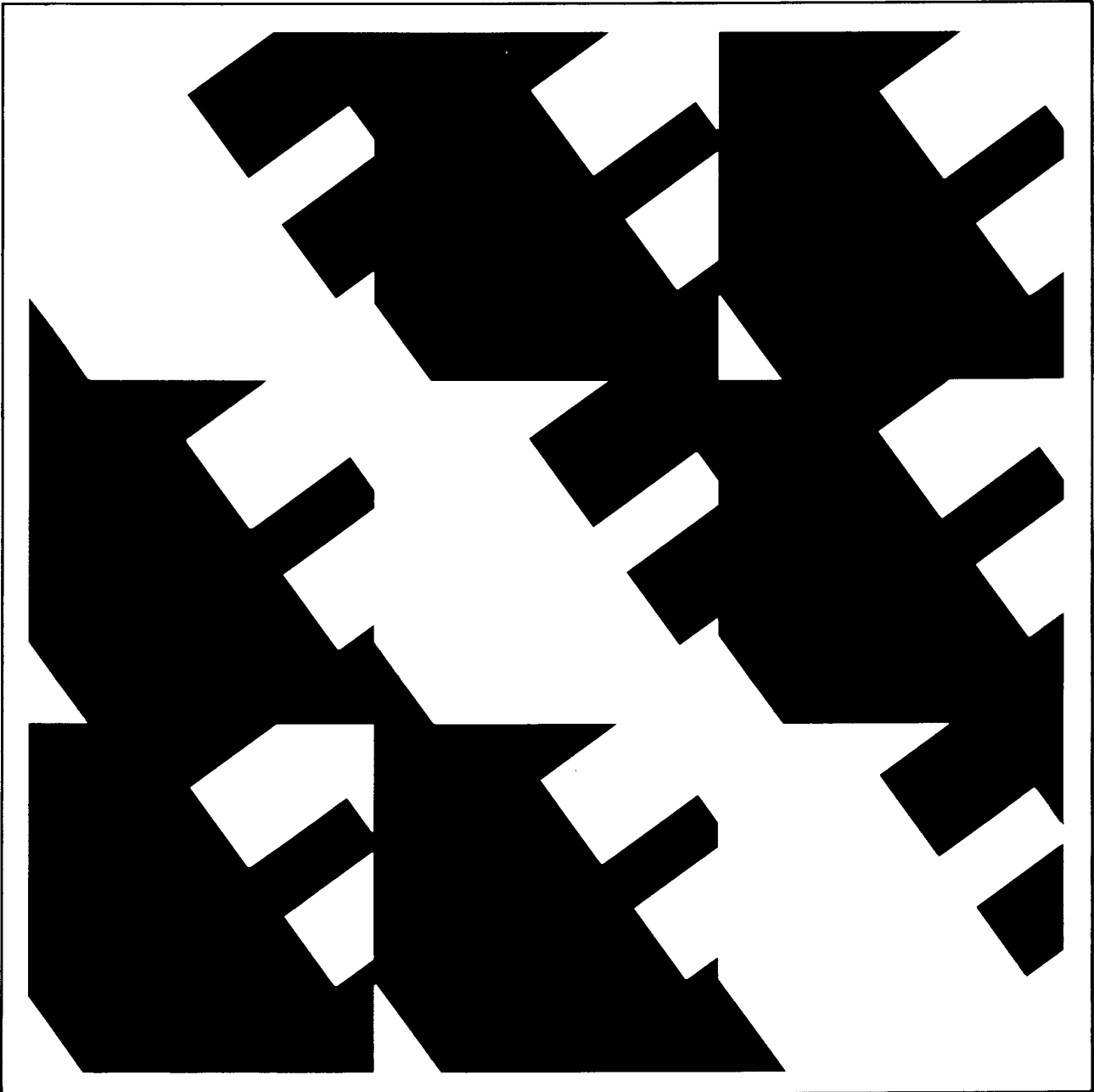


Master Test Code for Electrical Measurements in Power Circuits

IEEE Std 120-1955 – ASME PTC 19.6-1955



Published by The Institute of Electrical and Electronics Engineers, Inc 345 East 47th Street, New York, NY 10017, USA
November 25 1955

SH00588

ASME IEEE
PTC 19.6-1955 Std 120-1955

Master Test Code for Electrical Measurements in Power Circuits

(Effective November 25, 1955)

Reaffirmed March 21, 1972

IEEE Standards Board

Published by

**INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
345 East 47th Street, New York, N. Y. 10017**

FOREWORD

At the suggestion of members of the Rotating Machinery Committee of the AIEE, the Instruments and Measurements Committee voted, in 1950, the appointment of a subcommittee for preparing a Master Test Code for Electrical Measurements in Power Circuits.

Part 6, Electrical Measurements, of the ASME Power Test Code Supplement on Instruments and Apparatus of 1934 served to form the basis for the new document. Material was also taken from AIEE Test Codes 502 on Single-Phase Motors and 503 on Synchronous Machines. Other codes of the AIEE were reviewed and much new material was added.

