NBS CIRCULAR 578

Suggested Practices for Electrical Standardizing Laboratories

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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Preface

Since World War II there has been a very marked increase in the number and scope of private standardizing laboratories throughout the United States. The function of each such laboratory is to maintain the accuracy and uniformity of the measuring instruments and apparatus used by the organization or organizations that the laboratory serves. A basic phase in this process is necessarily to correlate the reference standards of the laboratory with those of the National Bureau of Standards. This Circular has been prepared to suggest techniques and principles that experience has shown to be useful in such operations. Although this Circular covers explicitly only the field of electrical measurements, many of the principles involved are equally applicable in other kinds of measurement.

A. V. Astin, *Director.*

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A number of basic principles are given that experience has shown to be important in the operation of private standardizing laboratories. Types of standard apparatus are classified and schedules appropriate for their intercomparison and for their checking at the National Bureau of Standards are suggested.

1. Introduction

The purpose of this Circular is to indicate recommended procedures and schedules for the calibration testing of electrical instruments and measuring apparatus used in the range of frequency from 0 to 30 kilocycles per second.

For many years the electric-power companies have maintained large and efficient laboratories [1, 2] [1] suited to their particular needs, and certain universities have similarly supplied services [3] to their teaching and research staffs. More recently, laboratories are being established in many newly founded manufacturing plants, in firms concerned with research and development, and in Government agencies (particularly in the military services). Although the particular problems that confront the various agencies may differ greatly, their standardizing laboratories have a great many common functions in their work of maintaining and disseminating the units of measurement.

The process of measurement always involves a succession of steps in which the units in terms of which the measurement of any quantity is expressed are transmitted by using measuring apparatus that has been standardized, by comparison with standards of a higher level, to calibrate other measuring apparatus which is to serve as a standard at a lower level. At the source is the National Bureau of Standards, authorized by Congress to establish and maintain the basic standards of the nation [4, 5]. Next, in any organization, may come a primary group of laboratory workers, which maintains its basic reference standards and in turn calibrates the working standard apparatus used by the next lower, or secondary, group, which in turn calibrates the instruments used in making measurements in the plant or shop. In some cases these latter two operations are merged in a single group, while, at the other extreme, a single primary group may serve many secondary groups located in different cities.

It is the rest of the organization that uses the shop instruments standardized by the working-standards group, and carries on the day-to-day work in the power systems, manufacturing operations, research studies, or acceptance tests. This use insures proper billing, adequate quality, and valid criteria for the acceptance of manufactured articles. In this Circular the terms "laboratory" or "standardizing laboratory" will be used to indicate the segregated part of the complete organization that is charged with the duty of supplying calibration services, at either the reference or the working-standard level, to the measuring apparatus used by the rest of the organization, which will here be designated as "plant" or "shop," even though it may actually be more correctly described as a research or testing laboratory.

For clarity in the rest of this Circular, the measuring instruments and apparatus used in an industrial organization will be referred to under the following categories:

(a) Reference standards, which embody fixed electrical quantities and serve to maintain their respective units during the intervals between checks with a laboratory at a higher echelon.

(b) Working standards, calibrated in terms of the reference standards and reserved for use in the calibration of shop instruments and apparatus. Working standards should never be used directly for measurements in the plant or shop.

(c) Comparison equipment such as bridges, potentiometers, etc., and consoles used in comparing shop instruments with working standards.

(d) Interlaboratory standards, often similar in construction to reference standards, used for transport to NBS and return in the periodic checking of the local reference standards.

(e) Shop instruments and measuring apparatus calibrated in the standardizing laboratory and used in the day-to-day operation of the plant.

[1] Figures in brackets indicate the literature references at the end of this Circular.

2. General Principles

The following general principles have been found by experience to be applicable to many of the problems involved in the maintenance of accuracy in laboratory work and any program of calibration service testing should conform to them so far as possible.

2.1. Competence of Personnel

The person in direct charge of any standardizing laboratory must be thoroughly familiar with the fundamentals of electricity and magnetism and with the principles of operation of all types of electrical measuring apparatus [8, 9]. To be competent to carry on within the laboratory the various sequences of calibration testing outlined below, he must have taken a college-level course in electrical measurements or have had laboratory experience equivalent thereto. It is very desirable that he be a graduate in physics or electrical engineering from an accredited college. He must be mentally alert to detect discrepancies and inconsistencies in internal check tests and to recognize abnormal behavior of any part of the apparatus or circuits. Unless persons of this type are available in a standardizing laboratory, both its calibration service and the measurement work that depends upon it throughout the plant is certain to become unsatisfactory, regardless of how often particular pieces of apparatus may be tested by other persons in some higher echelon or at NBS.

