characteristics of patterns that may lead to methods of recognizing distorted images.

Background: This project was suggested by Dr. L. S. G. Kovasznay, of Johns Hopkins University, who is now a part-time consultant on this project. He formulated the basic method of this project when considering a theory of the manner in which the human mind handles visual information. The following paragraphs are taken from his explanation of the development of the project.

A two-dimensional pattern can be handled by established techniques currently used in television. A known way of converting a stationary two-dimensional picture into an electrical signal makes use of a flying-spot scanner. This consists of a cathode-ray tube, a lens, a picture transparency, a light-collecting condenser, and a phototube, as shown in Figure 1, without feedback. The luminous spot scans an area on the face of the cathode ray tube. This in turn is focused on the transparency. The light transmitted through the transparency is collected by a condenser lens, and the light intensity variations are converted into an electrical signal by the phototube.

A basic modification of the usual flying-spot scanner is the introduction of feedback by applying the phototube signal to the intensity grid of the flying-spot cathode-ray tube.

If the feedback is strong, and is of a polarity that reduces the spot intensity, the system tends to minimize the signal output of the phototube, and therefore tends to produce a constant light intensity reaching the phototube through each point on the transparency. The result is that, for each light or transparent portion of the transparency, the face of the cathode-ray tube is darkened and vice-versa. The picture reproduced on the cathode-ray tube is therefore a negative, and because of the improvement due to negative feedback, the contrast range is the same as that of the original.

The finite response times of the various elements in the feedback loop are suppressed by this negative feedback, especially the delay time of the phosphor, and the phototube amplifier.

The pattern can be viewed on a second cathode-ray tube run as a "slave", with or without modifying networks inserted in the circuit between the two systems.

The mathematical equation governing such a system depends both on the circuits and on the method of scanning that convert the two spatial co-ordinates into a single time variable. In conventional television the two co-ordinate (horizontal and vertical) scanning velocities are very different and effectively unidirectional.

Mathematical functions in two dimensions can be studied by representing them on a transparency as an opaque wash so that the transparency at a given point represents the value of the function at that point. If a scanning method is used that is symmetrical with respect to horizontal and vertical axes and the forward velocity has the same magnitude as the return velocity (these conditions are met by triangular waves) the governing equations can be transcribed in the form of a partial differential equation. The boundary conditions can be introduced by superimposing an appropriate mask upon the original picture or pattern.

Another possibility of the feedback scanner is the study of patterns modified by such operations as differentiation, integration, LaPlace operator, square detectors or others, with a view to reducing the original pattern into some standard recognizable form.

Eventually this sort of approach may furnish a method for the exploration of the whole problem of pattern recognition by automatic means.

Dr. Kovasznay set up a system employing the sweep circuits and cathode-ray tube of a Dumont 304-H oscilloscope to furnish the sweeps and the flying spot. He utilized negative feedback with encouraging results. A diagram of that system is shown in Figure 1.

He used conventional sawtooth sweeps in the system he set up, but as mentioned above, a scan reversible in time, such as a triangular wave, was needed to produce a signal that can be more readily modified by electrical networks. The scan can be produced by impressing a triangular wave on the horizontal deflection plates of a cathode-ray tube and another triangular wave differing slightly in frequency applied to the vertical deflection plates. The scanning pattern produced is a lissajous figure composed of rectangles instead of the usual ellipses for sine waves. The pattern for a frequency ratio of 3 to 4 is shown in Figure 2. In practice, a frequency ratio of 256 to 257 would be suitable. Such a scan should produce a definition twice as good as high grade conventional television practice.

To sum up, the negative feedback is required to produce a video signal that is accurately proportional to the variations of light intensity in the picture. The special scan is required to produce a variety of signal that can be readily operated upon by simple computing networks.

A word on the applications: Important practical results may be derived from the recognition of patterns such as matching of fingerprints, automatic reading of printed or written matter, or possible weather prediction from synoptic maps. Significant contributions to fundamental research may result from solutions of non-linear partial differential equations. The equations in general cannot be solved by mathematicians at this time. A property of such equations is that integrals may contain discontinuities or "catastrophic" solutions, which either must be guessed, found experimentally, or as a result of practical experience, as for example, in the flow fields around air foils near sonic velocities.

Summary of Project Activity: Prior to the beginning of this quarter, it was decided that the first task would be the construction of a scanning generator for accomplishing Specific Objective 1 (b).

The purpose of this generator was to furnish suitable deflection voltage waves for the horizontal and vertical plates of the oscilloscope. Two waves were required, having frequencies of the order of 5000 cps, differing in frequency by about 10 cps. It was permissible for the frequencies to vary slightly but essential that their ratio remain constant at a value $\frac{M}{M+1}$ where M is an integer. This requirement followed from the necessity for a stable pattern, so that the output signal would be suitable for computing purposes, and so that the illumination of the pattern would be uniform.

Discussing the above in greater detail, to attain stability the elapsed time between successive patterns should equal an integral number M of wave periods of one frequency, and M + 1 wave periods of the other frequency. That is:

$$\frac{M}{f_1} = \frac{M+1}{f_2} \qquad (1)$$

Therefore

$$\frac{f_1}{f_2} = \frac{M}{M+1} \qquad (2)$$

and

$$f_2 - f_1 = \frac{f_1}{M} \qquad (3)$$

or

$$f_2 = f_1 + \frac{f_1}{M} \qquad (4)$$

The elapsed time between successive repetitions of pattern is $\frac{M}{f_1}$ so that the frequency of repetition of pattern is f_1/M. That is:

$$F = \frac{f_1}{M} \qquad (5)$$

$$= f_2 - f_1 \text{ by equation (3)} \qquad (6)$$

For initial experiments, value of $F \approx 10$ and $M \approx 250$ were selected as suitable. The corresponding frequencies would be $f_1 \approx 2500$ and $f_2 \approx 2510$.

The simplest source of a frequency f_2 having a proper relation to f_1 appeared to be a generator using subdivision:

M = An integer (see above) corresponding to 1/2 the number of discrete lines in the pattern.
f_1 = Lower of the two deflection frequencies
f_2 = Higher of the two deflection frequencies
F = "frame rate" (repetitions of the patterns each second)

Then if a mechanism were provided which would divide a frequency f_1 by an integer M and add the result to f_1, the sum would be a frequency f_2 conforming to equation 4.

Obviously with this method f_2 would hold a constant ratio to f_1 regardless of gradual variations in f_1.

This general method was first tried with a multivibrator chain which turned out to be insufficiently stable. A chain of binary dividers were then constructed which performed the division quite accurately with no noticeable jitter.

In addition (see Figure 3) a trigger circuit driven by an audio oscillator was added to convert the oscillator sine wave to a pulse train in order to furnish a suitable input to the chain. A filter was provided at the binary chain output to change the (divided) low-frequency square wave to a sine wave. This sine wave was applied to a synchronous motor which drives a sine-cosine resolver. The resolver has the property of adding its rotation frequency, F, to its input frequency f_1, resulting in an output frequency f_2. The sine-wave voltage at frequency f_2, is applied to an electronic switch and integrator which produces a triangular wave that is applied to the vertical deflection plates of a cathode-ray oscilloscope scanner. Similarly f_1 is converted to a triangular wave and applied to the horizontal deflection plates of the oscilloscope.

The electro-optical system was set up according to the block diagram of Figure 1, using the constant-velocity scan circuits. These circuits drive the amplifiers of a commercial Dumont 248-A oscilloscope. The amplified voltages are applied (within the oscilloscope) to a high-intensity 5RP-11A cathode-ray tube which is used as the feedback modulated light source. The expected negative picture appeared on the face of the cathode-ray tube.

In order to permit observation of the resulting picture without disturbing the optical system, a "slave" scope was added by paralleling the elements of another identical type cathode-ray tube across those of the original tube. For convenience in viewing, a long-persistence phosphor was used for the second tube.

The results obtained with and without feedback for a constant velocity scan are typified by the photographs, Figure 4. The results without feedback show the performance of the system as a flying-spot scanner. The increased range of contrast with feedback is evident. As expected, the video gain control adjustment in the feedback loop is not critical when feedback is used. The same control without feedback has to be carefully adjusted for optimum results.

Progress: The work was continued on the second specific objective of studying the result obtainable by operating upon the video signal with various networks, particularly differentiating types to study outlining effects.

Figure 5 indicates the effect of differentiating the signal resulting from scanning a portion of a picture that produces a signal shown as a solid line in Figure 5(a).

The dotted line indicates the closer approach to an abrupt rise and fall that may be achieved by subtracting the doubly differentiated signal in Figure 5(c) from the original signal (with suitable amplitudes).

In this manner an effect similar to the brightness contrast visual illusion described by Byram* which the reader may see in Figure 6 is produced artificially. (The steps look as if each varies across the step. The uniformity of each step may be checked by looking at each step after concealing the adjacent ones). A similar accentuation or Eberhard effect is described in **Hardy and Perrin's book.

In order to show how this effect is produced, it was necessary to prove that differentiating the video signal in time will produce space derivatives when reproduced as a picture. The mathematical analysis showed that a doubly (time) differentiated signal is proportional to the space gradient of the picture density. Further analysis showed that a picture detail slightly degraded by reason of the finite scanning spot size can be restored by adding the appropriate amount and polarity of those signals to the direct signal as indicated in Figure 5.

Photographs showing the improvement resulting from adding the negative of a doubly differentiated signal to the direct picture signal are shown in Figure 7. Figure 7 shows some improvement resulting in pictures which were in good focus. Figure 8 shows similar pictures taken with the scanning spot increased in size (and thereby defocused or diffused) a sufficient amount to diminish the differentiated signal by 50%. (The differentiated signal amplitude is quite sensitive to deviations from good focus). Similar improvement is obtained when optical defocussing occurs.