It should be noted that this code does not include all possible tests on electric apparatus or tests conducted for research purposes.

Throughout the development of this document excellent cooperation existed between AIEE and ASME at all levels of operation.

Subcommittee members who have served during all or part of the period from the initial appointments, in 1950, until the approval of the code by the Instruments and Measurements Committee in 1955, are,

C. J. Zeller, *Chairman* 1950-53

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Suggestions for improvement of this code will be welcomed. They should be sent to the Secretary of the AIEE Standards Committee, 33 West 39th Street, New York 18, N. Y.

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MASTER TEST CODE FOR ELECTRICAL MEASUREMENTS IN POWER CIRCUITS

GENERAL

1.10 Purpose—It is the purpose of this code to give instructions for those measurements of electrical quantities which are commonly needed in determining the performance characteristics of electric machinery and equipment. The choice of method and instruments to be used in any given case depends on the purpose of the measurement, the accuracy required, the time and testing equipment available and the nature of the circuit to be measured.

1.20 Scope—The methods given here include measurements, as made with either indicating or integrating instruments, of power, voltage and current in direct-current and alternating-current single-phase and polyphase rotating machinery, transformers, induction apparatus, arc and resistance heating equipment and mercury arc rectifiers. It also includes measurements made with supplementary instruments and devices. This code does not include such measurements as resistance and temperature which are often included in determining the performance characteristics of electric machinery. Instruments for these latter measurements will be found in the specific codes dealing with the particular measurement; such as, AIEE Master Test Code for Resistance Measurement, No. 550, and AIEE Master Test Code for Temperature Measurement, No. 551.

1.30 Units—The measurement of any electrical quantity is the comparison of that quantity with another quantity of the same kind which has been chosen as a unit. The fundamental or basic electrical units are based on the meter-kilogram-second system of absolute units.

1.31 Practical Absolute Units—The practical absolute units of the electrical quantities are:

Electromotive Force and Potential	
Difference (Voltage)	volt
Resistance	ohm
Current	ampere
Quantity	coulomb
Power	watt
Energy	joule (watt-second)
Capacitance	farad
Inductance	henry

1.32 Classes of Electric Measuring Instruments—Measurements in the engineering field of the more usual electrical quantities, such as voltage, current, power and energy, are usually made with indicating, curve-drawing or integrating instruments. These are available in various forms which are generally classified as standard instruments, portable instruments and switchboard instruments. "Standard instru-

ments" are high-grade, high-accuracy, indicating instruments which, while more or less portable, are intended primarily for the laboratory. So-called "portable instruments" are somewhat less sensitive but are strictly portable and specially applicable to general testing work, particularly outside the laboratory. "Switchboard instruments" are designed for permanent mounting on switchboards along with the equipment by means of which electric apparatus is controlled. They have to withstand severe conditions, such as being in the circuit continuously and the vibration which may exist. Therefore, they are more sturdy and somewhat less accurate than the portable form.

Portable indicating instruments are the most suitable class and form for general testing of electric equipment. They have the best combination of the important characteristics of sturdiness, portability, accuracy, and reliability. Where measurements must be made over a long period of time and it is not feasible to make continuous observations of indicating instruments, curve-drawing instruments may be employed but with the sacrifice of some accuracy. Of course, in the measurement of integrated quantities such as ampere-hours and energy (kwhr), integrating instruments, usually called "meters" are employed, in which total quantity to any given instant is indicated on a dial register.

1.33 Instrument Specifications—Reference is made to the American Standard for Electric Indicating Instruments, C39.1 - 1955, sponsored by the ASA Electrical Standards Board and prepared by a subcommittee representing both manufacturers and users of instruments. Both as to definitions and specific requirements, this standard is recommended to identify the particular types of instruments which should be used for power measurements. A study of the definitions will be of interest to those concerned with electrical measurements of high accuracy.

1.40 Range and Accuracy—The range of measurements of voltage, current or power is almost unlimited because the judicious use of instruments of appropriate range used, if necessary, with auxiliary devices such as shunts, series resistors and instrument transformers permits great flexibility in range.

1.41 Limits of Error—The limit of error of an electric indicating instrument is usually specified by the manufacturer as a percentage of full scale. This tolerance is applicable to an instrument in an "as received condition" or when used under reference conditions of temperature, humidity, position, etc. These conditions have been designated as influences in ASA C39.1-1955, American Standard for Electric Indicating Instruments. Where the instrument in use is subject to influences beyond those specified

as reference conditions, additional tolerances are permitted.

The accuracy obtainable in the measurement of an electrical quantity, as of any other quantity, depends upon various factors which enter into the determination, such as correctness of the method, constancy of the quantity being measured, condition of the instruments employed, number and magnitude of the unavoidable errors and correctness of the calculations. The following table indicates in a general way the accuracy of the final result which reasonably may be expected using portable instruments of the 1/4 of 1 percent accuracy class and switchboard instruments of the 1 percent accuracy class as defined in the American Standard C39.1 referred to above. The listing assumes average observers, testing electric apparatus under ordinary conditions, and with the use of such calibration corrections as may be included with the instrument. Where special care is taken by experienced observers, and the instruments are checked immediately before and after the test with application of the mean of the calibration corrections found, the errors may be reduced as much as 50 percent.