2.2. Position in Organization

Experience through the years has shown that the most satisfactory results are obtained by maintaining a definite separation of the standardizing laboratory from the rest of the organization. Responsibilities for accuracy are thereby made definite, and team spirit can be developed in the staff of the standardizing laboratory that keeps them interested in their work, which might otherwise seem routine and unimportant. This separation protects them from pressures that demand improper haste and sloppy workmanship, and gives them authority directly delegated from a high level in management.

Closely related to the foregoing is the valuable principle that team spirit can be developed and maintained by recognizing that the quality of the reference standards of a laboratory are to a considerable extent a measure of the competence of its staff ("a worker is known by the sharpness of his tools"). Hence, in cases where a given large organization maintains a plurality of standardizing laboratories in its plants in different cities, it is very desirable that each reference and interlaboratory standard should be assigned permanently to an individual standardizing laboratory, and returned to it following periodic checks at any laboratory of a higher echelon. If this is not done, it becomes difficult to fix responsibility for errors that may be discovered subsequently, and the laboratory workers lose the basis for much of their pride in workmanship.

2.3. Appropriate Scope and Accuracy

The nature and accuracy of the work done in a standardizing laboratory may vary considerably with the size of the plant it serves and the nature of the output of the plant. However, there are very few modern activities in which some phases do not require measurements of rather high accuracy. A standardizing laboratory must, of course, be equipped for calibration measurements of a higher accuracy than any used elsewhere in the plant, because the accuracy of measurement can never rise above that of its source.

Many such local standardizing laboratories provide service in many scientific fields, e. g., mechanics, heat, optics, and chemistry, in addition to their standardizing work in electricity and magnetism, which alone is the subject of this Circular. The direction and extent of such activities, as well as the degree of specialization in particular branches of electrical science, may greatly affect the types and ranges of the electrical standards required.

2.4. Laboratory Atmosphere

Atmospheric conditions are of considerable importance in an electrical standardizing laboratory. If the relative humidity exceeds 65 percent, a conducting film of moisture is adsorbed on the surface of many types of insulating material. Leakage over such surfaces, particularly to the circuit of a sensitive galvanometer, may introduce serious errors.

Certain types of apparatus, for example some wire-wound resistors of high value, show changes of several parts per 10^4 with prolonged changes in humidity. Such variations can be detected by comparing calibrations made near the middle of the winter heating season, during which indoor humidities are normally very low, with those made near the middle of the summer when the ambient humidity is high.

Most electrical apparatus is compensated for temperature to some extent. However, if the ambient temperature is subject to changes, the response of the various components may not be equally prompt. In such circumstances the compensation may be temporarily ineffective. It is therefore important that the laboratory temperature be held fairly constant (±2 deg F) at all times. Such room control also makes easier the task of the thermostats that control the baths in which more temperature-sensitive apparatus, such as standard cells or standard conductivity samples, are kept. The particular temperature chosen is of less importance. The conditions specified by the American Society for Testing Materials for its

"Standard Laboratory Atmosphere" are a relative humidity of 50 ±2 percent and a temperature of 23° ±1.1 deg C (73.4° ±2 deg F). This combination is widely used in tests of dielectrics and other materials, and, in addition, is very close to the maximum of comfort for the workers. Hence it is a good target to aim at in designing a new laboratory.

Freedom from vibration and dust are also important. A shop in which electrical instruments may be opened for repair should be scrupulously clean and dust free. Magnetic particles are attracted to the air gaps of permanent magnet instruments and must be constantly guarded against. Effective air filtering or electrostatic precipitation are very desirable.

2.5. Care of Standards

In many categories, a good standard piece of apparatus improves with age but deteriorates with handling and shipping. The shipping of primary and working standards and of comparison equipment can be minimized and the transfer of the units be achieved best by the use of interlaboratory standards of particular types that are as rugged as practicable.