Pictures taken with still greater spot defocussing show that a limit has been reached. This is to be expected since the slopes of a signal from a defocussed system are smaller, and some detail has been lost. The net result of adding the differentiated signal is to increase the apparent depth of focus. Similar effects are produced by doubly differentiating signals resulting from a conventional type television scan. As will be noted in Figure 9 there is enhancement of horizontal boundaries. There is however an improvement in the picture.

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* Journal O.S.A., V 34, 1944, p 730 Physical and Photochemical Basis of Visual Resolving Power, George M. Byram

** A. C. Hardy and F. H. Perrin, Principles of Optics

It will be noted that the density of increment of the fourth or innermost square in Figures 7 and 8 is somewhat less than that obtained in going from transparent region beyond the first boundary to the first square. This is the result of the limitations of the finite amount of feedback available. This effect was analyzed and it was shown that the feedback is most effective for thin transparencies.

The analyses did not account for some complicating factors that occur in practical equipment:

1. The phosphor persistence of the cathode-ray tube light source, a P-11 screen, is approximately 0.35 milliseconds for 70% drop in brightness.

2. The low-frequency response of the feedback amplifier used in the experimental work is insufficient to prevent the average brightness changes which introduce shading.

This effect is most noticeable in the conventional sweep picture, Figure 9. The alternative of using faster sweeps is precluded by the necessity for going slowly to reduce the effects of phosphor delay. It should be noted that this delay is partly reduced by the feedback. However the phase shift associated with the reduced low-frequency response of the present feedback amplifier also prevents the use of more feedback at the low sweep rates.

3. The analysis of feedback effects ignored the fact that the d-c or cutoff level in the scanner and slave oscilloscope can be set independently.

a. The cutoff level in the scanner source if set improperly could produce oscillations since the phosphor delay would produce a signal after the feedback voltage had driven the intensity grid below cutoff, the result would be cumulative, etc. There are of course the usual additional sources of instability in a feedback system.

b. A slave oscilloscope misadjustment of intensity has two effects:

(1) Portions of the picture that are weak in intensity (corresponding to thin portions of the transparency) may be suppressed.

(2) The contrast ratio between the brighter portions of the slave oscilloscope pattern and the darker portion is artificially enhanced.

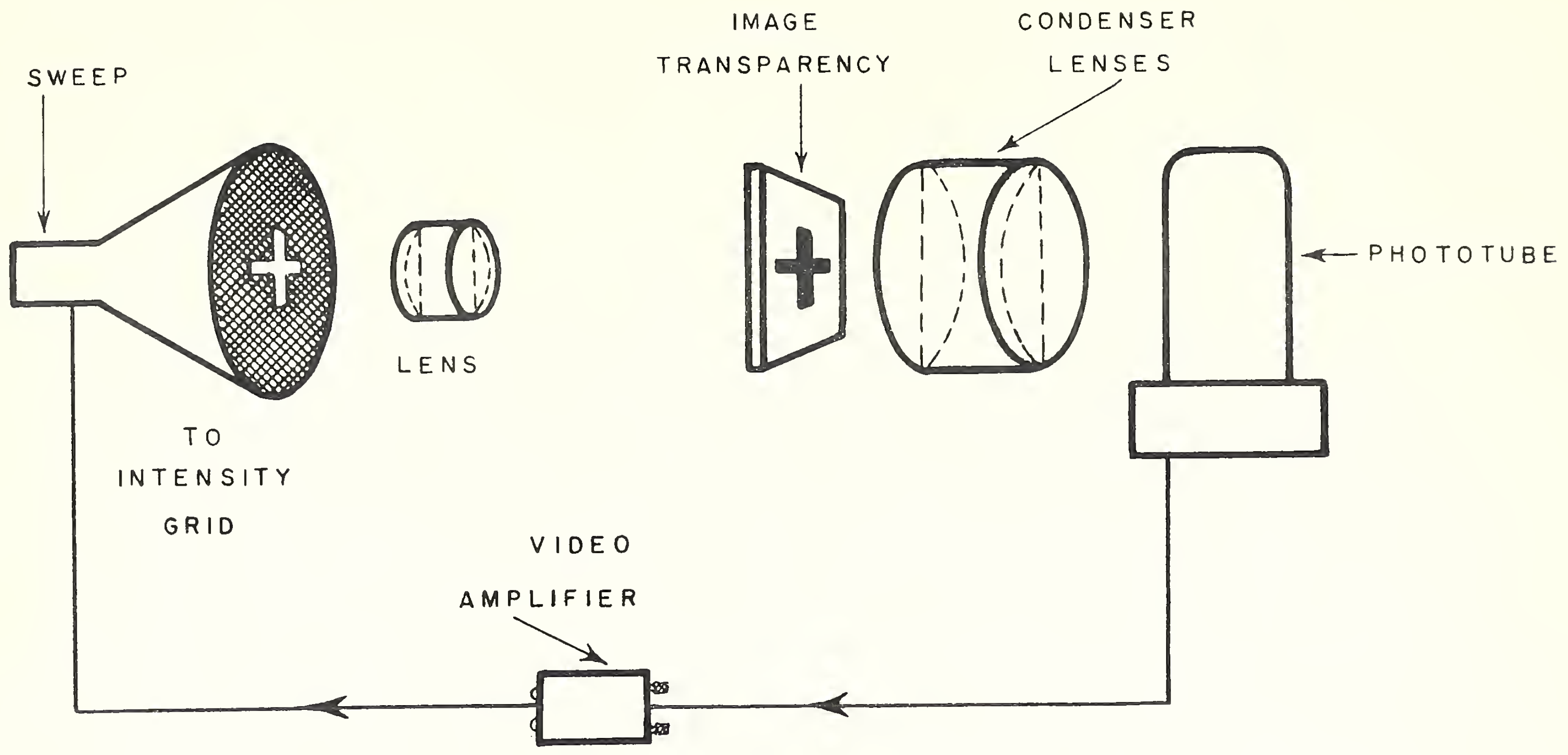
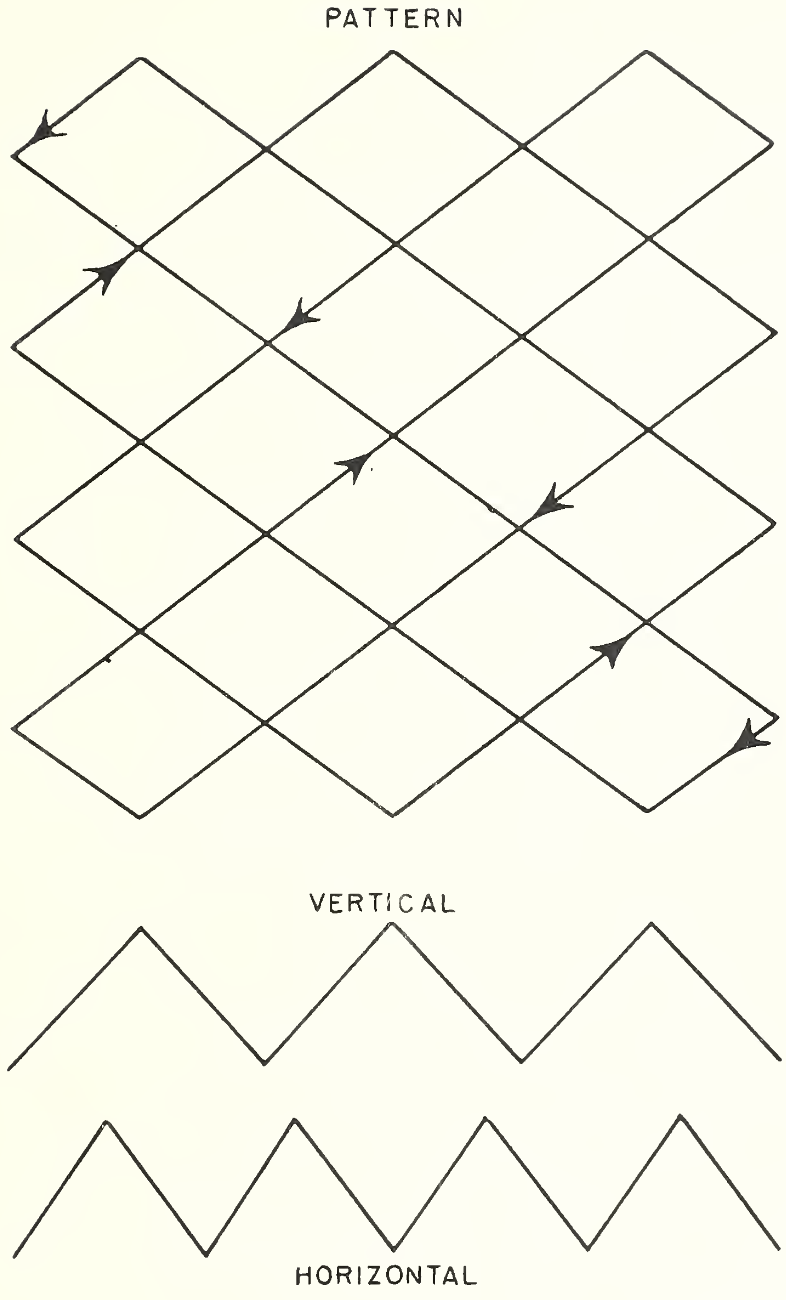