Quantity Measured and Instruments Used	Limits of error in percent of full-scale deflection, for self-contained instrument	Limits of error, in percent when used with auxiliary apparatus*
Voltage (Voltmeter)		
Portable, d-c	0.25	0.25 - 0.5
Portable, a-c	0.25	0.25 - 0.5
Switchboard, d-c	1.0	1.0 - 1.5
Switchboard, a-c	1.0	1.0 - 1.5
Curve drawing	1.5	1.5 - 2.0
Current (Ammeter)		
Portable, d-c	0.25	0.25 - 0.5
Portable, a-c	0.25	0.25 - 0.5
Switchboard, d-c	1.0	1.0 - 1.5
Switchboard, a-c	1.0	1.0 - 1.5
Curve drawing	1.5	1.5 - 2.0
Power (Wattmeter)		
Portable	0.25	0.25 - 0.75
Switchboard	1.0	1.0 - 1.5
Curve drawing	1.5	1.5 - 2.0
Quantity Measured and Instruments Used	Limits of error in percent of reading, for self-contained instrument	Limits of error, in percent when used with auxiliary apparatus
Energy (Watt-hour Meter)		
Direct Current	1.5	1.5 - 3.0
Alternating current, single phase	1.0	1.0 - 2.0
Alternating current, polyphase	1.0	1.0 - 2.0
	Limits of error in percent of actual scale range, for self-contained instrument	
Frequency (Frequency Meter)		
Portable	1.5	1.5
Switchboard	3.0	3.0

Quantity Measured and Instruments Used	Limits of error for self-contained instrument or when used with auxiliary apparatus
Power Factor (Power Factor Meter)	
Portable	Within 0.02 (2 percent power factor) from 20 to 40 percent, inclusive; rated current, and within 0.01 from more than 40 up to and including 120 percent rated current for a scale length of 0.5 lagging to 0.5 leading, inclusive, with rated voltage and frequency applied.
Switchboard	

1.42 Selection of Instruments—A test often represents considerable money value either because of a bonus or penalty dependent upon the results, or because of the investment in labor represented. The latter becomes a total loss if it is necessary to repeat the work owing to errors made in the test. It is evident that in such cases it is good economy to take great care in selecting the instruments to be used; and in any test, instruments should be chosen which are accurate and reliable so that the result obtained may be used with confidence. If possible the calibration record for several months back should be scrutinized; erratic performance or a recent change in calibration constitutes ground for rejection. The zero indication should be stable; there should be no signs of friction at any part of the scale; and operation at full load for a reasonable period of time should not alter the accuracy beyond the "Sustained Operation Influence" requirement of American Standard C39.1-1955 previously referenced. The ranges should be selected, if possible, so that the readings will be in the upper parts of the scales. In this respect, multiple-range instruments are especially desirable. It is preferable that the graduations of scales should be "open" throughout, that is, not unduly restricted at the ends, especially the lower end. The scale factors should be decimal multiples or numbers which make for easy computation.

1.43 Transportation of Instruments—Care should be taken that calibrated instruments are moved to the test positions from the laboratory without impairing their calibrations. If many instruments are to be transported considerable distances in a truck or car, it is well to use strong wooden boxes lined with heavy felt. The instruments should be placed upside down on cushions. This puts the pressure on the top bearing which serves as a guide bearing and lets the normal bottom bearing float and not be crushed. When instruments are carried by their handles, the weight of the moving system is usually removed from the pivot points. Instruments should be laid on the floor or table without jarring; a fall though a few inches may cause a conical pivot to produce sufficient stress to crack a jewel bearing. Certain instruments have means for taking the weight of the moving system off the lower bearing when not

*Auxiliary apparatus: shunts, multipliers, or instrument transformers.

**These values apply from 10 percent to 200 percent load current and from 1.00 to 0.50 power factor lagging.

in use. Care should be taken that this is done. Instrument transformers are best shipped in boxes separate from instruments.

- 1.50 Installation**—In testing electric apparatus, the set-up should be arranged in a neat and workmanlike manner.

The purpose of the test should be clearly understood and the proposed procedure carefully thought out and planned beforehand. Instruments should be placed on a firm steady non-magnetic table or bench, which is level, and switches conveniently located and the wiring neatly and logically arranged. Instruments and switches should be conveniently located to facilitate reading and to reduce the chance of errors due to manipulating the wrong switches.

- 1.51 Location in Circuit**—All measurements should be made at such points in the circuit that there will be no question as to the correctness of the results. That is, current connections for ammeters and wattmeters should be made at a point where the current is the same as at the machine or device terminals, while voltage connections should be made at the machine or device terminals or at a point sufficiently close so that the intervening voltage drop is negligible. In general all instrument connections should be made as near to the machine or device terminals as possible because all performance guarantees and data are usually given for measurements at the terminals.

