# TEST METHOD 1

## MEASUREMENT OF POTENTIAL

1.1 GENERAL. The terms "voltage", "electromotive force", and "potential" are considered synonymous herein.

1.2 INDICATING EQUIPMENTS.

1.2.1 DC VOLTAGE. Two types of instruments are recommended for measuring dc voltage - D'Arsonval voltmeters and digital measuring devices.

Voltmeter ranges can be further extended, even beyond 50,000 volts, by conjunctive use with a high voltage probe or with externally-attached multiplying devices. Such devices, commonly referred to as "resistor decade box", are precision-made, wire-wound resisters. They are carefully manufactured and calibrated to be electrically stable within specific tolerances over ranges of temperature and periods of time.

Voltmeters, especially millivoltmeters, should not be connected into circuits having voltages higher than the rating of the instrument. To measure voltages higher than the rating of a relatively low resistance instrument, a high voltage probe or a "resistor decade box" must be used with it. If a resister decade box is used, the correct voltage is obtained by solving the following equation:

$$E = \frac{V_r(R_v+R_m)}{R_v}$$

where:

E is the voltage to be measured.

$V_r$ is the reading of the voltmeter.

$R_v$ is the resistance of the voltmeter. (This may be found on the voltmeter dial or on the voltmeter cover.)

$R_m$ is the resistance selected on the resistor decade box. (This value is adjusted on the exterior of the resistor decade box.). This formula, solved for Rm, can be used for selecting the resistance to be used if the approximate value of E is known.

Because of the high-inductive-voltage surge which may bend the pointer on D'arsonval analog type meters, dc voltmeters should be disconnected from a field circuit before the field switch is opened. Because of high alternating voltages developed by transformer action in the field

windings during starting, dc voltmeters also should be disconnected from synchronous motors or synchronous condenser fields before the machines are started from the ac line.

1.2.2 AC VOLTAGE. Two type of (RMS) sensing are used to measure ac voltage. These type are dynamometer and digital type measuring devices. Dynamometer type voltmeter ranges usually are from 7-1/2 to 750 volts full scale. Dynamometer type voltmeters should not be used outside their rated frequency range. Digital type measuring devices usually have wider ranges and in many cases are autoranging.

1.3 RECORDING EQUIPMENTS. Recording voltmeters, transducers, or digital measuring equipments are used to measure transients or time-varying voltages. They shall meet or exceed the following specifications:

| | AC Voltage | DC Voltage |
|---|---|---|
| Deviation | 25 $V_{RMS}$ | 25 VDC |
| Response Time | | |
| 10-90% | 60 ms | 100 ms |
| Swing | 2.5-22.5 $V_{RMS}$ | 2.5-22.5 VDC |
| Total Deviation | 20 $V_{RMS}$ | 20 VDC |
| Slew Rate ($V_{RMS}$/ms) | 20/60 = .33 | 20/100 = .20 |
| Input Bandwidth | -3dB @ 1 kHz | -3dB @ 5 Hz |
| Output Bandwidth | -3dB @ 8 kHz | -3db @ 5 Hz |

1.4 POTENTIAL TRANSFORMERS. Potential transformers are used for two purposes: to isolate the testing instruments from the line voltage, and to act as multiplying devices for the instruments.

To obtain satisfactory accuracy when using a potential transformer, it should be used under conditions of voltage, frequency, and volt-ampere burden that the manufacturer rated it for.

# TEST METHOD 2

## MEASUREMENT OF CURRENT

2.1 GENERAL. Current is obtained from the formula

$$I = E / R$$

where I is the current in amperes, E is the potential reading in volts, and R is the resistance in ohms.

2.2 INDICATING AMMETERS. When any ammeter is used in a circuit having cyclic or varying current levels, such as exciter fields, it must be recognized that the accuracy of the instrument is compromised by these fluctuations, often by an amount that renders the instrument useless for the intended measurement. Filtering devices are available for minimizing the effects of these fluctuations.

2.2.1 DIRECT CURRENT. For the measurement of direct current, analog D'Arsonval-type or digital measuring devices are used.

For measuring current beyond the capacity of the instrument at hand, shunts are used to extend the range of the meters. Shunts are precision four-terminal resistors used to measure current by measuring the voltage drop between the voltage terminals with the current introduced at the current terminals. Shunts are normally calibrated for a specific millivolt drop at a specific known current. When D'Arsonval or digital measuring devices are used in connection with shunts, (as in an ammeter system), the millivolt rating of the equipment should be the same as that of the shunt at rated current utilizing calibrated leads.

2.2.2 ALTERNATING CURRENT. For the measurement of alternating currents (RMS) sensing and indicating meters such as iron-vane type analog instruments, and digital measuring devices normally are used. By combining these instruments with appropriate current transformers, any ac current measurements having practical significance can be made. Because of the nonlinear characteristics of most analog ac ammeter scales, they should not be used in the lower portion of their ranges.

2.3 CURRENT TRANSFORMERS. Current transformers are used for two purposes; to isolate the instrument from the line voltage, and to act as a multiplying device for the instruments.

It is desirable to use three current transformers with three measuring devices (or one measuring device and a suitable transfer switch) to measure the three line currents on three-phase, three-wire circuits. The use of less than three current transformers is usually not cost-effective, due to time consumed changing test connections, and may not provide the desired level of confidence for acceptance testing.