The adjustment of a piece of measuring equipment to be close to its nominal value is very often desirable in the shop instruments used in the plant, because of the great saving in time and reduction in possible erroneous applications of corrections that result. On the other hand, the exact opposite is usually true of working and reference standards. In general, such standards should not be readjusted, even if their values have gradually drifted materially away from their nominal values. Any standardizing laboratory naturally maintains records of the values of its reference standards [10]. These are preferably kept on an individual card or record sheet for each standard, so that its history is apparent at a glance. Each such record provides a valuable indication of the quality of the standard, and gives warning of deterioration and the need for replacement toward the end of its useful life. Frequent adjustments tend to interfere with such records and increase the probability of improper corrections, as the proper corrections before and after a slight readjustment may not be conspicuously different. Even more important is the risk that the adjustment may initiate a progressive drift in value of the standard as a result of introducing mechanical strain, or local heating.

2.6. Timing of Calibrations

The most desirable sequence of steps and the frequency with which comparisons of measuring apparatus should be made depend, of course, upon a great number of circumstances, such as the volume of equipment to be tested, the delicacy of the apparatus, and particularly the type of personnel by which it is to be handled. (For measurements made by inexperienced students or by military recruits, the likelihood of damage is much greater than when a laboratory is staffed by experts.) In every laboratory a real possibility is always present that an abrupt change may occur in some standard as a result of an unrecognized accident or abuse. Fairly frequent checks made locally are therefore an indispensable supplement to any program of calibrations to a higher echelon.

Cooperative arrangements with a similar laboratory in the same city may allow frequent checks to be made against an independently maintained group of standards. This may permit a much less frequent checking schedule between either laboratory and one of higher echelon.

In any laboratory, the accuracy needed in measurement may differ widely on different projects. Hence the frequency with which the working instruments should be checked may vary considerably from project to project, even though instruments of the same accuracy class are used [2, 6, 7]. The time intervals suggested elsewhere in this Circular for check tests represent in most cases the considered opinion of persons who have had long experience with standard apparatus of the types now commonly used. Similar test intervals are listed in the American Standards Association Code for Electricity Meters [2]. When a new type comes into use, it must be appraised by being checked at frequent intervals during its first few years of service. After its good stability has thus been demonstrated, the interval between tests may safely be made longer. Several types of standard capacitors and inductors are currently in this probational stage.

A procedure that is often of value, particularly for the checking of consoles and complex equipment such as a-c bridges, is to use an interlaboratory standard that is measured in one laboratory and shipped to a laboratory of lower echelon for a repeat measurement, the lower laboratory not initially being aware of the value obtained at the higher. This procedure can detect significant defects in the wiring or insulation of the test console, improper procedure and careless operations at the lower-level laboratory, as well as changes or deterioration in the reference or working standards of the lower laboratory.

When systematic local intercomparisons indicate changes or abnormal performance in primary or working standards, checks with a higher echelon are in order regardless of whether any formal scheduled time for such a check has been reached. If the local periodic checks uncover unsteadiness of operation, large sudden changes in value, or other indication of a constructional defect in the reference or working standard, this standard should be sent to its manufacturer for repair before it is submitted to NBS for calibration.

3. Reference Standards

The function of the reference standards of a laboratory is to maintain locally a continuity of value in the units of measurement that they embody. Successive comparisons with the higher-echelon standards of NBS by means of interlaboratory standards shipped back and forth will give an indication of any slow drift of the reference standard. When this cumulative drift exceeds the confidence interval of the values derived by the comparisons with the interlaboratory standards, the value assigned to the reference standard is corrected accordingly. The reference standards are used primarily to calibrate periodically the working standards of a lower echelon, such as indicating instruments. Also, on occasion they may be used as working standards themselves.

It is evident that both reference standards and working standards should be as permanent and reliable in construction as possible. Definiteness and repeatability are of major importance, whereas sensitivity, low losses, and freedom from extraneous influences are relatively much less important. Closeness of adjustment to nominal value is of decidedly minor importance. An undetected change in a reference standard may easily initiate a chain of error that will propagate throughout the plant and cause losses in time and material exceeding manyfold the original cost of the standard. Hence, these reference standards should be purchased only on very strict specifications, and from manufacturers of high reputation and of long experience in producing shop instruments and apparatus of demonstrated permanence.