The table or bench, on which the instruments are located should be placed within sight of the apparatus under test whenever feasible, so that the testing engineer can observe the operation of the machine at all times. (See also paragraph 1.60-1)

- 1.60 Precautions in Taking Readings**—The following precautions should be observed in setting up and using electric instruments for input or output measurements of electric apparatus:

(a) Indicating and curve-drawing instruments should be of such a range that the quantity being measured will produce a reasonably large deflection preferably more than half scale, as the observational error expressed in percent decreases in direct proportion to the increase in the magnitude of the deflection.

Integrating meters should be of such a range that the loads will come between 30 and 120 percent of the rated capacity of the meter.

(b) Reliance should not be placed on a single observation. When making direct measurements, such as voltage, more observations are required with a varying quantity than with a constant quantity, to give an average which is reasonably reliable. When making measurements for a derived quantity, such as resistance, observations should be made for several values of the quantities measured, thereby reducing the chance of accidental errors. For example, in measuring the resistance of a circuit by the fall-

of-potential method, the result of one observation of amperes and volts is not as reliable as the mean of several observations, each taken with a slightly different current, noting, however, that the accuracy increases only as the square root of the number of observations. Or if a resistance is measured with a bridge, the average of several measurements with different settings is usually more accurate than a single measurement.

(c) The possible presence of external or stray magnetic fields, both direct and alternating, should always be considered. Such fields may be produced by current in neighboring conductors or buses on switchboards, by certain electric machinery and apparatus and by structural iron and steel in buildings. These fields introduce errors by combining with the normal field of electric instruments and thus increase or decrease the deflection. Instruments should be selected conforming to American Standard C39.1 where magnetic field influence is limited to the best commonly accepted commercially obtainable values. Commercial indicating instruments are now usually equipped with magnetic shields but it is not safe to depend absolutely on them. The instrument should be placed as far as possible from any suspected source of stray fields. In the case of electrodynamic instruments the presence of a disturbing external field with a horizontal component may be detected by noting the change in indication when the connection of instrument leads is reversed. In the case of permanent-magnet instruments, the presence of a disturbing external field with a horizontal component may be detected by noting the change in the indication (assuming that the quantity measured and the field remain constant) when the instrument is turned through an angle of 180 degrees. In both cases, the average indication will be correct provided the difference is not over about 3 percent.

Where an instrument must be used in the presence of a disturbing stray field, it may be possible to shield it by placing the instrument in a wooden box lined and covered with laminations of soft sheet-iron or steel to a total thickness of $\frac{1}{4}$ to $\frac{1}{2}$ inch, with a suitable opening in the top for observing the pointer. The instrument should be calibrated in the box exactly as used in the test.

(d) Although many modern portable instruments of the usual types are magnetically shielded, they are often influenced by stray fields produced by wiring which is close to the instrument.

If the wiring cannot be arranged otherwise, the field produced should be reduced to a minimum by twisting together, for a distance of three or four feet from the instrument, the two conductors of each circuit carrying any appreciable current.

(e) To avoid possible errors due to stray magnetic fields from the instruments themselves, they should not be placed close together. A safe rule

is a distance of not less than 12 inches from center to center of adjacent instruments.

The secondary leads to voltage circuits should be kept close together to avoid induced voltages in secondary loops. Large currents at 60 cps or small ones at audio frequencies can cause large errors.

(f) Instruments with glass or hard-rubber covers should not be rubbed, especially with a dry cloth. The electrostatic charge thereby produced is often sufficient to change the deflection materially. If it should be necessary to rub the glass cover when readings are about to be taken, the electrostatic charge may be dissipated by breathing on the glass.

(g) Care should be taken that the introduction of instruments or other testing apparatus does not alter the quantities being measured or the circuit conditions. For example, the mistake has sometimes been made of using low-range instruments in the secondary circuit of a current transformer in order to secure a good deflection at light loads. It should be remembered that the impedance of otherwise identical ammeters or of the current coils of wattmeters varies inversely as the square of the rated current, so that the impedance of low-range instruments may be high enough to alter appreciably the ratio and phase angle of the current transformer.

(h) It is desirable, when feasible, to provide switches so that the instruments can be conveniently cut out of the circuit except when taken readings, provided this does not materially influence the quantities being measured. This reduces the danger of damage to instruments in case of trouble in the apparatus being tested and possible errors due to temperature changes and spring set in instruments not intended to be kept continuously in the circuit. Furthermore, a switch makes the quick substitution of another instrument convenient and safe.

Instrument switches in the secondary circuits of current transformers should be so arranged that the circuit is never opened when "alive", because of the high voltage which may be developed. (See also paragraph 4.40).

(i) Care should always be taken to see that all contacts are clean and that all connections are tight in order to avoid errors due to high contact resistance.

(j) When reading indicating instruments, it is desirable to tap the instrument gently to eliminate the effect of friction.

(k) Sufficient illumination should be provided so that instruments can be read easily, quickly and accurately.