**CAUTION**: ALLOWING DIRECT CURRENT TO FLOW IN EITHER WINDING, MAY CAUSE THE TRANSFORMER CORE TO BECOME MAGNETIZED AND IMPAIR THE ACCURACY OF THE INSTRUMENT. IN ADDITION, DANGEROUSLY HIGH VOLTAGES MAY BE INDUCED IN THE SECONDARY WINDING (PRIMARY OR SECONDARY), CAUSING POSSIBLE INJURY TO THE OPERATOR AND BREAKDOWN OF THE WINDING INSULATION. IF MAGNETIZATION IS SUSPECTED OR IF THE CALIBRATION IS NOT EVIDENT, THE TRANSFORMER SHOULD BE SUBMITTED TO A PROPER CALIBRATION FACILITY FOR CERTIFICATION. IN ORDER TO OBTAIN MAXIMUM SAFETY FOR OPERATORS AND APPARATUS, ONE SECONDARY TERMINAL MUST BE GROUNDED; THE METAL CASE OR CORE, IF ACCESSIBLE, MUST BE GROUNDED; CONNECTIONS MUST NOT BE MADE OR CHANGED WITH VOLTAGE ON; THE PRIMARY OF THE TRANSFORMER MUST BE CONNECTED IN THE LINE AND THE SECONDARY TO THE INSTRUMENTS, AND NOT VICE VERSA; AND THE SECONDARY OF THE TRANSFORMER MUST NOT BE OPENED WITH THE CURRENT FLOWING IN THE PRIMARY. A SHORTING SWITCH ACROSS THE SECONDARY WILL BE PROVIDED. THIS SWITCH WILL BE OPENED ONLY WHEN TAKING METER READINGS. THIS SWITCH NORMALLY WILL BE A PART OF THE CURRENT TRANSFORMER.

# TEST METHOD 3

## MEASUREMENT OF POWER

3.1 GENERAL. Mechanical power most commonly is expressed in horsepower. Electrical power ordinarily is expressed in watts.

There is no practical primary standard of electric power, the Watt being derived from the volt and ampere. However, expressed in terms of work performed, one kiloWatt (1,000 Watts) is equal to 1.34 horsepower.

Horsepower is the equivalent of the amount of work performed in a given time. One horsepower is the rate of work performed equivalent to raising 33,000 pounds 1 foot in 1 minute.

3.2 DC MEASUREMENT. DC power is usually found by computing the product of the voltage and amperage in the circuit. This is represented by the formula W = EI where W is in Watts.

3.3 AC MEASUREMENTS. AC power measuring equipment may be designed for use in single-phase or polyphase circuits. The formula for power in a single-phase circuit is W = EI cos ▼, where E is the line voltage, I is the line current, and cos ▼ is the power factor (see Test Method 7). For balanced three-phase circuits the power formula is W = ↗3 EI cos ▼, where E is the line-to-line voltage, I is the line current, and cos ▼ is the power factor.

Power measuring equipment is generally available with potential circuits rated from 10 to 600 volts, and current circuits rated from 1.5 to 200 amperes. Full scale readings for such instruments range from 15 to 120,000 watts. There are also special power measuring equipment designed for use at low power factors.

Transducers are available to convert real power (watts) to a dc voltage with the dc voltage directly proportional to the power. These transducers may be used during the performance of the tests contained in EGSA 107T providing the accuracy of the system (transducer and voltmeter) meets the instrumentation accuracy required in Test Method 17 and the normal instrumentation calibration requirements are met.

AC digital measuring equipments is available for measurement of power and may be used interchangeably with analog instruments.

# TEST METHOD 4

## MEASUREMENT OF FREQUENCY

4.1 GENERAL. Frequency is defined as the number of recurrences of a cyclic quantity per unit of time. For ac circuits, frequency normally is expressed in Hertz.

The primary standard of frequency is maintained at the National Bureau of Standards in the form of quartz-crystal oscillators maintained under carefully controlled conditions, at constant pressure. The oscillators control various standard frequencies ranging from 440 Hertz to 15 megaHertz. Some of these are broadcast continuously.

4.2 INDICATING EQUIPMENT. There are two types of measuring frequency. They are the type constructed on the resonant-circuit principle and the digital type measuring devices. The first type usually makes use of two or more resonant circuits and a differential-type measuring instrument. Thus, if one circuit resonates at a frequency slightly below the other, the ratio of the currents in the two circuits is a measure of the impressed frequency. Indicating frequency meters of this type have no springs to return the pointer to the end of the scale; therefore, the pointer will take no particular position when the instrument is not connected in a circuit.

These instruments will operate with satisfactory accuracy on voltages within 10 percent of their rating and generally are unaffected by voltage changes within this range.

Digital type measuring devices are also available for these measurements and may be used interchangeably with analog instruments, providing the frequency is not cyclic or varying.