IMAGE FEEDBACK SYSTEM

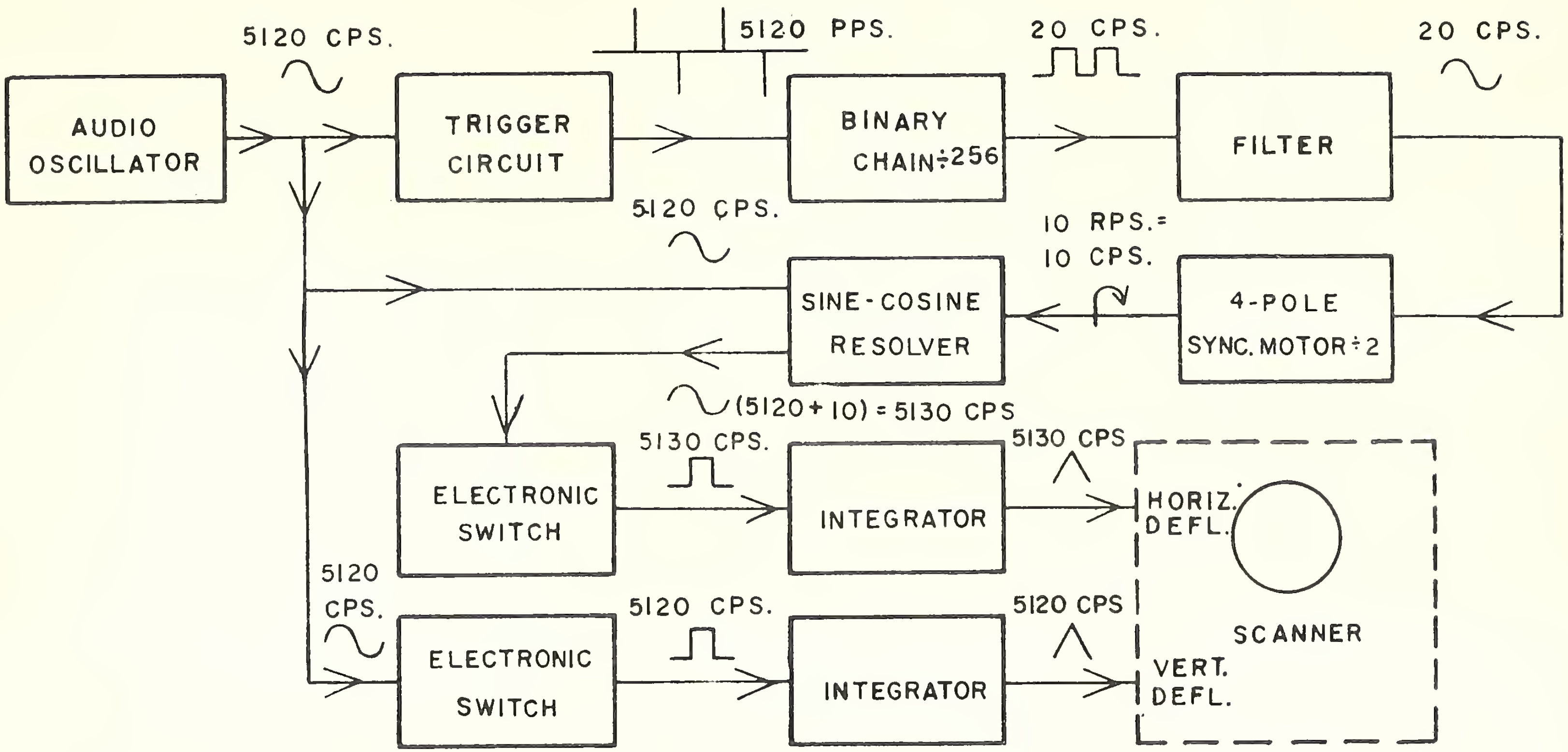
Fig. 1



SCAN: RATIO = 3 TO 4

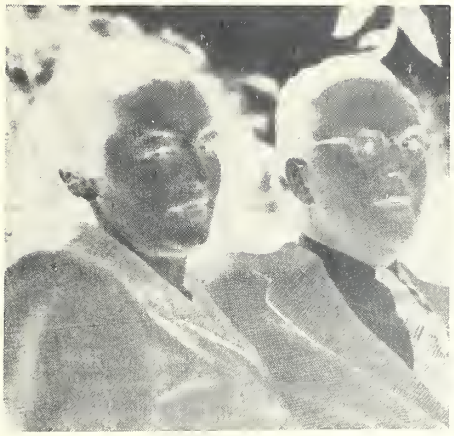
NBS

Fig. 2



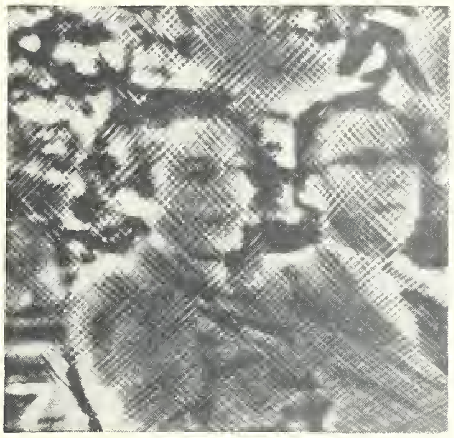
BLOCK DIAGRAM OF SCANNING GENERATOR

Fig. 3

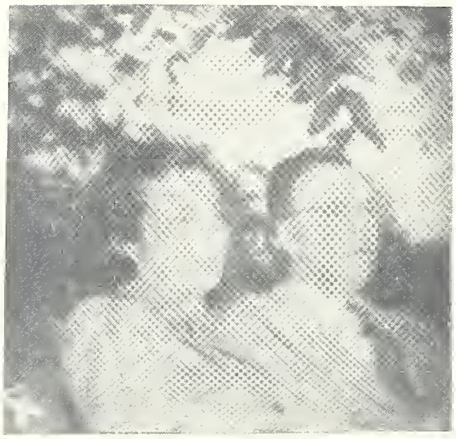


ORIGINAL NEGATIVE

PRINT OF ORIGINAL



SLAVE SCOPE PICTURE
WITHOUT FEEDBACK

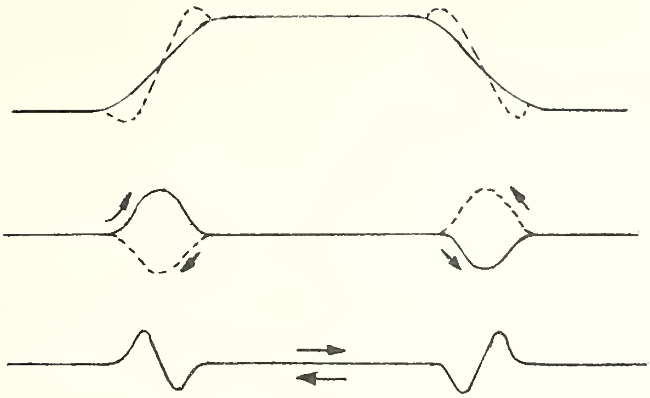


SLAVE SCOPE PICTURE
WITH FEEDBACK

SCANNING TUBE WITH FEEDBACK

NBS

FIG. 4 PICTURES OBTAINED WITH CONSTANT - VELOCITY SCAN



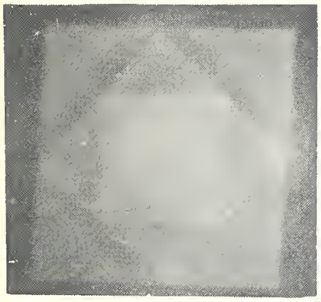
(a) Signal (dotted lines show result of substracting [C]

(b) First differentiation (sign depends upon direction)

(c) Double differentiation (sign independent of direction)

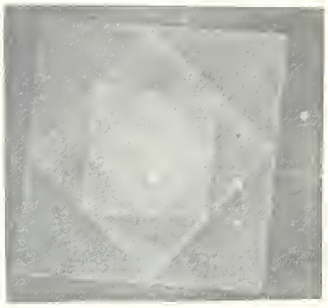
Figure 5 Signal and Its Derivative

Figure 6 Illustration of Brightness-Contrast Effect as Shown on a Step Wedge.



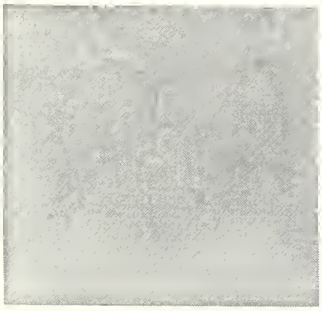
(a) POSITIVE

(b) SECOND DERIVATIVE



(c) COMBINED POSITIVE AND SECOND DERIVATIVE

(d) POSITIVE



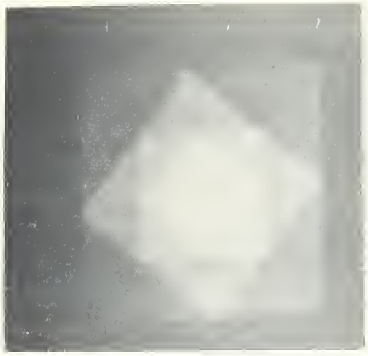
(e) SECOND DERIVATIVE

(f) COMBINED POSITIVE AND SECOND DERIVATIVE

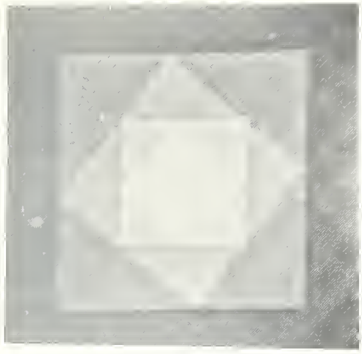
Improvement in figure 7 (a) over figure 4 (d) (slave oscilloscope with feedback) due to improved technique.

Horizontal position interchange between figure 7 and figure 4 is due to change in horizontal plates oscilloscope connections.