3.1. Standard Cells

A large and important laboratory, which is expected to need a standard of voltage with an accuracy of 0.002 percent and to certify the emf of unsaturated standard cells used in its plant or by its subcontractors, normally maintains as a reference standard a group of 5 or 6 cadmium standard cells of the saturated type. These cells are relatively permanent but have a temperature coefficient of about 0.005 percent per degree Celsius (centigrade) at room temperature. They must therefore be kept in a bath thermostatted to ±0.01 deg C [11, 12]. A highly refined, water-white, acid-free mineral oil, having a viscosity of about 0.25 poise at 25° C and a flash point of 170° C, has been found suitable for baths for standard cells and for resistors. Such a group of saturated cells should preferably be checked initially at NBS and its value reassigned annually for the first 3 years and biennially thereafter, by using a second group of 2 or 3 saturated cells as an interlaboratory standard. The individual cells of the reference group can be intercompared monthly. The reference group is used to check the laboratory's working-standard cells of the unsaturated type and, on occasion, shop-standard cells also.

For laboratories requiring an accuracy of not over 0.01 percent in their standard of voltage, the reference standard often consists of a group of three cadmium standard cells of the unsaturated type. The individual cells are intercompared weekly by connecting them by pairs in series opposition and measuring the differential emf. These cells have a very small temperature coefficient and can be shipped safely by parcel post (if carefully packed). However, they are less constant than saturated cells and their emf usually decreases at a rate ranging from 40 to 120 microvolts per year. Therefore, their values should be reappraised at least annually on the basis of a periodic check from a higher echelon. A second group of 2 or 3 unsaturated cells can be used as an interlaboratory standard for such checks. When the emf of an unsaturated standard cell has fallen below 1.0183 volts, it is approaching the end of its useful life and can no longer be used as a reference or an interlaboratory standard. Following a moderate change in temperature, many cells tend to show a very considerable change in emf, which may persist for several days. This thermal "hysteresis" must be guarded against by allowing cells to stand for some time after shipment before taking readings. Temperature troubles with unsaturated standard cells can be minimized by keeping them in a thermally lagged copper-lined box. This reduces temperature fluctuations and differences in temperature between the two electrodes. It is important that the leads be brought out through very high grade insulation to an external terminal board. [13,14].

3.2. Resistors

If the laboratory possesses at least two standard resistors of each decimal value covering the range over which it expects to make accurate measurements, one of these can be submitted to NBS every 2 years as an interlaboratory standard, while the other resistor of each pair remains undisturbed as a reference standard in its laboratory.

3.3. Inductors

Many laboratories find it useful to possess two fixed standard inductors of each decimal value over the range it expects to cover with accurate measurements. In recent years the quality of standard inductors has been greatly improved, and this Bureau does not yet have sufficient data on the stability of the newer types to make a definite estimate of their expected stability. It is suggested therefore that one inductance standard of each denomination be submitted annually to the NBS, until a sufficient history is obtained to predict its performance.

3.4. Capacitors

Reference standards of capacitance include small fixed air-dielectric units, precision-variable air capacitors, and solid-dielectric capacitors using mica or an equivalent dielectric. Fixed standards 1,000 picofarads (micromicrofarads) or less in value must be of three-terminal construction in order to avoid uncertainties due to stray capacitances. Precision-variable air capacitors are preferably hand carried, although shipment of the capacitor in its wooden container within a padded carton is usually satisfactory. Variable capacitors with noticeable backlash must be adjusted or repaired before submission to NBS for calibration. Capacitors with worm reduction gear are calibrated at the cardinal points corresponding to each whole revolution of the worm wheel. If the worm is eccentric, capacitance increments between cardinal points will depart from linearity, but it is usually not necessary to calibrate the vernier dial for every turn.

Each laboratory should possess two capacitance standards of each decimal value and type needed to cover the range of concern. After its initial check at NBS, one standard of each value can be kept as a reference standard while the other is submitted to NBS at regular intervals as an interlaboratory standard. This interval should initially be 1 year for any one pair of standards. After the first 3 or 4 calibrations, an examination of the record will indicate the appropriate future frequency of calibration, taking into account the actual accuracy demands made on particular standards. On variable air capacitors the eccentricity correction ordinarily will be determined only during the initial calibration; thereafter, calibration at a few cardinal points is usually sufficient.

3.5. Volt Boxes

Each laboratory should have one volt box with a plurality of ratios, which can serve as a reference standard. This can be checked initially at NBS. Unless the laboratory is rather large, this same volt box may be rechecked at NBS at intervals of 2 years, and thus serve as an interlaboratory standard also.