4.3 RECORDING EQUIPMENT. Recording frequency meters, transducers, or digital measuring equipment are used to measure the transient change in speed of a generator set due to a sudden change in load and the steady state stability of a generator set under constant conditions. They shall meet or exceed the following specifications:

| | 50, 60 Hz | 400 Hz |
|---|---|---|
| Deviation | ±2.5 Hz | ±25 Hz |
| Response Time | 5 Hz | 50 Hz |
| 10-90% | 250 ms | 250 ms |
| Swing | .5-4.5 Hz | 5-45 Hz |
| Total Deviation | 4 Hz | 40 Hz |
| Slew Rate (Hz/ms) | 4/250 = .016 | 40/250 = .16 |
| Input Bandwidth | -3dB @ 1 kHz | -3dB @ 1 kHz |
| Output Bandwidth | -3dB @ 3 Hz | -3dB @ 3 Hz |

# TEST METHOD 5

## MEASUREMENT OF RESISTANCE

5.1 GENERAL. The primary standard of resistance is the ABSOLUTE ohm, which is derived from the fundamental units of length, mass, and time. The National Bureau of Standards maintains the primary standards of resistance in the form of 1-ohm resistors, which are kept at constant temperature when in use.

The importance of accuracy in measuring resistance cannot be overemphasized. These measurements are used to calculate the efficiency of a generator, and to determine the temperature rise of the windings. Both of these are critical factors in design. These measurements also are employed to determine the correctness of the internal connections of the generator, and, at times, to ascertain whether a sample test generator is the same as the production model.

The leads of the winding to be measured must be clean. The terminal lugs should be cleaned with emery cloth to make sure that all foreign matter, paint, varnish, or oxide coating is removed and only bright, bare metal remains exposed for contact. Care must be taken to compensate for lead resistance to the test instrument if such resistance is of a significant value compared to the resistance being measured.

5.2 CLASSES OF RESISTANCE MEASUREMENTS. There are three general classes into which resistance measurements are divided. These are: LOW resistance, covering a range below 1 ohm; MEDIUM resistance, covering a range between 1 and 100,000 ohms; and HIGH resistance, covering a range above 50,000 ohms. These will be discussed in detail in the following paragraphs.

Circuits whose resistance is to be measured often are highly inductive, and damage to the galvanometer or detector may result unless the following precautions are exercised: Close the battery or supply switch first, wait a few seconds for the current to build up, then close the detector switch. After obtaining the setting or reading, open the detector switch first, then open the supply switch.

5.3 LOW RESISTANCE MEASUREMENTS. To measure resistance of less than one ohm, one of the following methods may be used: the Drop-in-Potential Method, or the Comparison Method.

5.3.1 Drop-in-Potential Method. A resistance may be calculated by means of ohm's law,

$$R = \frac{E}{I}$$

if the voltage across the resistance and the amperage through it are known. Thus, to measure a resistance by the drop-in-potential method, connect the unknown resistance in series with an ammeter and a source of constant direct current. Connect a voltmeter across the resistance. Then, calculate the resistance by dividing the voltmeter reading by the ammeter reading.

The ammeter and voltmeter should be chosen so that the deflections obtained are reasonably large in order to avoid the large percentage errors which may occur in the lower part of the instrument scales.

The current used should be great enough to give good instrument readings without heating the unknown resistance, which would change its value. If the current used is unsteady, simultaneous instrument readings should be taken by two observers. A series of such readings, when averaged, will give reasonably accurate results although the individual readings are in error.

The ratio of the voltmeter resistance to the unknown resistance affects the accuracy of the measurement because the voltmeter current flows through the ammeter. The fractional error is equal to the reciprocal of this ratio (the unknown resistance divided by the voltmeter resistance). If the ratio is 1,000 or less, the ammeter reading should be corrected accordingly.

For very precise work, the voltmeter should be replaced with a potentiometer, and the ammeter with a potentiometer and calibrated shunt.

5.3.2 Comparison Method. The comparison method of measuring resistance is an adaptation of the drop-in-potential method described above. However, the results obtained are independent of the current measurement.

In this method, connect the unknown resistance in series with a known resistance and a source of direct current. Measure the voltage across both resistances and calculate the unknown resistance by the following formula:

$$X = \frac{R\,E_x}{E_r}$$

where:

X is the unknown resistance.
$E_x$ is the voltage across X.
$E_r$ is the voltage across R.
R is the known resistance.

Maximum accuracy is obtained when R and X are equal.

The current source should be steady and the voltmeter should have a resistance 100 or more times the resistance of either R or X.

This method is especially applicable to a wide variety of measurements in which the actual value of each of a series of resistances is relatively unimportant, but in which all of the elements should be equal, such as the windings of a dc generator, or the field coils of an alternator. In this case, connect the elements to be measured in series and measure the drop across each one. If the resistance of one element is used as a standard, the calculations are the same as previously described.

5.4 MEDIUM RESISTANCE MEASUREMENTS. Resistance which falls between approximately 1 ohm and 100,000 ohms may be measured with an ohmmeter.

5.5 HIGH RESISTANCE MEASUREMENTS. Resistance's of 50,000 ohms and more may be measured by either of the following methods:

5.5.1 DC Voltmeter Method. A dc voltmeter with a resistance of approximately 100 ohms per volt, and a source of constant potential, usually about 500 volts, are employed in this method.

Connect the voltmeter directly across the source and note the reading. Insert the unknown resistance in series with the voltmeter and source and again note the reading.

Calculate the unknown resistance from the following formula:

$$X = \frac{R_v E - V_r}{V_r}$$

where:

X is the unknown resistance.
E is the supply voltage.
$V_r$ is the voltmeter reading in series with X.
$R_v$ is the voltmeter resistance.