FIGURE 7 SLAVE OSCILLOSCOPE PICTURES WITH CONSTANT VELOCITY SCAN



(a) POSITIVE



(b) POSITIVE PLUS SECOND DERIVATIVE

(c) POSITIVE

(d) POSITIVE PLUS SECOND DERIVATIVE

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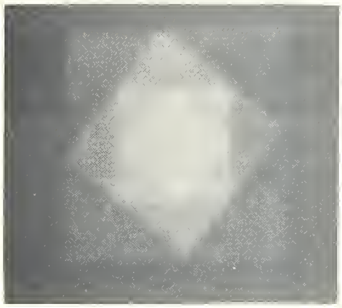
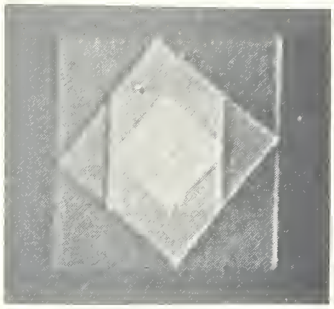
FIGURE 8 SLAVE OSCILLOSCOPE PICTURES WITH CONSTANT VELOCITY SCAN (WITH SCANNING SPOT DEFOCUSSED)



(a) POSITIVE



(b) POSITIVE PLUS SECOND DERIVATIVE

(c) POSITIVE

(d) POSITIVE PLUS SECOND DERIVATIVE

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FIGURE 9 SLAVE OSCILLOSCOPE PICTURES WITH HORIZONTAL (TELEVISION TYPE) SCAN. (VERTICAL DERIVATIVE IS NOT EFFECTIVE)

Future Activity: Some of the problems that will be investigated are:

A. Those of apparatus

1. The specific requirements for scanning methods will be studied in more detail.

2. Different methods of accomplishing the constant velocity scan will be evaluated in view of (1) above.

3. Other methods of picking up the picture signal, particularly using camera tubes, such as the orthicon, vidicon, or image dissector types. (This one may await further investigation of the technique mentioned below).

B. Further investigation of the technique.

1. Continued investigation of the contouring and picture manipulation by circuit modifications discussed in this report.

2. Continuation of the pursuit of the Specific Objectives, particularly the mathematical ones, since those are apparently essential to the recognition function.

As the investigation progresses, more uses for the signal derived from an electro-optical system may appear.

Precision Microwave Interferometer - NBS Project 1409-30-6817, Microwave Standards Section, Edward S. Dayhoff

General Objective: To develop a design for microwave interferometer of great absolute accuracy for measurement of wavelengths and for the measurement of distances in terms of wavelengths of microwave radiation (3 mm region), and suitable for measuring the dielectric properties of materials; to determine the capabilities of such a device in those and other measurement problems.

Specific Objectives: To construct a chain of frequency multipliers which will produce power in the millimeter wavelength region of sufficient strength and purity to be useful for illuminating a high accuracy interferometer.

To construct a microwave interferometer enabling measurements of wavelength in the microwave region to a precision better than 1 part in 10^6.

To perform the necessary theoretical analysis to enable corrections to be made to the readings of the above instrument so that the result will have an absolute accuracy better than 1 part in 10^6 and to evaluate possible different types of instruments to determine what types are best suited to measurements of high accuracy.

Background:

1. Millimeter wavelength work in general: The region of wavelengths between 6 mm and 1 cm is a twilight region where the techniques and instruments quite successful at longer wavelengths become very difficult to apply. Wavemeters, for example, must be made extremely small, and are very delicate to manufacture and not very accurate. The same applies to other items of microwave instrumentation. Even oscillators (reflec klystrons) which are available as signal sources in this region are weak, very unstable, and difficult to operate. The region below 6 mm in wavelength is even more difficult. Wavemeters are quite impractical for measuring wavelengths, standing wave machines and other items requiring complicated machining are almost impossible to make because of their small size and there are no oscillators for signal sources (except some special pulsed magnetrons, hardly useful for laboratory measurements). Some laboratories have used crystal harmonic generators and even harmonics from pulsed magnetrons as power sources but there appears to be still a good deal of room for improvement of these devices. Indeed, recently several laboratories have devoted a fair amount of effort to the problem of discovering or developing some totally new source of energy in this region of the spectrum. Such a totally new source of energy would be widely useful but would not meet the needs of applications requiring a precisely known frequency. It is clear that the situation in the microwave spectrum below 6 mm wavelength is very unsatisfactory so far as instrumentation is concerned.

2. Millimeter Microwave Interferometers: The desirability of an interferometer of some type for wavelength measurements has been recognized for some time. The cavity type wavemeter with its delicate machining could be dispensed with if a laboratory-sized interferometer of suitable accuracy could be developed. Several laboratories have been conducting work along these lines, among which are the Columbia Radiation Laboratory, where a convenient but not accurate laboratory use instrument of the Fabry-Perot type has been developed for the region from about 15 to 6 mm and the National Physical Laboratory where an instrument requiring a monstrous vacant room and giving very high accuracy in the region around 1.3 cm has recently been reported. The Columbia instrument was intended from the beginning to be a general use instrument of moderate accuracy for use to as short a wavelength as possible (1 mm would be desirable) for measuring magnetron wavelengths. Unfortunately its resolution becomes very poor below 6 mm and furthermore it gives an erroneous answer by several percent in this region. It would seem that a study of accuracy in interferometers for this region of the spectrum is at present a pressing need.

Summary of Project Activity: This project was started in April 1952. The first task was the writing of an informal survey which was completed by the end of June 1952.

Progress: Interferometer Design. The chief problems have been proper treatment of diffraction phenomena and of the microwave optics of the illumination system. A suitable method of treating the diffraction phenomena has been decided upon and approximate formulae for design purposes obtained. Experimental checking must wait until more stable equipment is ready. The interferometer contemplated is to follow as closely as possible the design of optical interferometers.

Test Bench Interferometer. A 5-inch aperture radius interferometer was set up for testing purposes using K-band radiation from a reflex klystron oscillator. Unfortunately instabilities of both electrical and mechanical nature prevented it from being used for any but relatively rough measurements. It has, however, been useful for developing techniques of measurement and for setting up suitable auxiliary instrumentation.

Multiplier Chain. In order to obtain highly coherent radiation of high stability for illuminating the interferometer, a chain of frequency multipliers starting at 100 kc and going to K-band with considerable output power is under way. Currently it produces power at 88 Mc. The initial pair of multiplying stages (which multiply by factors of 17 and 13, respectively) have attracted some interest, however a final judgment must await the completion of the chain.

Millimeter-Band Harmonic Generator. It is intended to use crystal rectifiers as harmonic generators to extend the output frequency of the multiplier chain to the neighborhood of 100,000 Mc. Several harmonic generator units and detector units for this frequency have been under construction for several months. There have been delays due to difficulties in obtaining machine shop time. These units are now very near completion. Several Hybrid tee waveguide junctions were completed.

Future Activity: Experimental verification of the diffraction estimates will be made as soon as the apparatus permits. Construction of more refined apparatus capable of accurate comparisons with length standards will begin when it has been determined that suitable designs and methods of use have been arrived at. Possible alternate methods for accomplishing the same objectives will continue to receive such consideration as is felt to be warranted in each case.

Survey of Analog-to-Digital Converters - NBS Project 8253,
Missile Instrumentation Section, M. G. Pawley

General Objective: To make available in the form of a critical survey, comprehensive information on the current status of development of instruments for analog-to-digital conversion, including an evaluation of their applications and of their theoretical and practical limitations, useful in the planning and conduct of research and development on such devices and useful for general guidance in instrumentation problems concerned with analog-to-digital conversion.

Background: Although analog-to-digital converters are used in a number of different applications and new types are being developed to meet new situations, the use and development of such devices has been hampered by the lack of a comprehensive picture of the requirements to be met and the techniques presently used to meet them. Most information exists in such widely scattered places as manufacturer's catalogs, reports to government sponsors, and occasional articles in technical journals. A need exists for a comprehensive survey to bring this material together.

Progress: Information has been collected on analog-to-digital converters manufactured by commercial companies and those being developed by these companies and by governmental agencies. Most of the information has been obtained by mail and some by personal visits and review of published articles. Several schemes of organization of the material for the report are being considered.

Future Activity: Future activity will be similar to that mentioned in the preceding paragraph. The final report on the survey is scheduled for completion during Fiscal Year 1953.

Research and Consultation on Instrumentation Information - NBS Project 3300-51-7505, Office of Basic Instrumentation, Joshua Stern

General Objective: To provide access to existing instrumentation information, published and unpublished, towards solving instrumentation problems.

Specific Objectives: To improve accessibility of both published and unpublished instrument information by developing improved systems for storage and retrieval of information, by fostering developments elsewhere which will make more easily available information of instrumentation interest, by surveying specific developments in instrumentation, by providing consultant services in instrumentation.

Background: While good access to information is important in any research endeavors, the rather recent emergence of the field of Instrumentation as a new coordination of knowledge from a variety of previously existing fields has brought with it some particularly severe problems. The major problems are the inadequate coverage of instrument information by abstracting and indexing services whose main interest is the information obtained by use of the instrument and the non-existence of efficient classification systems for instrumentation. In common with all others concerned with access to information is shared the problem posed by the overwhelming rate at which information is being generated. Development of mechanical aids promises greatly improved information access. In order to make use of the potentialities of these devices, it is necessary to have information classifications specifically designed with mechanical retrieval in mind. Such classifications do not exist for the field of instrumentation.

Summary of Project Activity:

Task I. Multidimensional Classification of Instrument Information. Consideration of the various ways in which the problem of classification has been approached in the past led to the recognition of the basic "multidimensional" nature of human knowledge. The concept that information might be located in a system of "coordinates" by the interaction of a number of identifying terms was studied, and discussed at a conference attended by a number of individuals interested in documentation problems. It was generally concluded that this approach was a desirable one for this specific application. A system based on eight dimensions has been evolved as follows:

"Dimensions"			Estimated Breakdown
1.	Condition, quantity, or factor to be measured	25 major headings	3,000 entries
2.	Principle of measurement	50 " "	600 "
3.	Object being measured	100 " "	10,000 "
4.	Name of Instrument	50 " "	4,000 "
5.	Field of Application	-----	300 "
6.	Stages in Measurement Process	-----	550 "
7.	States of Development	-----	25 "
8.	Character of Document	-----	25 "

The entries have been selected and their suitability studied.