(l) When making a test in a power station or similar place, obviously the instrument should be located where there is as much freedom as possible from vibration, magnetic or electrostatic fields, and abnormal temperatures. Where excessive vibration

cannot be avoided, the instruments should be placed on pads of sponge rubber, hair felt, or similar material.

(m) At voltages of 500 volts and greater, the electrostatic attraction between moving and fixed parts may become serious. This attraction will disappear if the two parts are at the same electrostatic potential. When grounding is permissible, this can be done by connecting the circuit to earth at the point where the instrument is connected, care being taken that the moving-coil end of the instrument is on the ground side. When the instrument must be used at a high potential difference to ground, it must be thoroughly insulated from the ground and the moving element connected to the case or to an electrostatic shield around the instrument. Such a connection is a source of danger and great care must be taken that the observer does not come into contact with the instrument or the shield. The latter may be conveniently made from ordinary iron-wire netting.

(n) In shunted ammeters, errors may arise from the unequal percentage increase of resistance for the shunt and the millivoltmeter, due to the passage of the current. In old instruments, with internal copper shunts, this error is pronounced. In precision ammeters this error is not troublesome.

In voltmeters, if they are kept in circuit, there will be heating of the series resistance and movable coil due to the passage of the current, but because of the low net temperature coefficient of direct-current instruments the resulting error will not be great. The energy dissipated at full-scale deflection is about 1.5 watts in some types.

In wattmeters and alternating-current voltmeters, together with their accompanying multipliers, much more heat must be dissipated—about 7 watts in a 150-volt instrument at full-scale deflection. In addition, the proportion of copper to zero-temperature-coefficient resistance wire is greater than in direct-current instruments. The liberation of so much heat in a confined space affects not only the resistances but the springs as well. The permanent state of temperature is attained gradually, and as a result there is a progressive change in the corrections when the instrument is left in the circuit. In all cases, high-resistance multipliers must be properly ventilated.

1.70 Corrections—The zero setting of the instrument should be observed before taking readings. If the instrument has no zero adjuster or if the adjuster is not accessible to the observer, the necessary correction must be applied to the observed reading. If the instrument is provided with a zero adjuster, the pointer can be set on the zero mark and the observed reading will then be correct, provided there are no other corrections to be applied. The zero setting may be affected by temperature changes

and by the position of the instrument and should therefore be checked before taking readings if either of these effects is subject to change. If the zero reading of an instrument is altered more than 0.5 to 1 mm by tipping the instrument 10 degrees in any direction from the normal (horizontal) position of use, the moving system is not well balanced and the instrument should be carefully leveled before using.

- 1.80 Calibration**—In all tests made under this Master Test Code the electric instruments for measuring voltage, current, power, and energy shall be calibrated before and after the test with as little lapse of time as feasible between the calibrations and the test. Calibrations shall be made with (a) secondary standards which have been certified by the National Bureau of Standards, or (b) with standardized instruments which have been calibrated with such standards and which are used for standardizing purposes only.

VOLTAGE MEASUREMENTS

- 2.10 Description**—Voltage measurements in connection with tests under this Master Test Code shall be made, in general, with portable indicating voltmeters. Switchboard instruments are not usually considered acceptable but if they are used, the calibration shall show the errors under the conditions of use, i.e., as to position, temperature, distance from observers, etc.
- 2.20 Direct-Current Voltmeters**—A voltmeter for direct current is essentially a low-sensitivity portable galvanometer provided with a scale over which moves a pointer attached to the moving system. The scale is calibrated in volts by comparison with an indicating instrument of higher accuracy or by means of a potentiometer. Practically all direct-current voltmeters employ the principle of D'Arsonval galvanometers. They consist essentially of a light rectangular coil of fine wire wound upon an aluminum frame, pivoted in jeweled bearings and capable of rotating in the annular space between a core and pole pieces; a permanent magnet is arranged to produce a constant and uniform radial magnetic flux in the annular gap. The aluminum frame, being a closed secondary circuit, acts as a brake or damper while the coil is deflecting, thus quickly bringing the moving system to rest. A light tubular pointer attached to the coil moves over a graduated scale. The current is introduced into the coil by two spiral springs which also provide the controlling force. Since the field strength and the gradient of the controlling forces are uniform, the deflection is proportional to the current passing through the coil, and the scale divisions are uniform; in such a case the instrument is said to have an "evenly divided" scale. A resistor of high resistance is connected in series with the moving coil in order

that the small current required for full-scale deflection may flow when a given maximum voltage is applied. This resistor is known as the series resistor, and may be either installed in the instrument case or in an external case. A multiplier is a particular type of external series resistor which is used to extend the voltage range of an instrument beyond some particular value for which the instrument is already complete.