This method should be used only when the supply voltage is steady. When the voltage is unsteady, simultaneous readings of E and $V_r$ should be taken with two voltmeters. In this case, $R_v$ is the resistance of the voltmeter in series with X.

Caution must be exercised in the use of this method because of the high voltage supply.

5.5.2 Megger Method. A "megger", or insulation resistance tester, is a self-contained direct-reading instrument, consisting of a small magnetic generator, battery, or electronic power supply, standard resistance; and a differential-current milliammeter.

The electromotive force of the generator is impressed upon the unknown resistance and the standard resistance, in parallel. The two currents are compared in the differential-type instrument so that the instrument reading depends only upon the value of the unknown resistance and is independent of the applied emf.

The megger always should be operated until the indication is steady and constant before a reading is taken.

# TEST METHOD 6

## MEASUREMENT OF TRANSIENT AND WAVEFORM

6.1 GENERAL. Electrical transients and waveform may be observed by connecting an oscilloscope to the circuit in question. Waveform cannot be determined by using a harmonic analyzer to measure the magnitude, or relative value, of the component frequencies, and plotting the waveform from these values, since the phase angle differences of the various harmonics would not be known. However, harmonic analyzers may be used to determine a measure of deviation of an unknown wave from a sine wave.

6.2 OSCILLOSCOPE. Oscilloscopes are extremely versatile instruments which are procurable in single-beam and multi-beam models

Oscilloscopes use two different kinds of storage - digital and cathode-ray-tube (CRT) type. Digital scopes store data representing waveforms in a digital memory; CRT storage scopes store waveforms within the CRT; either on a mesh or special phosphor coating.

A digital oscilloscope is an instrument that digitizes, stores, and displays a digital representation of analog signals. It can permanently display the analog trace of a transient signal. Digital scopes have fast analog-to-digital converters.

A digital oscilloscope is an instrument that digitizes, stores, and displays a digital representation of analog signals. It can permanently display the analog trace of a transient signal. Digital scopes have fast analog-to-digital converters. These converters can sample and digitize information at rates from one data point every 200 seconds to 2 million data points per second. They can store 16,000 points of data internally and unlimited amounts using external accessories. Voltage resolution of 1 part in 4,000 is possible. Time and voltage may be displayed in Alpha numerics on the CRT. Digital storage requires digitizing and conversion processes. "Digitizing" consists of "sampling" and "quantizing". Sampling is the process of obtaining the value of an input signal at a discrete point in time; quantizing is the transformation of that value into a binary number by the analog-to-digital (A/D) converter. The time base determines how often digitizing occurs. The time base uses a digital clock to time the A/D conversion and to store the data in memory. The rate at which this happens is the digitizing (or sampling) rate. Once the data is stored in the digital memory, it can be recalled for displaying or further waveform processing.

The oscilloscope is used for the observation of waveform and transients, by connecting the signal under observation to the Y, or vertical-axis, input terminals. The internal sweep, which supplies a sawtooth signal, with a magnitude linearly proportional to time, is then applied to the X, or horizontal-axis, input terminals and synchronized to the signal being studied. The resulting screen image shows the waveform of the unknown signal as time progresses.

A camera attachment can be used to obtain a record of the waveform.

The following precautions should be observed when using an oscilloscope:

CAUTION: Care must be exercised when observing line to line voltage since the scope may be grounded through the bench power cord. If measurement is above ground potential, isolate scope prior to use. Due to the internal high voltage hazard, the equipment should not be operated with the case removed.

(1) A small spot or highly intensified line should not be kept stationary on the screen since such spots or lines will cause the screen to burn or become discolored.

(2) To preclude spurious deflections, the instrument should be kept as far as possible from magnets, power transformers, reactors, or busses carrying current.

(3) If extremely large power line voltage fluctuations are present, it may be necessary to employ a regulated power supply. However, precautions against spurious magnetic fields should be observed (2 above).

(4) The image must be kept on the plane portion of the screen. If the image is extended to the edge of the screen, it will be distorted, due to the curvature of the tube. Moreover, the linearity of the oscilloscope amplifier is seldom satisfactory when the signal is amplified to the value necessary for full screen projection.

106.1.3 HARMONIC ANALYZER. The harmonic analyzer is essentially a precise electronic voltmeter combined with a tunable band-pass filter with provisions for determining the magnitude or the relative value of voltages of different superimposed frequencies applied to its terminals.

To obtain the harmonics with a harmonic analyzer, the signal is connected to the input terminals and the magnitude or relative value of the fundamental and harmonics is determined in accordance with instructions obtained from the manufacturer of the harmonic analyzer.

CAUTION: Care must be taken to assure the analyzer is ungrounded when used on line-to-line voltages. Personnel must be aware that this above ground potential is present and must not touch the analyzer and a grounded conductor at the same time.

6.4 TRANSIENT WAVEFORM RECORDER. A waveform recorder is most simply described as an analog-to-digital converter with memory. These waveforms can then be output in various ways. The display output reconstructs the stored digital data via a digital-to-analog (D/A) converter at a repetitive cycle for a flicker-free presentation on a x-y monitor or an oscilloscope. A plot may be obtained from the D/A output for record and analysis. Digital output is also available for interface with external computer input busses. The feature facilitates incorporation of the instrument into extensive automated data collection and analysis systems. Digital oscilloscopes with storage capability are also transient waveform recorders.