A selection was made of a suitable system for experimental use of the multidimensional classification. The "peek-a-boo" system was selected as the most suitable for this purpose. The multidimensional classification was brought to completion adequate for application to the experimental use with the "peek-a-boo" system of information retrieval. A number of conferences were held to achieve a suitable rounding-off of the classification. Studies were initiated for the establishment of guide lines for the selection of reference material for storage in the experimental application.

Task II. Development of Mechanical Method for Information Storage and Retrieval. Investigations carried out on existing developments in this field have led us to the belief that mechanisms are already far in advance of the other aspects of the information retrieval problem. Our activities on this task have been largely limited therefore to watching new developments in the field. Broad aspects of some mechanical systems for information retrieval have been worked out. These will remain of academic interest until the classification and coding problems have been solved sufficiently to permit choice of the most suitable mechanization.

Task V. Preparation of a Guide and Source List of the Literature of Instrumentation. This task was undertaken for O.B.I. by Dr. Julian F. Smith of the Library of Congress. This work has been completed and the resulting report entitled "Instrumentation Literature and its Use", is ready for limited distribution. It is hoped that arrangements can be made with one of the professional societies to reprint the report for wider dissemination.

Progress:

Task I. Multidimensional Classification of Instrument Information. A "peek-a-boo" card has been designed for use in the experimental application of the multidimensional classification. The card will be of a size suitable for storage in letter size file cabinets.

A field of 7" x 7" on the card is imprinted with a 100 by 100 division grid which will accomodate 10,000 references. Two holes punched outside of the reference area will be used for positioning the superimposed cards for "punching in" operations and "reading out" operations. All cards pertaining to a particular reference are to be punched simultaneously with the document identification hole. The size of the reference hole is 0.040" and the hole locations are separated 0.070" on centers. Preliminary experimentation with holes of the size chosen show that it is surprisingly easy to perform unambiguous coincidence determinations with only hand stacking. It is also found to be unnecessary to view the cards against a lighted background. Coincidence can easily be observed when the cards are merely laid on a relatively dark background such as a desk top. The problem of printing registry however turned out to be a severe one. Ordinary printing methods appear to be able to meet only the minimum requirements. Investigation has revealed the possibility of achieving far greater precision of registry by punching positioning holes and printing simultaneously. The precision promised by this technique together with the gratifying experience with ease of comparing cards suggests that even smaller holes and consequently greater card capacity are feasible. While a capacity of 10,000 references per card was selected as adequate to the present application, the number of information fields for which the peek-a-boo system is appropriate may be expected to increase rapidly with increasing card capacity. It is of interest to compare the storage efficiency which may be achieved from peek-a-boo cards with magnetic storage. Using holes 0.015" in diameter and separated 0.025" on centers, 625 bits of information may be accomodated in one square inch of card. This compares very favorably with the 1,000 bits which it is conservatively estimated can be accomodated by magnetic storage techniques. Against the smaller access time obtainable in magnetic storage may be balanced the superior mechanical simplicity of the manual peek-a-boo system.

Plans for conducting the experimental application of the multidimensional classification have been refined and efforts made to recruit additional personnel for the work. These efforts resulted in the addition to the O.B.I. staff of one person with wide experience in documentation work who will devote a large fraction of time to the experiment.

Task II. <u>Development of Mechanical Method for Information Storage and Retrieval.</u> No activity during this period.

Task V. <u>Preparation of a Guide and Source List of the Literature of Instrumentation.</u> Data for use in future improvement of the guide is being accumulated.

Future Activity: It is planned to vigorously pursue the experimental application of the multidimensional classification by classifying information and recording the classification on peek-a-boo cards. No systematic attempt will be made to treat old information in this way. The work will be started with abstracts published in 1953. The sources to be covered are tentatively set as Science Abstracts, T.I.P., and Chemical Abstracts. The rate at which these can be processed can only be very roughly guessed at present. As soon as sufficient information has been processed, experimentation with use of the classification as a search medium will commence.

Miscellaneous Investigations in Basic Instrumentation - NBS Project 3300-31-7507, Office of Basic Instrumentation, W. A. Wildhack

Objective: To carry out preliminary investigations of various instrumentation problems and to carry these to a point where a report can be issued or where investigation is seen to be of sufficient importance and complexity suggested by a separate project.

This project was established as a general project for preliminary investigations which might later develop into separate projects, very short studies, etc. At the end of the reporting period, the project comprised the following active tasks:

A Diaphragm-Type, Capacitance-Type Micromanometer, Office of Basic Instrumentation, T. A. Perls, W. H. Kaechele, D. S. Goalwin

Objective: To investigate the pressure sensitivity attainable from the combination of a very sensitive flexible diaphragm with an extremely sensitive and stable electronic system for the measurement of minute displacements, the resonant-bridge carrier system.

Background: Details of the resonant-bridge carrier system have been recently published by G. W. Cook of the David Taylor Model Basin, in the January 1953 issue of "Electronics", p. 105.

Summary of Project Activity: Details of the design and calibration of the diaphragm-type, capacitance-type micromanometer are contained in NBS report 2165, to be issued in January 1953. A calibration curve corresponding to the highest sensitivity obtained in these tests is shown in Figure 1.

Progress: The report was completed.

Humidity Measurement by Spectroscopic Methods, Office of Basic Instrumentation, W. A. Wildhack, J. Stern

Objective: To investigate the possibility of utilizing the hydrogen excitation spectrum for absolute humidity measurements at low temperatures.

Background: Most measurements of humidities with dew points below 0°C are of low accuracy, and theoretical considerations indicate that a substantial improvement in precision of humidity measurements

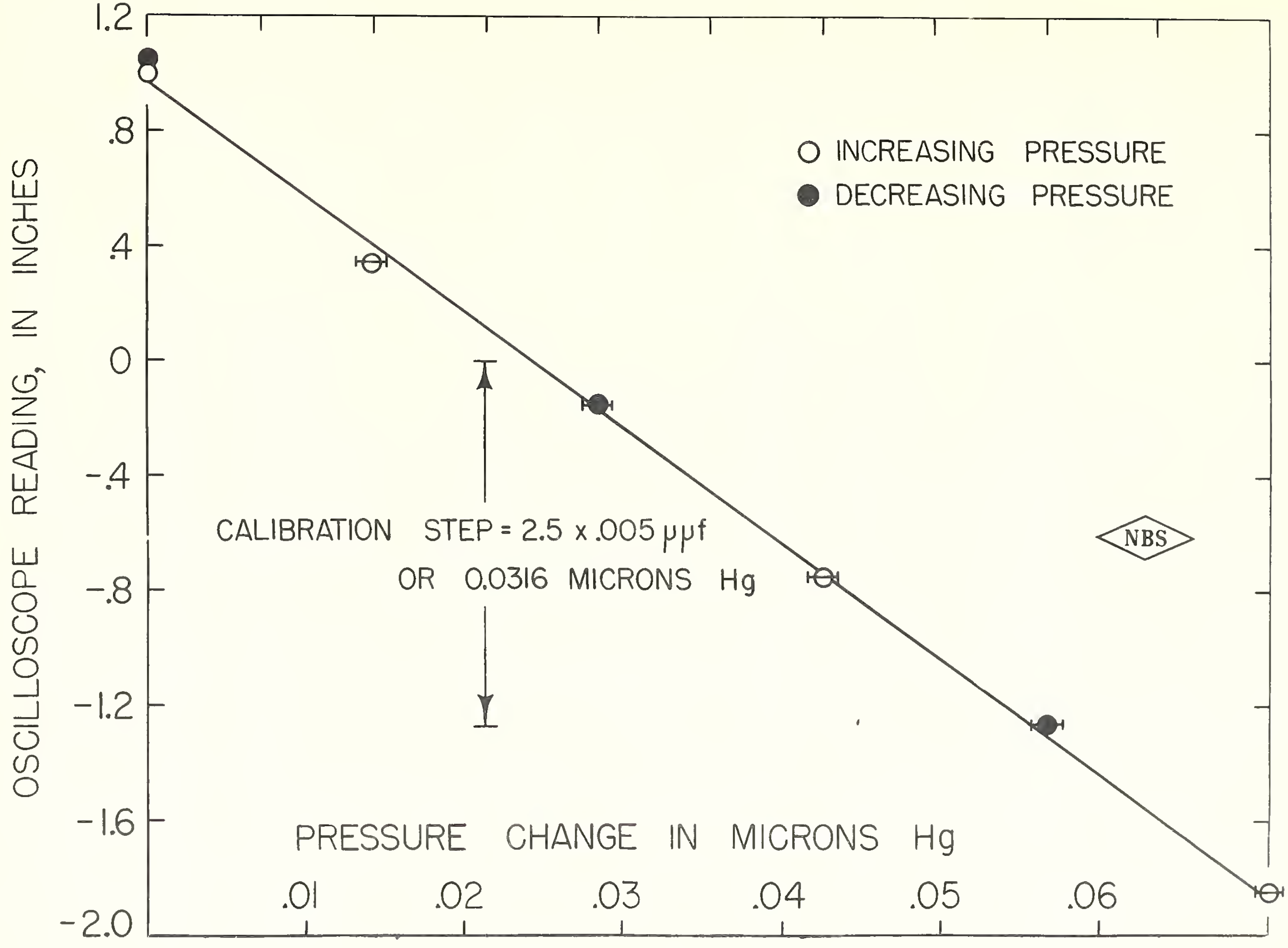

FIGURE 1 EXPERIMENTAL CALIBRATION CURVE OF CAPACITANCE-TYPE MICROMANOMETER, AT AN ELECTRODE SPACING OF ABOUT 0.0035 inch.

in this range may be realized by measurement of the intensity of lines of the hydrogen spectrum of air containing water vapor.