- 2.30 Alternating-Current Voltmeters**—Alternating-current voltmeters for engineering power tests at frequencies between 25 and 125 cycles per second are either the electrodynamic type or the soft-iron-vane type. Both of these types are made in the ordinary portable form but working standards, such as laboratory standards and precision voltmeters, are usually of the electrodynamic type. Electrodynamic type voltmeters can be used up to frequencies of 1000 cps provided they are compensated for such a frequency coverage or the frequency correction specified by the manufacturer is applied. At higher frequencies the reactance of the coils becomes dominating and introduces gross errors. Since the inductance of a soft-iron-vane voltmeter is not usually specified by the manufacturer, and may vary with frequency as well as scale deflection, frequency corrections are generally too involved to be readily applicable to this type. For making voltage measurements at frequencies above 125 cps frequency compensated voltmeters must be used. Some of the more common frequencies encountered in the extended range have been 180 cps for portable machine tools and high-speed motors, 400 and 800 cps for aircraft, 960 to 3000 cps for electric-furnace applications, and 8,000 to 12,000 cps for industrial heat-treatment use. Frequency-compensated voltmeters rated at 0-150 volts can be used for voltage measurements in the compensated range. Unfortunately, frequency compensation in low-range voltmeters requires large components and, therefore, low-range frequency compensated voltmeters are not readily available. At frequencies up to 10,000 cps, thermocouple voltmeters can be used, but at higher frequencies, errors are introduced in this type due to skin effect in the multiplier. These voltmeters are more sensitive than dynamometer and iron-vane instruments but have the disadvantage that an overload greater than 50 percent may burn out the heater in a second or two. Rectifier type voltmeters can be used up to 20,000 cps, but accuracy is then sacrificed since these instruments have frequency, wave form, and temperature errors. At still higher frequencies, vacuum-tube voltmeters have to be used to minimize the frequency error.
- 2.31 Electrodynamic Voltmeters**—In electrodynamic voltmeters the deflection is the result of the reaction between one or more movable coils and the field produced by one or more fixed coils, the coils being connected in series and to the voltage to be

measured. The deflection of the movable system is a measure of the current in the circuit of the instrument and therefore of the voltage impressed at the terminals.

An important feature of electrodynamic voltmeters is that they can be calibrated with direct current, the average of a direct and a reverse reading being taken as the correct value. For commercial frequencies they are practically independent of frequency changes.

In most instruments of this type, a single coil moves within two parallel fixed coils. The deflection is a function of the square of the current in the coils and of the angle between the planes of the fixed and moving coils.

The "Thomson inclined-coil" voltmeter is of this class, except that the plane of the fixed coils makes an angle of about 45 degrees with the shaft of the moving coil for the purpose of extending the scale.

- 2.32 Soft-Iron-Vane Voltmeters**—This type utilizes the reaction between a temporarily magnetized piece or pieces of soft iron and the magnetizing field. In the "Thomson inclined-coil" instrument of this type the plane of the energizing coils makes an angle with the shaft, which carries a member comprising one or more approximately rectangular pieces of very thin, soft iron. These pieces of iron are attached to the shaft at an angle so that rotation is produced by the tendency of the iron to become parallel to the field established by the coils.

In "repulsion" instruments of this type, the reaction which produces the deflection may take place between two pieces of soft iron subjected to the same magnetic field. In the "book" or radial-vane type of instrument, one rectangular vane is attached to the instrument shaft. The other rectangular vane is attached to the field-coil frame and is stationary. When current is established in the field coil, both iron vanes are inductively magnetized in the same polarity, and their like poles therefore repel. These instruments have a substantially uniform scale. In the "concentric-vane" type the effect of increased vane separation as the pointer moves up-scale is obtained by tapering the vanes, so that there is less exposure of one to the other as the deflection increases. The concentric-vane construction requires more operating power than the radial-vane type and produces a less-uniform scale distribution. However it offers the advantage of scale-distribution control through special shaping of the vanes.

- 2.33 Damping of A-C Voltmeters**—In some instruments, air damping is provided by means of a light aluminum vane attached to the movable system and moving in a stationary enclosing chamber. In others, magnetic damping is effected by the motion of an aluminum plate between the poles of a permanent magnet.

- 2.34 Frequency Compensated Voltmeters**—This type has part of the series resistor shunted by a suitable capacitor to extend the frequency range over which the effect of inductive reactance appreciably changes the magnitude of the current through the instrument coil.

- 2.35 Thermocouple Voltmeters**—This type employs a fine heater wire in series with a resistor. A permanent-magnet moving-coil type of millivoltmeter is used to indicate the electromotive force produced in the thermocouple attached to the heater wire. The scale of a thermocouple instrument closely approximates a square-law scale since the power in the heater is proportional to the square of the current.

- 2.36 Rectifier Voltmeters**—Instruments of this type usually employ copper-oxide rectifiers. Usually four copper-oxide disks are connected in a circuit with a permanent-magnet moving-coil type milliammeter. Full-wave rectification of the alternating current is thus secured. Suitable series resistances are provided to give the desired ranges. The deflections are proportional to the average value of the current in the indicating instrument, but the scale is calibrated in rms values. Errors will result if the wave shape departs appreciably from a sine curve.