Transient waveform recorders have fast analog-to-digital converters. These converters can sample and digitize information at rates to 10 million times per second and can store 4,000 points of data at this acquisition rate. Voltage resolution of 1 part in 1,000 is possible.

# TEST METHOD 7

## MEASUREMENT OF POWER FACTOR

7.1 GENERAL. Power Factor is the ratio of the total power (in watts) flowing in an electric circuit to the total equivalent volt-amperes flowing in the circuit. In single-phase and balanced three-phase systems it is equal to cos ▼, where ▼ is the phase angle between the voltage and current in a single-phase circuit, or between the phase voltage and phase current in a balanced three-phase circuit.
Reactive volt-amperes (VARS) is the product of the reactive voltage and current, or the product of the voltage and reactive current in an ac circuit.

7.2 INSTRUMENTS AND EQUIPMENT FOR POWER FACTOR MEASUREMENT. The dc wattage is computed by ascertaining the product of the voltage and current in a circuit (W=EI). When this same mathematical process is applied to an ac circuit, the resulting answer is not necessarily a measure of the power. It is either equal to or greater than the actual power. If this product, called "apparent power" (VA, or Volt-Amps), is divided into the actual power (W=EI cos ▼) of a circuit, the resulting decimal figure (cos ▼) is the POWER FACTOR of the system.

Load banks are routinely used to simulate load conditions for electrical power generator set testing and evaluation. Information on load banks is contained in Appendix A of this handbook.

When the load is entirely resistive, the power factor will be unity. If any inductance is in the circuit, the value of the power factor will be less than unity and is said to be "lagging" (current "lagging" or not in phase with the voltage). Thus, if the power actually consumed by an inductive load is 300 watts and the product of the voltage and amperage is 500 volt-amperes, the power factor is 300/500, or 0.6 lagging. If capacitance is present in the circuit, the value of the power factor will be more than unity and is said to be "leading" (current leading voltage).

When measuring a three-phase balanced system, that is, one in which the voltages are equal in the three phases and in which the currents are likewise equal, and no current in the neutral conductor, the formula for power is W= EI cos ▼ where E and I are line voltage and current respectively. Here, again, cos ▼ is the power factor.

Instruments are designed which will measure the power factor in single-phase circuits, and others are designed to measure the power factor in balanced three-phase circuits. No instruments are designed to measure power factor directly in unbalanced three-phase systems nor in systems in which the alternating current wave is greatly different from a sine wave. When it is desired to determine power factor in these cases, more rigorous methods of analysis are necessary. These are beyond the scope of this standard but are amply discussed in handbooks on electrical metering and instrumentation.

In measuring low values of power factor, care should be taken not to use an instrument which is accurate only for high values of power factor.

In the following discussions, balanced polyphase systems and sinusoidal voltages and currents are assumed.

7.3 INSTRUMENTS FOR REACTIVE VOLT AMPERES. Power factor may be determined from the equation:

$$PF = \cos(\tan^{-1} \frac{VAR}{W})$$

where:

PF is the power factor.
VAR is the reactive volt-amperes.
W is active power.

Reactive volt-amperes may be measured on an ordinary wattmeter, providing either the voltage or current coil is excited by a signal proportional to, and vectorially in quadrature with, its normal wattmeter excitation. The two common methods of providing such excitation are described below.

7.3.1 Series Reactance Method. The potential coil excitation may be shifted 90 degrees by the insertion of a series reactance in the potential coil circuit. This type of instrument is connected in the same manner as a standard wattmeter and may be used in single-phase circuit, as well as in individual phases of a polyphase circuit. In order to measure VAR in a three-phase circuit, two VAR meters of this type are connected in the same manner as the wattmeters in the two-wattmeter method of measuring active power (figure 25.1-21 of Test Method 25.1).

7.3.2 Cross-Phase Method. In three-phase systems, the active component of current in one line is in quadrature with the voltage between the other two lines, while the reactive component of the same current is in phase with this voltage. Thus, an ordinary wattmeter connected with its current coil in one line and its potential coil between the other two lines indicates VAR directly. Total VAR for the system is the wattmeter reading multiplied by the square root of three.

7.4 PHASE ANGLE METERS. Various other instruments, graduated in terms of either phase angle or power factor, are available for power factor measurements. These instruments may operate on any of a number of principles such as the use of phase angle itself, or the use of a mechanical comparison of the speeds of a watthour meter and
VAR-hour meter to indicate power factor directly. They should be connected in accordance with manufacturer's instructions, depending upon the type to which they belong.

7.5 TWO-WATTMETER METHOD. When active power is being measured by the two-wattmeter method, the power factor may be calculated from the two readings by applying the following formula:

$$PF = \cos \blacktriangledown = \frac{W_1 + W_2}{2 \nearrow W_1^2 - W_1 W2 + W_2^2}$$

where:

PF is the power factor.
$W_1$ is the higher wattmeter reading, which may be either positive or negative.
$W_2$ is the lower wattmeter reading, which may be either positive or negative.