The intensity of a spectral line is proportional to the amount of material present. The intensity depends also on other factors such as the source intensity, but the ratio of the intensity of two spectral lines of two different substances in a sample depends only on composition of the sample. The intensity of a line or band due to pressure of water vapor to the intensity of a line or band from gas present at constant concentration in air, such as argon or nitrogen, would be a measure of the quantity of water vapor. Thus it should be possible to detect small amounts of water vapor and to make quantitative determinations of humidity independent of temperature.

Summary of Project Activity: Spark excitation was used to produce the air spectrum. The hydrogen alpha line at 6563 A was chosen for the experiments since it is the strongest line in the available region of the spectrum. The nitrogen line at 6610 A was used as an internal standard. The first approach involved photographing the spectrum of air having different water vapor concentrations. The humidity was controlled by passing the air through condenser coils maintained at different temperatures. Line intensities were measured by the use of a microphotometer and indicated the possibility of measurement of humidities with dew points lower than -20°C.

Apparatus to permit substituting photomultiplier tubes for the photographic plate was then designed and constructed. A circuit was built to compensate for dark current. Improved apparatus for laboratory control of humidity was assembled in which air was saturated at higher than atmospheric pressure and then expanded to atmospheric pressure to obtain a known humidity. Experiments were carried out to determine the most effective method of excitation of hydrogen.

Calibration experiments were performed to determine whether the humidity of the air sample (known from its saturation temperature) correlated best with (1) the ratio of the output of the photomultiplier tube when illuminated by the hydrogen line to its output when illuminated by a nitrogen line or (2) the ratio of the hydrogen line to the total illumination from the spark. In either case the use of only one photomultiplier tube requires that the intensity of the various lines be determined at different times. This occasions no error if the average excitation is reasonably steady over a number of seconds, and if the observation on each line gives a reading indicative of this average. These conditions were investigated and found to be fairly well fulfilled by the apparatus. The background illumination on the photomultiplier cell (that is, the signal obtained between lines during the scanning) was found to be fairly constant but not entirely accounted for.

It was discovered that the compressed air from the high-pressure tanks contained small amounts of hydrogen, presumably due to rust formation in the steel cylinders. A catalytic hydrogen remover was procured and installed in the air line.

With these improvements, it was found that a reliable measure of humidities could be obtained down to saturation temperatures of about -40°C, where the saturation vapor pressure is 0.1 mm. Hg. At this temperature, the uncertainty in the determination was about ±15%.

Progress: Favorable results obtained elsewhere in the Bureau on excitation of hydrogen and deuterium spectra by use of radio frequency excitation at reduced pressure led to experiments using this type of excitation for the measurement of humidity. Earlier work on this project had been entirely devoted to exciting the spectrum in air at atmospheric pressure with a spark discharge. The sensitivity of detection with low pressure discharge was found to be somewhat greater than that obtained with spark excitation and it appears that measurements of absolute humidity might be made to dew-point as low as -50° C or lower before the uncertainty becomes as great as 10% of the humidity measured. Both sensitivity and accuracy of the radio-frequency excitation method require more precise measurement and control of the pressure and temperature, and possibly flow of the low pressure gas in the excitation tube. The apparatus is being improved for this purpose. Experiments have been made using two photomultiplier tubes, with recording of ratio of their signal, to permit more nearly instantaneous measurement of ratios of the hydrogen line to the total intensity of the spectrum or to the intensity of a selected reference line.

Future Activity: The low-pressure gaseous discharge method will be more adequately evaluated with the improved equipment and some further tests are contemplated of the spark excitation method using ratio recording against a reference line. The report, which has been partially written, will be completed.

Vibration Measurement by Interferometric Methods, Corona Laboratories, J. W. Smith

Objective: To conduct a preliminary survey of interferometric methods of measuring the amplitudes of mechanical vibrations over a frequency range from 0 to 10,000 cycles per second and an amplitude range from 10^{-6} to 10^{-2} inches. More specifically, to evaluate the feasibility of adapting to vibration measurement the instrumentation techniques employed by R. D. Huntoon in his electronic fringe interpolator for an optical interferometer (NBS Report 1228). To consider other methods and equipment presently available or adaptable to such measurements. To prepare an NBS Report summarizing the results of the survey.

Background: This survey is part of a more comprehensive study of methods of measuring vibrations and, in particular, of calibrating vibration pickups. There is considerable need for a reliable device to measure vibration amplitudes in the small-displacement region where microscope methods become imprecise.

Progress: Since, in measuring vibration with the aid of optical interferometry, the characteristics of the light source will have a crucial effect on the precision obtainable, some consideration is being given to the suitability of various light sources, including the factors of spectral width and intensity fluctuation.

One simple scheme for pickup calibration has been thought of: With a vibrator used as one plate of the interferometer, photomultiplier signals would be fed to the horizontal plates of an oscilloscope, and the output from a vibration pickup on the same vibrator would be fed to the vertical plates. The resulting pattern would then indicate the vibration amplitude.

Future Activity: An analysis of the fringe system in the image plane of an interferometer under various conditions is planned. Experimental and theoretical analysis will be continued on the simple calibration scheme with one vibrating plate as well as on the scheme with both plates vibrating - one at a known amplitude and frequency, the other with the amplitude to be measured. The task should be completed with a report by June 30, 1953.

Preparation of Final Report on Spring Transducer, Office of Basic Instrumentation, W. A. Wildhack, T. A. Perls, J. H. Pinkard

The research on the Spring Transducer was carried out under NBS Project 3300-31-7500 and the Objectives, Background and Summary of Project Activity for this work are discussed in the previous

Progress Report of the Office of Basic Instrumentation (NBS Report 1923). During this period, experimental data were assembled from all work done on Spring Transducers since 1948, and these data were fitted into a detailed outline for the final report. Some sections of the report have been written on a part-time basis.

Barium Titanate Accelerometers, Office of Basic Instrumentation, T. A. Perls, C. W. Kissinger

Objective: To investigate design characteristics and calibration methods for barium titanate accelerometers.

Summary of Project Activity: Only a small amount of preliminary work was done on this project prior to this reporting period. This work was primarily concerned with determining the causes of the relatively large transverse response (10-50% or more) observed in most commercially available and laboratory made barium titanate accelerometers.

Progress: Investigation was continued of means to remedy various defects of barium titanate accelerometers. New impetus was given to this task by a request from personnel at the Aberdeen Proving Ground, for an accelerometer suitable for recording extremely high accelerations, and having a natural frequency of about 100 Kc. Early tests, as of the end of September, were very encouraging. Preliminary data also pointed toward both an explanation for and a possible reduction of, the observed transverse sensitivity of small barium titanate accelerometers. Experimental models of a total of 12 designs were built and tested, with successive improvements with regard to shielding natural frequency, sensitivity, transverse response, and spurius effects due to cable loading and mounting procedure. Methods were developed to obtain accurate determinations of transverse response (see figure); and some preliminary work gave encouraging results in calibrations up to accelerations of over 4,000 g's.

Future Activity: A report (NBS 2390) will be prepared covering this work. Investigations will continue on several of the design features and calibration methods for these accelerometers. Planning will continue for a conference to be held, possibly in April or May, on the design, calibration and performance of barium titanate accelerometers. Further work on specific models for high frequency response, and for high ranges, and on calibration methods, will be continued under a project to be supported by the Aberdeen Proving Ground, (3304-40-7510).

Preparation of Final Report on Pneumatic Instruments Based on Critical Flow, Office of Basic Instrumentation, W. A. Wildhack, T. A. Perls, C. W. Kissinger

The research on Pneumatic Instruments Based on Critical Flow was carried out under NBS Project 3300-31-7501 and the objectives,