In making core loss measurements on transformers performance data on a sine-wave basis is standard. It is not always feasible to obtain a sine-wave voltage for these measurements and therefore two voltmeters, an average reading and an rms voltmeter, are used in determining the hysteresis and eddy-current losses. The hysteresis loss, which is the larger component depends upon the average voltage; the eddy-current loss depends upon the rms value of voltage. The usual procedure in core loss measurements is to set the value of any test voltage of the proper frequency by means of the average voltmeter of the rectifier type and note the corresponding watts and rms voltage.

- 2.37 Vacuum-Tube Voltmeters**—There is a great variety of vacuum-tube voltmeters available and care should be exercised in choosing one to assure that it is the type desired for the particular measurement being made.

The popularity of vacuum-tube voltmeters is chiefly due to their high input-impedance and wide frequency range. Most vacuum-tube voltmeters are calibrated in terms of the rms value of an applied sine wave voltage. However, since the instrument actually responds to the peak, peak-to-peak, or average value of the voltage wave, or some combination thereof, the indications of a vacuum-tube voltmeter on other than sine waves should be used with caution.

- 2.40 Measurement of High Voltages**—Theoretically any high voltage can be measured with a voltmeter having sufficient non-inductive resistance in series with it. Practically, this method is applicable up to only a few thousand volts because of the relatively large power consumption in the resistance and the necessity for insulating a cumbersome resistor. Also the method is dangerous with ungrounded systems. In alternating-current circuits, any considerable

amount of inductance and capacitance in the resistance must be avoided. The measurement of alternating voltages of more than 300 volts should preferably be made with a voltmeter and a calibrated instrument potential transformer.

When using a potential transformer with a voltmeter for measuring voltage, the true ratio should be known and this ratio when multiplied by the true volts corresponding to the indication of the voltmeter, gives the voltage being measured. The actual ratio may differ from the nominal ratio by as much as 0.5 to 1 percent; hence it should be known and not merely assumed to be the same as the nameplate value. For further discussion of potential transformers see INSTRUMENT TRANSFORMERS in this code.

High voltages are also measured with electrostatic voltmeters. These instruments are quite satisfactory for the measurement of high alternating voltages, but since the force developed between the plates is proportional to the square of the voltage low-torque difficulties are encountered at low voltages. They are provided with scales which make them direct reading and at low frequencies the power consumption is negligible. When used on direct current the electrostatic voltmeter becomes a zero-current device except for the initial charging current. Its use is, therefore, indicated in the measurement of high-voltage, low-current rectifier power supplies.

- 2.50 Range and Accuracy—See paragraph 1.40 and 1.41.
- 2.60 Procedure—See paragraph 1.51.
- 2.70 Precautions in Taking Readings—See paragraph 1.60.
- 2.80 Corrections—See paragraph 1.70.
- 2.90 Calibration of Voltmeters—Portable direct-current indicating voltmeters are calibrated (a) by comparison with a carefully calibrated laboratory standard voltmeter or (b) by direct comparison against a standard cell by means of a potentiometer and volt box. In either case, both are connected to a source of steady voltage which can be adjusted conveniently to any value by means of a rheostat or otherwise, and the readings of the standard are determined corresponding to various indications of the voltmeter being checked. A higher accuracy is obtained if the indication being checked is a graduation rather than an interpolated setting. Comparison at the major scale points is sufficient unless the subdivisions are obviously non-uniform.

Dynamometer types of alternating-current voltmeters with negligible inductance can be checked with direct current against a direct-current standard voltmeter or by direct comparison with a standard cell using a potentiometer and volt box. Direct and

reversed readings must be taken at each point. The true voltage as shown by the standard, is noted for a given indication of the instrument being checked with each direction of current through the instrument and the average is taken as the true value corresponding to the indication.

Soft-iron-vane instruments can be checked with direct current with only fair accuracy. With each direction of current the desired indication must be reached by carefully increasing from a lower value and again by decreasing from a higher value, care being taken to avoid overshooting in each case. Four values are thereby obtained which must be averaged.

If suitable facilities for a direct-current check are not available or the highest accuracy is desired, the calibration should be made with alternating current against a standard voltmeter of a type that can be calibrated on direct current. A standard so used is referred to as a "transfer instrument".

Thermocouple voltmeters can be calibrated with direct current taking direct and reversed readings, but calibration on 60 cps is preferred and is generally more accurate. Rectifier and vacuum-tube voltmeters should be calibrated with alternating voltages against secondary standards; the calibration of vacuum-tube voltmeters should be at sufficiently frequent intervals to compensate for changes in tube characteristics; intervals of 100 hours of use are suggested.