3.6. Time Standards

Although time is not an electrical quantity, many electrical laboratories require reference standards of time or of frequency. A high-grade seconds pendulum clock with photoelectric pickup or a standard crystal-controlled oscillator may form the reference standard. Either can be calibrated by reference to the standard-frequency radio signals emitted by NBS stations WWV or WWVH.[2] By the use of a multivibrator in combination with the reference-standard oscillator, the frequency of working-standard oscillators can be calibrated over a wide range. Such an oscillator can be used to control a standard frequency circuit to which, in turn, synchronous timers can be connected to serve as working standards for measuring time intervals. The use of the frequency of local electric-power circuits as a time standard, while very convenient, may be subject to errors approaching 1 percent for short periods of time, even though the average frequency over a longer time as shown by a clock is very high. These short-time fluctuations in frequency are materially less if the supply is tied in synchronism with a large power system.

[2] For information on this service, consult Radio Standards Division, National Bureau of Standards, Boulder Laboratories, Boulder, Colo.

4. Working Standards

The working standards constitute the principal tools of the standardizing laboratory. They are calibrated at intervals by comparison with the reference standards, and used in the daily work of checking shop instruments. The number needed of any one kind and range will depend upon the volume of testing service demanded in that range. If the volume is very small, and also in special cases where extreme accuracy is needed, a reference standard can be used as a working standard also.

4.1. Standard Cells

Most laboratories will need a number of unsaturated cadmium standard cells to serve as working standards and relieve their reference cells of excessive use and of the hazard of accidental abuse. Such working-standard cells should be checked against a reference standard at intervals of 1 or 2 weeks.

4.2. Resistors

Depending upon the nature of the work in the laboratory, there will probably be required, in addition to sets of fixed standard resistors, a number of dial-type resistance boxes, perhaps including resistors in the megohm and multimegohm ranges, and also resistors or shunts capable of carrying larger currents than are appropriate to the reference standards. These working standards may initially be tested at NBS to determine the effects, if significant, of current and temperature on their resistance. Thereafter these working standards need to be checked, using a moderate current, at intervals of about 6 months by comparison with the reference standards of resistance, using a direct reading ratio set, Wheatstone bridge, or double ratio set [15], or the potentiometer method. If it is believed that a resistor has been overloaded, it should be checked against the appropriate reference standard without delay, and if a significant change in value has occurred since the last regular check, the overloaded resistor should be checked at frequent intervals until its resistance again becomes steady.

Most standard resistors are made of manganin. This alloy has the valuable property of showing low thermal electromotive force to copper and of changing relatively little in resistance with change in temperature. The resistance, R_t, at a temperature t° C is related to that, R_{25}, at 25° C by the formula

$$R_t = R_{25}\{1+\alpha(t-25)+\beta(t-25)^2\}.$$

Here the coefficient α is usually less than 10×10^{-6} and β usually lies between -3×10^{-7} and -6×10^{-7}.

4.3. Capacitors and Inductors

Each laboratory should compare all of its working standards with its reference standards once a year, and also immediately after an interlaboratory group has been calibrated at NBS. Working standards that are used frequently, or upon which great dependence is placed, may be compared with the laboratory reference standards whenever an important series of plant calibrations is undertaken.

4.4. Volt Boxes

A small laboratory may find it sufficient to use its reference volt box as a working standard also. This can be checked initially and at intervals of 2 years at NBS. It is well to measure and record the resistance of each section of each volt box initially, and monthly thereafter, as a means for detecting possible changes such as might be caused by inadvertently overloading one of the lower-voltage ranges. More often other working-standard volt boxes will be used as auxiliaries to potentiometers for the calibration of both working-standard indicating instruments and shop instruments. These can be compared monthly with the reference-standard volt box by a null method [16].

4.5. Indicating Instruments

Direct-current and alternating-current ammeters, voltmeters, and wattmeters of either the 0.1-percent or the 0.25-percent class [17] will be needed for the range of current, voltage, and power over which the shop instruments used in the plant are to be checked. The a-c instruments must be of the electrodynamic, electrostatic, or electrothermal (thermocouple) types, which can be used on direct as well as on alternating current [6, 8, 18]. The usual a-c instrument of the moving-iron type is not suitable as a transfer standard. The working-standard indicating instruments can be submitted to NBS for an initial test, and the a-c instruments for the additional determination, on appropriate ranges, of the ac-dc difference by comparison with a transfer instrument. This ac-dc difference test should cover the full range of frequency over which the instrument is likely to be used. After this initial test, they can be retained in the laboratory and checked in terms of a standard cell and standard resistor, using a potentiomenter. Preferably, the frequency of these checks ranges from 2 weeks to 2 months, depending upon the frequency of use of the working standards and their reliability as indicated by earlier check tests. Direct-current working-standard indicating instruments, when built into a console, usually have terminals so arranged that the instrument and its range-extending resistors can be checked by using a potentiometer and a bridge. Alternating-current instruments may have to be checked by comparison with interlaboratory standard instruments of a multirange type.