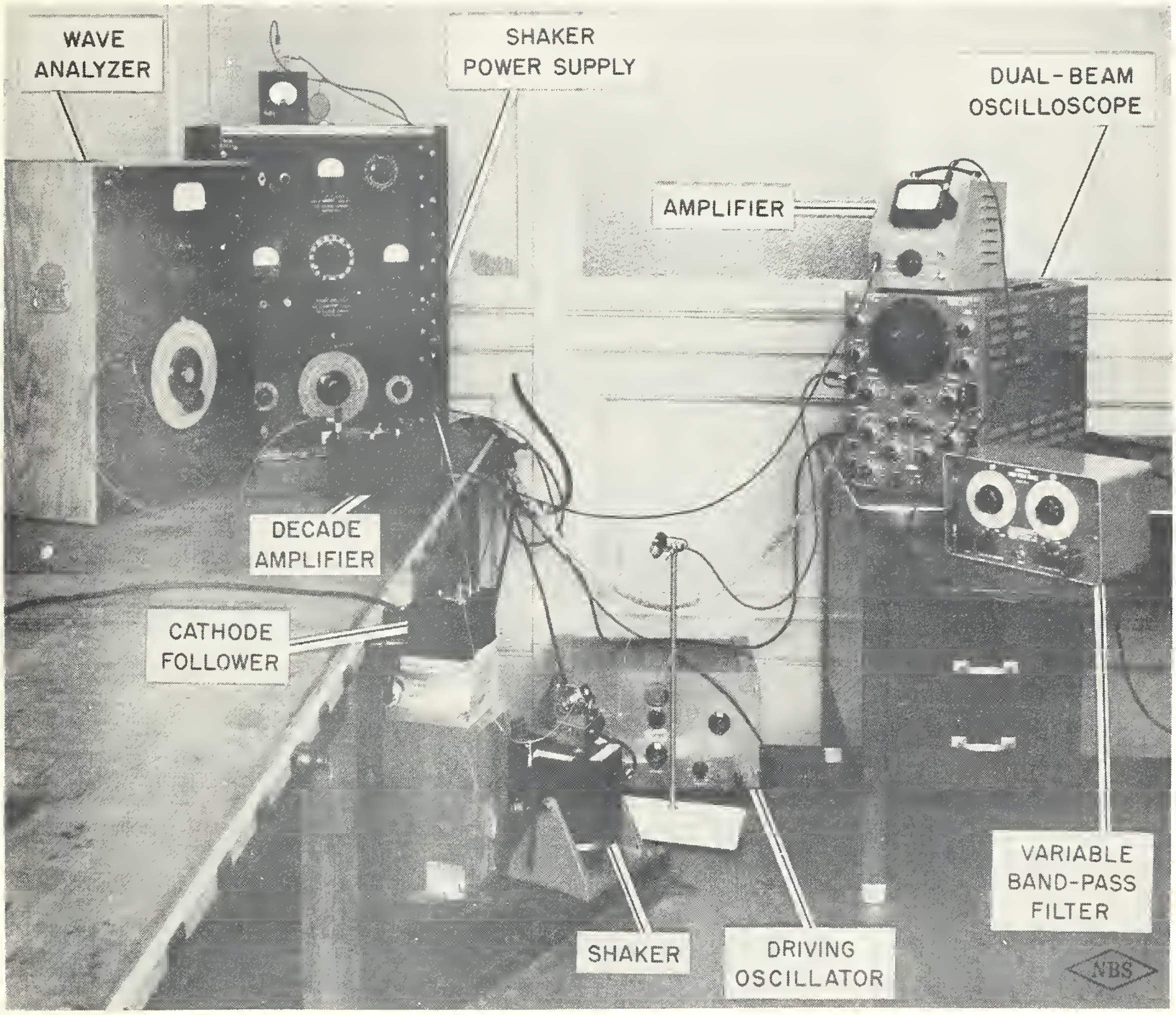

FIGURE 1 TEST SETUP FOR DETERMINATION OF TRANSVERSE RESPONSE OF BARIUM-TITANATE ACCELEROMETERS.

Background and Summary of Project Activity for this work are discussed in the previous Progress Report of the Office of Basic Instrumentation (NBS Report 1923). During this period work was continued, on a part-time basis, in preparing several sections of the final report.

Survey of Thickness Measurements - George Keinath, (Larchmont, N.Y.)

Objective: To make available comprehensive information on the current status of development of thickness measuring devices of all types, and an evaluation of their applications and limitations useful in instrumentation problems concerned with thickness measurements.

Progress: This task was started during the reporting period. Collection of pertinent literature and manufacturers' data has been essentially completed and the material organized. Portions of the report have been prepared in draft form.

Survey of Variable Inductance Velocity Transducers - R. J. Jeffries, (Michigan State College)

Objective: To make available in the form of a critical survey comprehensive information on the current status of development of variable inductance velocity transducers and an evaluation of their theoretical and practical limitations useful in the planning and conduct of research and development on such devices and useful for provision of general guides and instrumentation problems concerned with velocity measurements.

Progress: This task was started during the reporting period, and effort so far has been applied to the collection and organization of pertinent literature and manufacturers' data.

Electrical Noise from Instrument Cables Subjected to Shock and Vibration, Office of Basic Instrumentation, T.A. Perls

Objective: To investigate, and find remedies for, the electrical noise generated in instrument cables subjected to shock and vibration.

Background: Previous work on the reduction of cable noise was carried out under NBS Project 3300-31-7502 (1), and is described in NBS Report 1388 as well as in an article in the June 1952 issue of the Journal of Applied Physics.

Progress: Work on noise-free cables was continued, including tests on multiconductor cables, as shown in Fig. 1, in which test results are shown for four different constructions of double-conductor-shielded cables. These cables differ only in the presence or absence of the conductive coatings on the inside surface of the large dielectric tube and on the outside surfaces of the small dielectric tubes. It is seen that conductive coatings on all contacting dielectric surfaces are required to reduce the noise from about 10 volts to about 1 mv. (The bond between the conductive coatings and the inside of the large dielectric tube was not as good in these tests as for the usual single-conductor-shielded cable, and accounts for the residual noise of about 1 mv. seen in the type-4 cable.)

Noise-free cables were made in 3 feet lengths for use with accelerometers developed and built under project 7507-Task 22. The sensitivity of the test setup for cable noise was extended to 500 microvolts full scale, with an amplifier-noise level of 5 to 10 microvolts in a limited band of frequencies (19 to 40 cps). This allowed intercomparison of various low-noise cables; (see Fig. 2). It is seen that the cable with conductive coatings bonded to the dielectric is the only one which retains its low-noise characteristics after repeated squeezing with pliers, simulating rough field conditions. The noise on the other test cables is increased by about a factor of 10 after this rough treatment.

Underwater explosion tests were conducted with 10-foot lengths of laboratory-made jacketed cable, in an 11 foot water tank at the David Taylor Model Basin. Liason was maintained with several manufacturers interested in the commercial production of this cable.

Future Activity: Project considered completed.

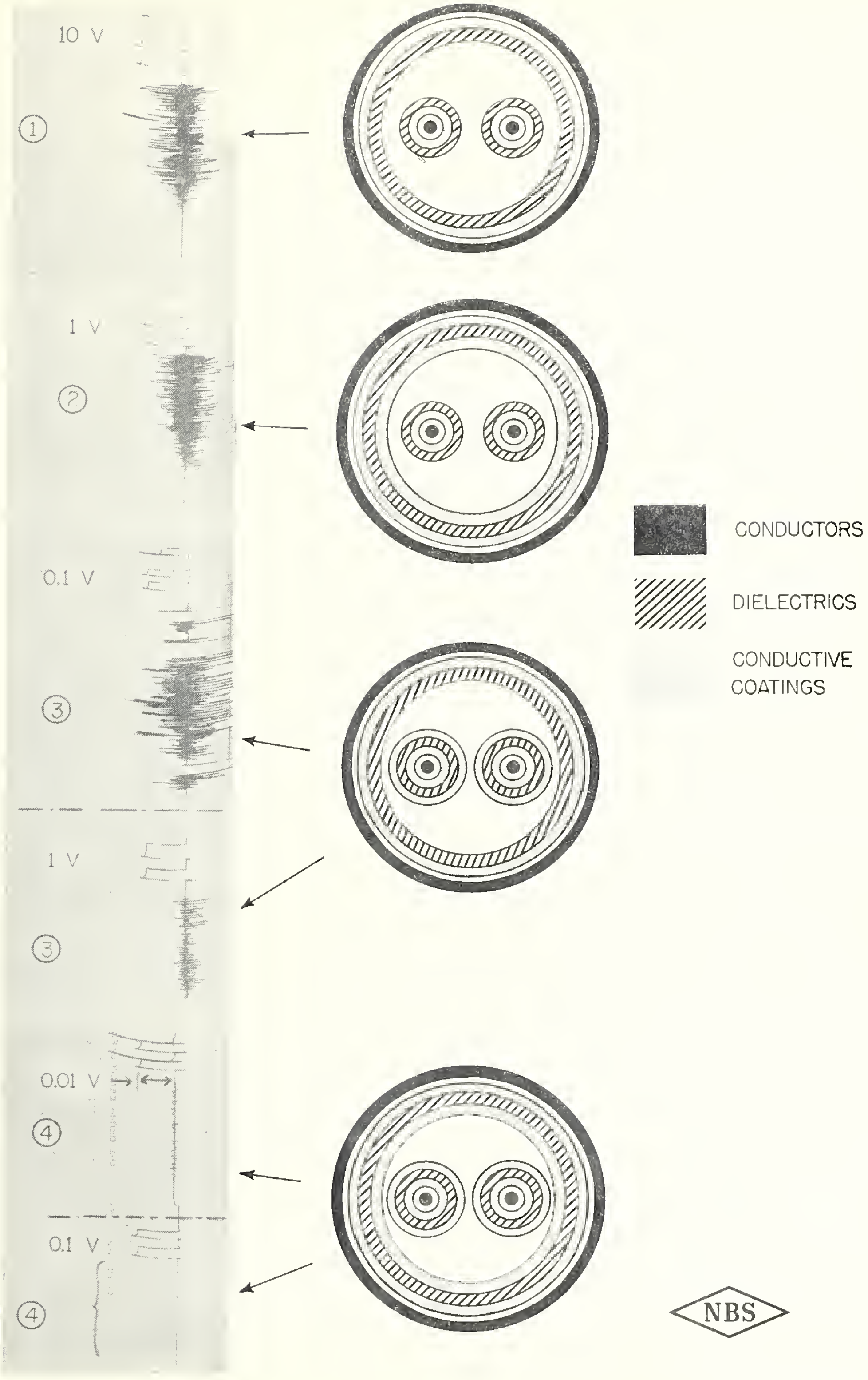

FIGURE 1 NOISE TESTS ON 4 POSSIBLE CONSTRUCTIONS OF DOUBLE-CONDUCTOR-SHIELDED CABLE.