CURRENT MEASUREMENTS

- 3.10 Description—Current measurements in connection with this Code shall be made in general, with portable indicating ammeters. The principle of all ammeters is essentially the same as that of the electrodynamic, soft-iron-vane and thermocouple voltmeters described under VOLTAGE MEASUREMENTS. As stated under GENERAL in this Code the range of measurement of current is almost unlimited through the judicious use of auxiliary devices such as shunts for direct current and current transformers for alternating current.
- 3.20 Direct-Current Ammeters—Direct-current ammeters are usually low-range voltmeters connected across a resistor of low resistance (shunt) which is connected in series with the circuit in which the current is to be measured. The deflections will be proportional to the potential drop across the shunt and, therefore, to the current through it. This potential drop is kept small so that the energy loss in the shunt will not be large. Hence the instrument is essentially a millivoltmeter but the scale is usually graduated to read directly in amperes.
- 3.21 Portable Ammeters—Portable ammeters having ranges up to 25 amperes are usually "self-contained", that is, the shunt is within the instrument case. For ranges greater than 25 amperes the shunt is usually

separate from the instrument proper but connected to it by detachable leads.

- 3.22 Ammeter Shunts**—An ammeter shunt is constructed to have a resistance as nearly constant as possible, under all conditions. The resistance metal has a low temperature coefficient of resistance and the temperature is kept low either by connecting several strips in parallel and making the current density low, or if the current density must be high, using short lengths of the resistance metal with heavy copper terminals designed to dissipate the heat by conduction and radiation.

Furthermore, the resistance metal should have a low thermal emf against copper for two reasons: first, if one end of the shunt becomes hotter than the other because of poor contact at one current connection or to a poor connection in the cable or bus structure near that end of the shunt, a thermal emf will be produced in addition to the potential drop across the shunt; second, when current passes through the junction of two dissimilar metals which have a thermal emf with respect to each other, a Peltier effect results, that is, heat is absorbed or produced. Hence, one junction tends to become cool and the other to become hot and the resultant difference in temperature will produce an emf.

The potential drop in the shunt at full-scale deflection is usually about 50 to 200 millivolts. Instruments used for high-accuracy measurements are designed to require 100 to 200 millivolts at full scale. The shunt is usually separate from the instrument for all ranges of current so that one millivoltmeter may be used with several shunts. Whenever the shunt is separate from the instrument, the leads form a part of the instrument circuit and should never be altered without recalibrating the instrument or taking care that the resistance of the leads is kept the same as originally. In order not to introduce high contact resistance care should be taken that the terminals of leads, instrument, and shunt are clean and that the connections are tight. Obviously, broken strands of wire in flexible leads (such breaks frequently occur near the terminals) will introduce an error through change of lead resistance.

Direct-current ammeters are adjusted by changing the resistance of the shunt, the resistance of the millivoltmeter circuit, or both. Formerly, each instrument and shunt were adjusted together but it is becoming customary to adjust all of the instruments of a given type to deflect full scale with the same potential drop in millivolts at the terminals. The shunts for these instruments are all similarly adjusted to give the same potential drop, thus making all shunts and instruments of a given type interchangeable. The shunts should be adjusted by varying the resistance between the potential taps and not by adjusting a resistance wire connected in series with the instrument leads.

In the application of shunts to the measurement of direct current the precautions for use, as outlined in paragraph 3.23, should be followed if accurate and reliable measurement is to be secured.

- 3.23 Measurement of Large Direct Currents**—Large direct currents are measured in the same manner as small currents, i.e., with millivoltmeters connected to shunts—the shunts being correspondingly larger in physical dimensions and lower in resistance. Certain precautions should be observed, however, when using large shunts. Shunts of several thousand amperes in capacity should be designed with long, multiple-leaf copper blocks to insure that the current distribution will be uniform through the shunt and will be the same after installation as when it was calibrated. Every time a large shunt is connected to a multiple-leaf bus structure, the contact resistance distribution is changed and if the junction is close to the resistance strips, the current will not be distributed uniformly among them.

In installing large capacity shunts in a bus structure they should preferably be placed in a horizontal bus run with the leaves mounted in a vertical plane, the shunts being so located in the bus structure as not to be immediately adjacent to right-angle turns in the bus. In addition, they should not be mounted in immediate proximity of large switches that are likely to "run hot" or any other heat producing element that would raise the temperature of the shunt unevenly and they should never be mounted vertically as the upper terminal would be heated by rising air currents. This latter practice would result in a thermal gradient across the shunt. All shunt connection surfaces should be clean and the joints made tight.

- 3.24 Transducers for Measurement of Large Direct Currents**—Large direct currents can also be measured by means of transducers which have the characteristics of current transformers. Transducers are sometimes used when the usual method of employing shunts is not convenient because of the size of the shunts and the difficulty of dissipating the losses occurring in them. A measuring transducer consists of two iron cores, called transducer elements, each forming a closed magnetic circuit around the d-c conductor. Each core has an a-c winding and the two windings are connected in series in such a manner that a current through them will in one of the coils assist the conductor field while in the other coil it will oppose it. The windings are energized with an alternating voltage and the current which flows is measured, preferably with a rectifier type ammeter. The rectified mean value of the alternating current is proportional to the direct current in the conductor. The a-c circuit is sufficiently sensitive to reflect closely the oscillations and variations in the direct current. Measuring transducers have a limiting error of $\pm$ two percent or less, but in the smaller