4.6. Watthour Meters

Laboratories that have occasion to test large numbers of watthour meters, as do those of power companies, are best guided by the Electrical Metermen's Handbook [1]. This book was prepared by a committee of experienced meter engineers for the instruction of meter-laboratory personnel.

If the laboratory has occasion to test watthour meters only rarely, it is sufficient to have available an electrodynamic wattmeter of suitable range and a standard of time accurate to the degree needed in the energy measurement. The wattmeter can be calibrated by using direct current and a potentiometer, and then used to hold a known constant power while the revolutions of the watthour meter are timed.

In intermediate cases it may be desirable to install a group of three working-standard watthour meters. These can be calibrated as indicated in the preceding paragraph, and each can be used to check a number of other meters. To minimize friction they should be used without register mechanisms but with photoelectric pickups. The complete but time-consuming calibration against the wattmeter need be made only at intervals of a month or so, provided quick intercomparisons among the three working-standard meters shows no relative change in their rates. Provision can be made by means of suitable precision current transformers so that the standard meter can be operated always at about its full-load speed, even when the meter under test is at light load.

4.7. Instrument Transformers

Many laboratories will need a set of multirange current and voltage transformers covering the range of current and voltage over which other shop transformers are to be calibrated. An initial calibration at NBS, using the burden of the standard circuit of the transformer testing set (plus ammeter or voltmeter), can be made at 60 cycles per second. The errors of current transformers in general are smaller at higher frequencies, but the initial tests should include tests at 400 or 800 cycles per second if the transformer is to be used at such frequencies. Subsequent tests at NBS need be made only at intervals of 5, or even 10, years.

5. Comparison Apparatus

The term "comparison apparatus" includes equipment by means of which the calibration of a shop instrument or standard is checked by comparing it with an appropriate working standard of the laboratory. In many cases the working standard is substituted for the device under test in the same circuit of the comparison equipment, and the change in its indication is taken as the measure of their difference. Such substitution methods are in general capable of very high accuracy, and should be used wherever practicable.

In other cases a working standard is in effect built in as part of the comparison equipment. Examples of the latter are (1) the working standard indicating instrument built into an instrument testing console and (2) the rheostat arm of a Wheatstone bridge when used directly (as contrasted with its use by substitution).

5.1. Consoles

These devices, containing appropriate sources, adjusting transformers and rheostats, and panel instruments for approximate adjustment, will provide the circuits for the comparison of shop indicating and recording instruments with working-standard instruments [19, 20]. In some types of console the working-standard instruments and their auxiliary range-extending apparatus also are permanently built into the equipment [20]. If suitable special terminals are available, these working standards can be calibrated like portable standards. If not, some secondary procedure must be set up by which the console in effect tests other working standards that have previously been checked over the full range. The console can be shipped direct from the manufacturer to the laboratory. The person in charge of calibration work at the laboratory can then satisfy himself, by appropriate measurements of insulation resistance and of circuit resistance, that the connections are correct and that the leakage and lead resistance are not such as to introduce errors. In general, these particular hazards are less if the leads can be run directly in the open between the working standard and the instrument under test.

The working-standard indicating instruments are sometimes mounted at an angle of 45° for greater convenience in reading. This arrangement, however, tends to introduce additional pivot friction. Care must also be taken to insure that no ferromagnetic material is located near enough to either the instrument under test or the standard instrument to affect its calibration. Even nonmagnetic metal supports can cause trouble by providing eddy-current circuits which can affect unshielded a-c instruments. Stray magnetic fields from supply transformers and rheostats (particularly those wound on enameled steel tubes) must be eliminated. The familiarity that the supervisor will obtain by carrying on this acceptance test forms an essential part of his training for the job. His success in it can be verified adequately by the use of a group of indicating instruments as interlaboratory standards in annual tests. The local checks of insulation and of lead resistance should be repeated every 6 months.