# TEST METHOD 8

## MEASUREMENT OF TIME

8.1 GENERAL. The primary standard of time in the United States is based on astronomical observations made by the Naval Observatory at Washington, D.C. Time signals based on these determinations are sent out by Naval Radio Stations and by Station WWV of the National Bureau of Standards. Secondary standard clocks may be pendulum controlled or synchronous clocks driven by a constant frequency source such as a tuning fork, or crystal oscillator. These secondary standards may be checked against the Observatory time by using the radio broadcasts.

8.2 MECHANICAL TIMERS. Mechanical clocks for laboratory use usually are of the stop watch kind. They are specifically designed for measuring time intervals of the order of an hour or less. The start and stop mechanisms of a stop watch and clock frequently cause errors because of lag or jumping of the sweep hand when the mechanism is operated. It is frequently more accurate to start the watch at approximately 10 seconds before zero and then start the process to be timed as the hand sweeps through the zero. The percent of error of a stop watch may be minimized by making all time observations at least 1 minute long.

8.3 ELECTRICAL TIMERS. Several types of electrical timers are used to measure time intervals. The most common of these is the synchronous stop clock. This device operates in the same manner as the mechanical stop watches described above except that the hands are started and stopped by a small magnetic clutch engaging the hands with either a synchronous motor drive or a brake. Thus, the errors involved in starting and stopping are much less than those of the mechanical timers. Electrical timers of this type depend upon the frequency of the power source for their speed and are no more accurate than the power source to which they are connected. For this reason, they should never be driven by the power from an engine-generator set.

Digital readout stop watches or timers are commonly used during generator set testing. These devices utilize very low power drain solid state electronics and may be battery powered.

Electronic counters, utilizing controlled frequency supplies, are quite often used, especially where the required accuracy of the time interval measurement is high.

8.4 WAVEFORM TIMING TRACES. Waveforms (see figure 8-1) always require some sort of time scale if any measurements are to be made on them. The provision of such a scale is quite simple with most types of waveform recorders. A standard frequency from a crystal or tuning fork oscillator may be impressed upon the element, or a commercial power voltage may be used as a timing trace. On an waveform, when position is the important quantity rather than time, as in engine indicator diagrams, the timing trace maybe supplied by a contactor on the engine crankshaft, or by a magnetic pickup from a slotted iron disk on the crankshaft. Oscilloscopes may be provided with a so-called Z-AXIS control. This acts to blank out the trace when a signal is applied. Thus, a periodic pulse may be used to dot the trace and consequently show time intervals by the distance between dots. Oscilloscopes without Z-AXIS control can be made to show a dotted trace by interrupting the signal periodically. This latter method is much more difficult to calibrate and should be avoided wherever possible.

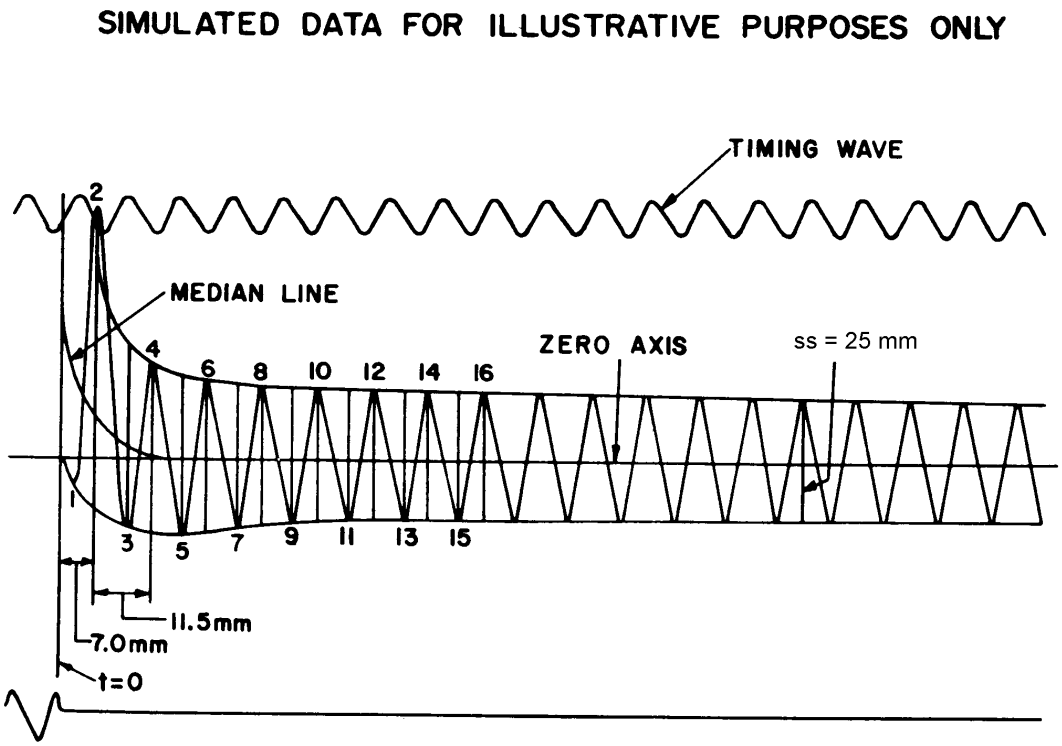


FIGURE 8-1 Sample waveform, showing median line

# TEST METHOD 9

## MEASUREMENT OF SPEED

9.1 GENERAL. Speed of rotation is derived by counting revolutions and measuring elapsed time. This operation may be performed very accurately by means of a counter and electric clutch, automatically timed by a synchronous clock and a standard frequency source.