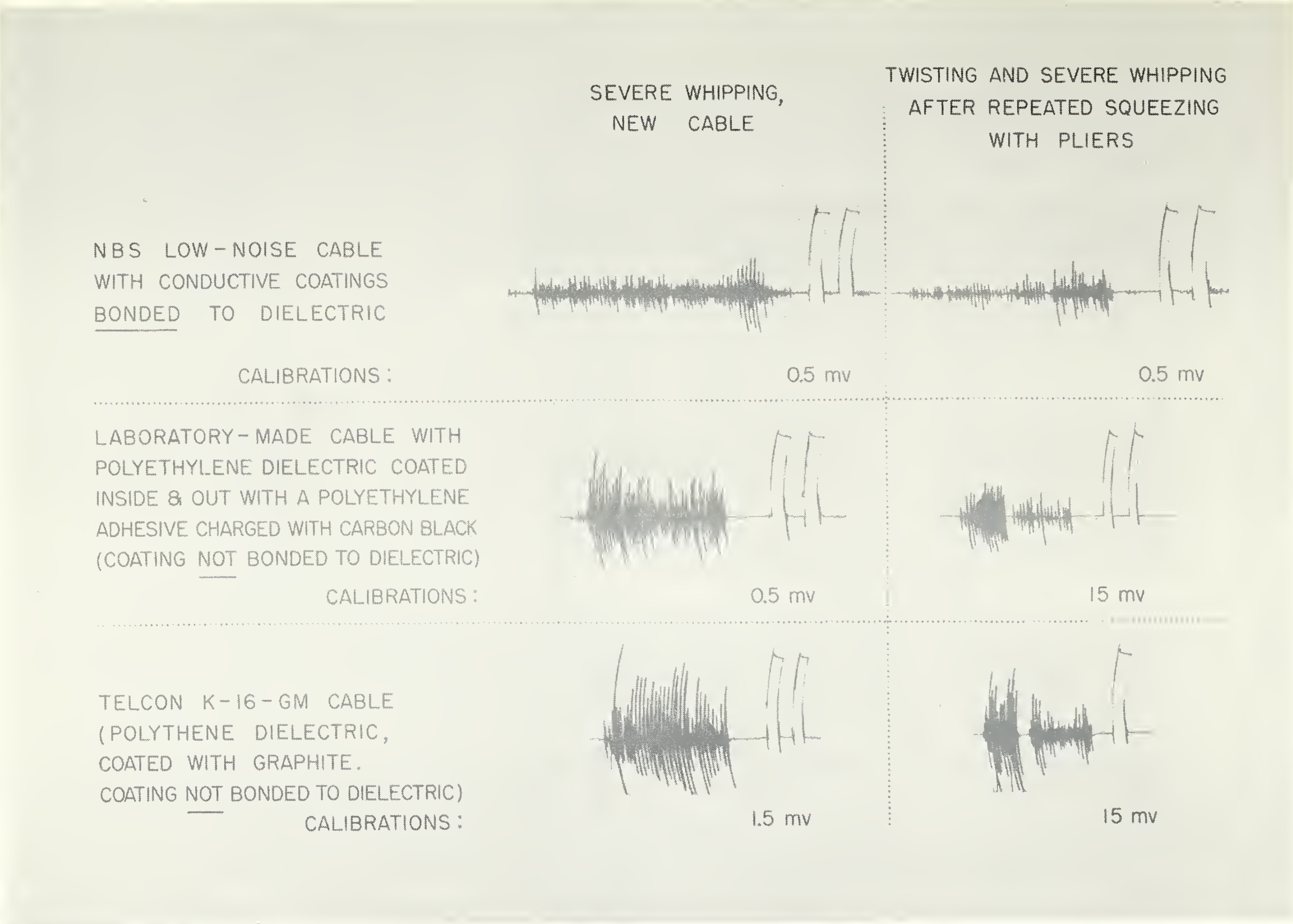

FIGURE 2 INTERCOMPARISON OF 3 LOW-NOISE CABLES, BEFORE AND AFTER REPEATED SQUEEZING WITH PLIERS TO SIMULATE ROUGH FIELD CONDITIONS.

Stability of Feedback Systems - NBS Project 3300-31-7509 (Continuation of 7507 (5)), Office of Basic Instrumentation, H. L. Mason, J. F. Koenig

General Objective: To study, compare, and evaluate various analytical methods for predicting stability characteristics of feedback systems.

Specific Objectives: Develop analytical methods for the computation of linear and non-linear feedback control systems, including systems containing non-linearities such as contactors, coulomb friction and backlash. Continue study of foreign literature on feedback control systems, and prepare translations of selected articles.

Background: Servomechanisms and other automatic control systems are widely used in military and industrial applications. Often the physical parameters of the device to be controlled are not known exactly. Even when they are, the mathematical methods available for predicting transient performance of linear systems are either laborious or approximate. Analog computers can solve rather complicated problems quite rapidly, but generally require the preliminary guidance of an analytical solution. Further, there are many systems in which the operation of one or more elements cannot be adequately represented by linear equations. The ranges and types of nonlinearity that can be handled mathematically are quite limited, and one must usually resort either to the analog computer or to linear approximations. There is therefore a need for more convenient, more comprehensive, and more comprehensible methods for analytical treatment of linear and of non-linear problems.

Summary of Project Activity: A study of the literature in this field was started and a number of foreign articles were translated. Three of these, describing the use of an amplitude-dependent transfer function in predicting stability of loops with non-linear elements, were prepared in report form, NBS Report #1691.

A new method was developed for analyzing non-linear feedback control systems containing non-linearities such as contactors, coulomb friction, and backlash. This method involves approximation by a special type of linearization. This permits the construction of a stability diagram which shows how far a stable system is from instability in terms of the amount by which three parameters may change before the system becomes unstable. Another method was developed for obtaining the same type of stability diagram. In addition, the absolute stability of the class of non-linear systems was expressed in terms of a determinant criterion based on a characteristic equation with complex coefficients, which relates stability to the position of the roots in the complex plane. A paper describing both methods was prepared.

A paper, "On the Zeros of Polynomials and the Degree of Stability of Linear Systems" was partially completed. This research paper presents a method, called the "root trajectory" method, which gives all the zeros of any n-th degree polynomial, and shows how they change as physical parameters are simultaneously varied. The paper presents new theorems and uses these in combination with known theorems.

Progress: Continued study of the literature of automatic control indicates that existing indexes are insufficiently detailed to provide a satisfactory classification for the specialist's reference files. Preparation of a new list of subject headings, extending and supplementing selected items from the TID list of June 1952, has been begun. It is also evident that there are gaps in the listing and translation of foreign articles and effort has been made to fill some of these.

A paper has been written, and is now under review, describing the two methods mentioned above, for analyzing the stability of feedback systems whose linear elements provide adequate low-pass filter action for linearizing nonlinear effects. The final draft of the paper "On the Zeros of Polynomials and the Degree of Stability of Linear Systems" has been submitted for publication.

An analytical method for meeting relative stability criteria has been developed. This is covered by a paper "A Relative Damping Criterion for Linear Systems" which is presently being reviewed.

In the first semester of the NBS in-hours graduate course "Instrumentation", organized and presented this fall for the first time, a major fraction of the time has been devoted to the theory of automatic control systems. Beginning with measurands and the statistical interpretation of experimental data, the syllabus proceeds to the study of components of the control loop, typical forms and functions, their combination, and finally to the transient-state and frequency-dependent responses of open and closed loops.

Future Activity: It is expected that reviewing of the last two papers mentioned above will be completed. Study of the literature will be continued, with special attention to theory and to aircraft control systems. As work progresses on the list of subject headings, topical classification will be made of recent material in these two fields, and it will be tied in with the OBI multidimensional system.

REPORTS AND PUBLICATIONS RELATED TO THIS PROGRAM

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2. Instrumentation in Perspective
   W. A. Wildhack, Science, Nov. 3, 1950, vol. 112, #2914, pp. 515-519

3. A Versatile Pneumatic Instrument Based on Critical Flow
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4. An Externally Excited Electronic Power Switch for Producing Variable Width, Variable Repetition Rate Rectangular Pulses
   Jack Sargent, NBS Report, July 29, 1949

5. Attenuation of Oscillatory Pressures in Instrument Lines
   A. S. Iberall, NBS Journal of Research, vol. 45, July 1950, RP 2115

6. Permeability of Glass Wool and Other Highly Permeable Media
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7. The Effective Gamma for Isentropic Expansions of Real Gases
   A. S. Iberall, Journal of Applied Physics, vol. 19, No. 11, Nov. 1948, pp. 997-999

8. Evaluation Report on German Subcutaneous Metal Indicator
   S. R. Gilford, NBS Report I-123

9. Analysis of Solids with the Mass Spectrometer
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    W. A. Wildhack, T. A. Perls, Feb. 28, 1951, OBI Status Report

11. A Fifty-Fold Momentary Beam Intensification for a High-Voltage Cold-Cathode Oscillograph
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    Guy F. Barnett, NBS Report 1076, April 2, 1951

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15. New Tools for Research
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Lawrence T. Fleming, Instruments, August 1951, vol. 24, No. 8, p. 105

17. Operational Aspects of Instrument Design
Churchill Eisenhart, Science, October 7, 1949, vol. 110, No. 2858, pp. 343-346

18. Electrical Noise from Instrument Cables Subjected to Shock and Vibration
Thomas A. Perls, NBS Report 1388, January 1952

19. A Miniature Barium Titanate Accelerometer
Lawrence Fleming, NBS Report 1094, November 28, 1951

20. Electron Interferometer
L. Marton, The Physical Review, March 15, 1952, vol. 85, No. 6, 1057-1058

21. A Program of Research and Development in Basic Instrumentation
LCDR Frank L. Thomas, USNR, Monthly Research Report of the Office of Naval Research, January 1952

22. Translation of Papers on Stability of Non-Linear Feedback Control Systems
Office of Basic Instrumentation, NBS Report 1691, May 29, 1952

23. Fifth Conference on Basic Instrumentation, April 29-30, 1952
Sponsored by Office of Basic Instrumentation
NBS Report 1693

24. New Pulse Transformer Gives Faster Response
NBS Technical News Bulletin, May 1952

25. Damping of Elastically Supported Element in a Vacuum Tube
Samuel Levy, Edward V. Hobbs, Wilhelmina D. Kroll, Leonard Mordfin, NBS Report 1707, June 1952

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28. A Magnetostriction Magnetometer
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32. A Phase-Sampling Telemeter
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34. An Evaluation Study of a Fast-Neutron Spectrometer Based on the Total Absorption Principle
Marshall R. Cleland, NBS Report 2036, Oct. 1952

35. Study of Performance of Photomultipliers Operated at High Voltage
Ben Petree and Frank Viers, Jr. NBS Report 2065, Nov. 1952

THE NATIONAL BUREAU OF STANDARDS

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