5.2. Direct-Current Bridges, Direct-Reading Ratio Sets, Universal Ratio Sets, Direct-Current Potentiometers

These can be tested initially at NBS and in most cases need only to be resubmitted at intervals of 3 years. During the interim, local checks can be made at intervals of 6 months by using the bridge or ratio set to measure or compare interlaboratory-standard resistors. A potentiometer can be given a rough check at least annually at one point by using it to measure a standard cell of known emf or, alternatively, by using a single cell first as the standard by which to adjust the potentiometer current and then as the unknown to be measured.

5.3. Lindeck Potentiometer

Any laboratory will find very useful a combination of a standard resistor and milliammeter (of the 0.25% class) to use as a low-range Lindeck potentiometer for the purpose of intercomparing the various standard cells in the laboratory by measuring the differences between them in pairs. The resistor and milliammeter can then be checked on the same schedule as the working-standard resistors and the working-standard instruments, respectively [12, 21, 22]. Care must be taken to minimize thermal emf in such a circuit.

5.4. Voltage-Calibrating Transformers

The ratios of the voltages of the various tapped sections of the secondary winding to the voltage of the tertiary winding to which the standard voltmeter is connected can be determined initially at each operating frequency. This should be done with no load and with rated load on the secondary while the standard voltmeter, or an impedance duplicating it, is connected to the tertiary. Subsequent tests need be made only at intervals of 5 or even 10 years.

5.5. Instrument-Transformer Test Sets

The instrument-transformer test sets can easily be checked annually at the 100-percent point and also at one other point.[3] These checks can be supplemented by using the test set and working-standard instrument transformer to measure once a year the ratio and phase angle of an interlaboratory-standard instrument transformer of the same range, which is checked at NBS every 5 years. These test sets are currently available for use at 60 and 25 cycles per second only. Radical modifications in procedure or in component values are required if they are to be used at other frequencies.

6. Interlaboratory Standards

Interlaboratory standards in general are similar in nature and inherent accuracy to reference standards and working standards. The smaller laboratories may well use some of their reference standards to serve as interlaboratory standards also. These should, so far as possible, be of rugged construction to minimize damage and change of value in shipment. On this account they usually are standards of fixed value rather than continuously adjustable devices.

[3] Simple methods for such one-point checks on instrument-transformer test sets are now being developed at the National Bureau of Standards.

The function of an interlaboratory standard is to transmit some one of the electrical units of measurement from a laboratory of higher echelon, such as the NBS, to the local laboratory. It is sent systematically to NBS for a calibration and is compared before and after this operation with the appropriate reference standard of the local laboratory. In those cases in which a large organization maintains a plurality of separate standardizing laboratories under its authority, a single set of interlaboratory standards may profitably be circulated to give a "round-robin test" by being sent to 3 or 4 of the company's laboratories in succession between trips to NBS. Such a program provides a check both on the comparison apparatus and on the operating competence of the personnel at the various laboratories. It also performs the function of maintaining the assigned values of the reference standards of each laboratory in concordance with NBS standards.

6.1. Shipment

Electrical measuring instruments such as ammeters, voltmeters, wattmeters, and watthour meters contain extremely delicate jewels and pivots, upon which the operation of each instrument depends. These delicate parts must be carefully protected from mechanical shocks and jars during shipment. Sensitive instruments will not arrive in satisfactory operating condition unless great care is taken in packing. Every effort is made to handle and to repack these instruments carefully at the Bureau, and whenever possible the return shipment is made in the original container.

Before each instrument is packed, all binding posts should be tightened, and any externally operated clamping device for the moving system should be switched to the "clamp" or "transit" position. Plugs and other small accessories should be enclosed in a small separate container tied to the instrument. Glass windows of instruments lacking protective cases should be protected by pieces of thin wood or heavy cardboard before wrapping. Each instrument should then be wrapped in heavy manila paper or similar covering and sealed with gummed tape to exclude dust and excelsior.

Boxes in which instruments are packed should be strong, preferably of wood, with screwed-on tops to avoid damage to pivots or jewels, which may be caused by a hammer or nail puller.

Clean, fresh excelsior or its equivalent in special packaging material should be used as the shock-absorbing material. A layer of excelsior at least 3 to 4 inches deep, pressed down firmly, should surround each wrapped instrument. Instruments having pivoted components should be packed upside down.

High-grade pivoted instruments of the laboratory-standard type, which have comparatively heavy moving systems without clamping devices, should be packed with special care and should always be individually shipped in wooden boxes with 4 to 6 inches of excelsior around the wrapped instrument. Portable standard watthour meters (rotating standards) should also be individually packed.