Rotational speed may be translated to frequency by the use of an ac generator driven by the rotating element. This then may be measured electrically (see Test Method 4).

9.2 SPEED COUNTERS. One of the ways to measure speed during a test is to count revolutions for a measured time interval. This may be done by observing the readings of a counter permanently attached to the machine shaft, or by temporarily attaching a counter to the shaft, through a friction wheel or disk. In either case, the duration of the observation should be great enough to minimize all the errors due to starting and stopping the stop watch or counter. In the case of a portable counter, which, in use, is started and stopped, either the counter should be started as the clock hand sweeps through zero, or vice versa. No attempt should be made to start both the counter and stop watch simultaneously.

9.3 DIRECT READING TACHOMETERS. Several methods are used to indicate speed directly. Among them are the position of centrifugal flyballs, the voltage of a magneto, the pressure of a centrifugal hydraulic pump, photocell sensors, and the eddy-current drag of a rotating magnet on a conducting disk. Each of these devices may be used as a tachometer, and each has its own advantages and disadvantages. Direct reading tachometers are available either for positive connection to the machine under test, or for hand use.

Chronographs or recording tachometers are speed recording instruments in which a graphic record of speed is made. In the usual forms, the record paper is driven at a certain definite speed by clockwork or weights, combined with a speed controlled motor or device such that a specific distance of chart travel represents a definite time. The pen which makes the record may be attached to the armatures of electromagnets, servo-driven, or operated on a proportional electrical signal. The speed sensing pickup may consist of a mechanically coupled tachometer generator or a magnetic proximity device whose function is to generate a voltage, the magnitude of frequency of which is supplied to the recorder. Some recorders accept electrical signals directly from the ac generator output and record the frequency on the chart as a corresponding speed (revolutions per minute).

9.4 STROBOSCOPES. Stroboscopic methods are especially suitable for determining the speed of machine parts which are not readily accessible, where it is not practicable to use mechanical methods, or where the speed is variable. Stroboscopes are devices for producing periodic light flashes of high intensity and short duration. If a piece of moving machinery is illuminated by such a light source, an observer sees the machine only during the periodic light flashes. If the period is adjusted to coincide with a periodic movement or rotation of the machine, the machine will appear to stand still. Any deviation from syncronism will appear as a slow movement of the machine through its operating cycle. Therefore, if the frequency of the light is

held constant, the machine speed may be held constant by keeping it "standing still". Also, if a disk having radial stripes is mounted on the machine as a target for the stroboscope, and the stroboscope is excited with a constant frequency, the machine speed may be held to any integral multiple or fraction of the stroboscope frequency.

# TEST METHOD 10

## MEASUREMENT OF TEMPERATURE

10.1 GENERAL. Temperature measurement by electric means is carried out almost exclusively with direct current. There are three methods used to determine temperatures of various components of an engine-generator set, as well as the temperatures of coolants, lubricants, etc. These three methods are: contact, resistance, and embedded detector.

When temperatures are to be obtained by thermocouples, resistance thermometers, or other electric temperature measuring devices, care should always be taken to insure that these elements and their indicating instruments are functioning properly. The wiring between the detecting elements and the indicating instrument should be installed so there are no loose connections. A quick check to determine the functioning of an instrumented generator set is to take a complete set of ambient temperature readings on the set prior to starting the set. The set should not have been operated for 12 hours prior to the readings. The complete set of readings should then be compared with the temperature of principal metal parts of the machine, as measured with several reliable mercury or alcohol thermometers. The electric devices should indicate consistent temperatures in close agreement with the thermometers. If appreciable temperature differences exist, a check should be made for loose connections, stray fields, and the possibility that the machine has not reached a uniform temperature. It may be necessary to replace the faulty temperature measuring device.

The temperature rise of certain components and materials during operation of the generator set is an important characteristic. Temperature rise is defined as the difference between the temperature of the component or material, and the ambient temperature, at a point in operation of the generator set where temperatures have stabilized. Temperature stabilization of a component is reached when three consecutive readings, taken at 10-minute intervals, of an individual component or material, are the same, or within the limits of variation as specified in the contracts.

The limits of temperature rise for various components and materials are given in the contracts.

10.2 CONTACT METHOD. The contact method consists of determining temperature by placing a liquid thermometer, a resistance thermometer, or a thermocouple in direct contact with the component or material whose temperature is to be measured.

When these devices are used in connection with the measurement of surface temperatures, they shall be covered with oil putty, or a felt pad. The covering material is used to protect the temperature device from the air above the surface but should not be so large as to interfere with the natural cooling of the surface by circulation of the ambient air.

Thermometers with broken columns should not be used.

During use, the thermometer bulb shall not be located higher than any other part of the thermometer.

A thermocouple consists of two metals in contact with each other. The two metals are of different molecular structure, and electromotive force is produced at the junction of the two metals due to temperature. The electromotive force produced at the junction is compared to

another thermocouple output that is at a known temperature, usually either 0 °C or room ambient as measured by a thermometer.

Thermocouples are fabricated in different shapes and in different combinations of metals to suit individual locations and for different ranges in temperature. These thermocouples are used in connection with various types of thermal potentiometers which indicate temperature in degrees, or in numbers which can be converted to degrees. Complete temperature data acquisition systems are commercially available for handling inputs from a few to several hundred thermocouples.

To determine the temperature rise, convert both the ambient temperature readings and the maximum contact device readings to degrees Celsius. Then subtract the ambient from the contact readings.

10.3 RESISTANCE METHOD. The resistance method determines temperature by the comparison of the resistance of a winding, at the temperature to be determined, with the resistance of the winding at a known temperature. Since a small error in measuring either the hot or cold resistance will make a comparatively large error in determining the temperature rise, the most accurate method in obtaining resistance should be employed. Whatever method is used will utilizes the characteristic of generator windings whereby a change of resistance is proportional to a change of temperature. The following steps will be followed in determining the temperature rise by this method.

(1) The resistance of the winding at a known temperature shall be obtained. Cold resistance measurements shall be made with the generator set at approximately the surrounding ambient temperature; that is, the measurements shall be taken after the generator set has been inoperative for a sufficient time (approximately 12 hours) to bring the major generator mass temperature, as measured by a thermocouple, to within 3 °C of the ambient temperature.

(2) The device being tested shall be operated as prescribed by the test method until it reaches the condition at which the temperatures or temperature rise of the winding is to be obtained.

(3) The ambient air temperature at this time shall be recorded and if in degrees F, it shall be converted to degrees C.

(4) The hot resistance of a dc field winding may be computed from the ammeter and voltmeter readings, as follows:

$$R_h = \frac{V_{ef}}{I_{ef}}$$

where:

$R_h$ is the hot resistance of the field winding.

$V_{ef}$ is the voltage across the field winding.

$I_{ef}$ is the current in the field winding.

(5) The above method may be used on the stationary fields but should not be used on rotating fields. However, the method described in (6) below, is preferred.

(6) Whatever means of accuracy will be used to determine the hot resistance of the generator armature, exciter armature, and the generator field except in the case of rotating windings of less than 1 ohm resistance (see Test Method 5).

(7) The drop-in-potential method will be used to obtain the hot resistance of rotating windings of less than 1 ohm resistance (Test Method 5).

(8) To determine the hot resistance by either methods, the following shall be observed:

(a) The generator will be shut down.

(b) A reading shall be made immediately (in less than 30 seconds).

(c) Additional readings will be made at intervals of 30 seconds or less for at least 3 minutes. If the resistance is increasing at the end of 3 minutes, readings shall continue at 30 seconds intervals until the resistance definitely begins to decrease.

(d) A precision timer will be employed to determine time from shutdown to initial reading and between subsequent readings (see Test Method 8).

(e) The resistance readings will be plotted against time on semi-logarithmic paper. Time will be plotted along the divisions of equal size and resistance will be plotted along the logarithmic divisions. This curve will be extrapolated (extended) from the first reading back to the time of shutdown. The highest resistance on the curve will be used as the hot resistance. Automated data systems may be utilized for numerical calculations and presentation of this data. In lieu of plotting the data, a linear regression (least squares fit) may be used to determine the resistance at shutdown. The temperature rise for copper windings is calculated from the formula:

$$T_r = T_h - T_a = \frac{R_h}{R_c} (234.5 + T_c) - (234.5 + T_a)$$

where:

$T_r$ is the temperature rise in Celsius degrees.

$T_h$ is the temperature of the winding in degrees C when hot resistance ($R_h$) was measured.

$T_a$ is the ambient temperature in degrees C.

$R_h$ is the hot resistance.

$R_c$ is the cold resistance.

$T_c$ is the temperature of the winding in degrees C when cold resistance ($R_c$) was measured.

10.4 EMBEDDED DETECTOR METHOD. The embedded detector method of determining temperature employs thermocouples or resistance temperature detector built into the machine. Usually they are used on machines rated above 500-kW and then only if other means of temperature measurement are not practicable.

The embedded resistance temperature detector is a resistance of a known value at a specific temperature. To determine a temperature with an embedded resistance detector, accurate measurement of the detector resistance will be made (see Test Method 5) and the temperature calculated from the formula:

$$T_r = T_h - T_a = \frac{R_h}{R_c} (234.5 + T_c) - (234.5 + T_a)$$

(The above formula applies only to copper windings.)

where:

$T_r$ is the temperature rise in Celsius degrees.

$T_h$ is the temperature of the detector in degrees C when $R_h$ is measured.

$T_a$ is the ambient temperature in degrees C.

$R_h$ is the hot resistance.

$R_c$ is the known resistance of the detector at $T_c$ degrees C.

$T_c$ is the temperature of the detector in degrees C when the known resistance ($R_c$) was measured.

10.5 CONVERTING FAHRENHEIT TO CELSIUS, AND VICE VERSA.

To convert Fahrenheit to Celsius:

$$C = \frac{5}{9}(F - 32)$$

To convert Celsius to Fahrenheit:

$$F = \frac{9}{5}C + 32$$

When converting a temperature rise from degrees Fahrenheit to degrees Celsius, and vice versa:

Temperature rise in degrees C. = 5/9 (Temperature rise in degrees F.)

Temperature rise in degrees F. = 9/5 (Temperature rise in degrees C.)

**NOTE**: The addition or subtraction of 32 degrees is not used for temperature rise conversions because a difference in temperatures, rather than a temperature, is being converted.