Certain heavy accessories used with instruments, such as ammeter shunts, current transformers, and voltage (potential) transformers, should be packed in separate boxes to avoid possible damage to the instruments. Heavy pieces should always be shipped in wooden boxes and held in place, if necessary, by checks or cleats. Large transformers, especially those having oil-filled iron cases, should be crated singly, and arranged whenever possible so that the terminals can be made accessible for tests without removing the entire crate.

The tops of boxes and crates must be marked "This Side Up." Boxes containing delicate instruments should be marked "Fragile, Handle With Care." Those containing any glass parts should be marked "Glass." Failure to use such markings precludes recourse in the event of loss or damage in shipping.

6.2. Standard Cells

A laboratory having reference-standard cells of the saturated type would logically provide itself with a group of about three saturated standard cells which can be sent to the NBS annually, while the reference cells are new, but biennially thereafter. Cells of this type must be kept upright at all times and protected as far as possible from shock and temperature changes. This necessitates hand carrying and arrangements at each end for installing them in a thermostatted bath [11, 12]. Smaller laboratories having unsaturated reference standards may use 2 or 3 unsaturated cadmium standard cells as interlaboratory standards. These can be shipped by parcel post. Shipments in extremely cold or hot weather should be avoided. If each interlaboratory cell is compared with the cells of the laboratory reference group before and after their transport to NBS, a very desirable check is obtained on any changes that may have occurred during transport. If any one cell shows the same value relative to the local group, before and after its travels, it is highly probable that its emf did not change and recover by an equal amount. If all cells are unchanged, the probability of the comparison being valid is greatly increased.

6.3. Resistors, Capacitors, and Inductors

Fixed standard resistors, capacitors, and inductors, whether of the fixed-unit type or groups of these combined in dial-type boxes, are satisfactory as interlaboratory standards and can be used at intervals of 1 to 2 years for comparison with NBS, depending on the stability of the reference standards that they serve. Intercomparison between the laboratories of a single organization at intervals of 1 year may prove useful in cases where the volume of testing at the individual laboratories is large and the working standards at these laboratories are therefore unusually liable to deterioration or accidental damage. The values of the interlaboratory standards of this group should be such as to cover the range of measurements with which the laboratory is concerned.

6.4. Instrument Transformers

Standard multirange current and voltage transformers can be obtained which are of quite rugged construction and give reliable performance for long periods of time. For a small laboratory, a single set of such transformers covering the complete range may be tested initially at NBS and resubmitted at intervals of 5 or even 10 years for verification. A larger laboratory in which the program of transformer testing cannot be interrupted will need a duplicate set of standard-instrument transformers, one set being used as interlaboratory standards at intervals of 5 years, while it and the other set both serve as working standards the rest of the time.

6.5. Indicating Instruments

The use of indicating instruments as interlaboratory standards is often of great value as an over-all check on the comparison equipment and on personnel and procedures. On the other hand, in general, the actual transport of the units of measurement from a higher to a lower echelon is done more accurately by standard cells and resistors. The transfer of the electrical units from d-c to a-c standards is based on the initial tests at NBS [23] of suitable 0.1-percent or 0.25-percent wattmeters, ammeters, and voltmeters. It may be found desirable, as a guard against accidental changes, to verify the performance of the transfer standards by comparing them with similar interlaboratory standards at 5-year intervals. A group of multirange a-c instruments may be used as interlaboratory standards to check the over-all accuracy of the a-c working standards built permanently into some types of consoles.

7. Summary

In the foregoing sections, some of the basic principles on which the operations of an electrical standardizing laboratory should be based have been listed; the types of standard equipment needed have been classified; and the intervals at which these pieces of equipment should be intercompared locally and checked by comparison with a laboratory of higher echelon have been suggested.

The most important considerations in such an enterprise are:

(1) The leader must have a high degree of technical knowledge and competence in the specialized field of electrical measurements;

(2) The measuring apparatus must be adequate and chosen specifically to fit the kinds of measurement and level of accuracy demanded;

(3) The checking procedures must be definite and followed carefully, but should be flexible enough to meet emergencies;

(4) The laboratory must accept responsibility for the internal consistency of its measurements, and should look to a higher echelon (such as NBS) only for its initial calibration and for periodic checks to detect drifts in the values of its reference standards.

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