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NAVAL SHIPS' TECHNICAL MANUAL

CHAPTER 491

ELECTRICAL MEASURING AND TEST INSTRUMENTS

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NOTE

THIS CHAPTER HAS BEEN REFORMATTED FROM DOUBLE COLUMN TO SINGLE COLUMN TO SUPPORT THE NSTM DATABASE. THE CONTENT OF THIS CHAPTER HAS NOT BEEN CHANGED.

CHAPTER 491

ELECTRICAL MEASURING AND TEST INSTRUMENTS

SECTION 1.

INTRODUCTION

491-1.1 SCOPE OF CHAPTER

491-1.1.1 This chapter contains engineering information on electrical measuring and test instruments used on board ship.

a. These instruments are used principally for measuring basic parameters such as current, voltage, resistance, and speed of rotation, or for general purpose testing of elements that are common to most electrical systems such as fuses, vacuum tubes, and condensers. For convenience the chapter includes a brief description of each instrument. The descriptive data are based upon current specification requirements and the actual instruments onboard ship may differ in minor respects. Detailed information and operating instructions contained in the manufacturer's instruction book should be consulted.

b. Measuring and test instruments of a highly specialized nature are covered in the chapters of the manual dealing with the associated circuits and equipment.

c. Instruments operating on the same general principles as those discussed herein are also utilized on shipboard as components of equipments which provide indications of some nonelectrical quantity; for example, a voltmeter may be used as part of a propeller-revolution indicating equipment. In the case of instruments utilized for this purpose, the instructions contained herein are applicable for use as a general guide.

491-1.2 CLASSIFICATION OF INSTRUMENTS

491-1.2.1 Electrical measuring and test instruments are classified with respect to the following characteristics (Table 491-1-1 is a tabulation of measuring and test instruments furnished to naval ships):

a. The electrical quantity or characteristic measured, or the type of test function for which designed; and, if applicable, whether used on alternating or on direct current circuits; for example, direct current ammeters, alternating current voltmeters.

b. The type of mounting: switchboard or portable (abbreviated as S and P in Table 491-1-1). In some cases instruments are mounted on a switchboard but provision is made for removing the instrument from the board and using as a portable meter. This is the case, for example, with volt-ohm-milliam meters mounted on new-design interior-communication switchboards.

c. Other features such as degree of enclosure, nature of mounting arrangements, sizes, ranges, grades, shock resistance and type of external power supply.

491-1.3 PORTABLE INSTRUMENTS

491-1.3.1 ALLOCATION. Portable instruments are furnished to each vessel in accordance with the allowance established in the Ship Portable Electrical and Electronic Test Equipment Requirements List (SPETERL). These instruments are normally assigned to the custody of specific working groups on board ship as follows:

a. User code 1. For maintenance of prime electronic systems by Data Processing Technicians, Data Systems Technicians, Electronic Technicians, Fire Control Technicians, Operational Specialists, Radiomen, Sonar Technicians, and Communications Technicians.

b. User code 2. For maintenance of electrical equipment and systems by Electricians Mates.

c. User code 3. For maintenance of interior communications and gyro compasses.

d. User code 4. For maintenance of weapon equipment and systems by Fire Control Technicians, Gunners Mates, and Mine Technicians.

e. User code 5. For maintenance of reactor instrumentation equipment and systems by Electricians Mates, Electronics Technicians, and Interior Communications Electricians.

Table 491-1-1 ELECTRICAL MEASURING AND TEST INSTRUMENTS AND ACCESSORIES ON NAVAL SHIPS

For measurements of	For testing of	Instrument or accessory	For use on AC or DC circuits (if applicable)	Mounting
Current		Galvanometer	D.C.	P.
		Ammeter	D.C.	S.P.
		do	A.C.	S.P.
		do	A.C., D.C.	P.
		Ammeter, splitcore	A.C.	P.
		Shunt	D.C.	S.P.
		Current transformer	A.C.	S.P.
Voltage		Voltage tester	A.C., D.C.	P
		Voltmeter	D.C.	S.P.
		do	A.C.	S.P.
		do	A.C., D.C.	P.
		Multiplier	D.C.	S.P.
		Potential transformer	A.C.	S.P.
Power		Wattmeter	D.C.	S.P.
		do	A.C.	S.P.
Reactive power		Varmeter	A.C.	P.
Energy		Watt<#0106>hour meter	D.C.	S.
		do	A.C.	S.
A.C. circuit characteristics		Frequency meter	A.C.	S.P.
		Power factor meter	A.C.	S.P.
		Synchroscope	A.C.	S.
		Phase rotation indicator	A.C.	P.
		Excitation indicator or stability meter.	A.C.	S.
		Oscilloscope	A.C., D.C.	P.
		Voltage tester	A.C., D.C.	P.
Resistance		Testing generator	A.C., D.C.	P.

Table 491-1-1 ELECTRICAL MEASURING AND TEST INSTRUMENTS AND ACCESSORIES ON NAVAL SHIPS - Continued

For measurements of	For testing of	Instrument or accessory	For use on AC or DC circuits (if applicable)	Mounting
		Resistance box	A.C., D.C.	P.
		Decade testing sets	A.C., D.C.	P.
		Insulation resistance	A.C., D.C.	S.P.
		testers	A.C., D.C.	P.
		Growler		
		Ohmmeter	A.C., D.C.	P.
Voltage, resistance, and current		Volt-ohm-milliammeter	A.C., D.C. (milliamps D.C. only)	P.
Voltage, current, power, and power factor		Power analyzer	A.C., D.C.	P.
Voltage, resistance, and current	Vacuum tubes	Vacuum tube analyzer	A.C., D.C. (milliamps D.C. only)	P.
Speed of rotation		Stroboscopic tachometer		P.
	Fuses	Neon lamp tester	A.C., D.C.	P.
Capacity	Condensers	Capacitor analyzer		P.
Continuity	Fuses	Voltage tester	A.C., D.C.	P.
		Voltohmeter		P.

491-1.3.2 INTERCHANGE. While the instruments listed in the preceding subparagraphs should be in the normal custody of that group, an exchange of instruments between groups should be freely made whenever necessary such as for emergency repairs, or special maintenance problems, for example, if some group makes a particular type of measurement or test so rarely that it would not be justified to supply the group with that type of instrument for exclusive use. The interchange of instruments should be encouraged so that each instrument is utilized to its fullest extent. Compliance with this procedure will help to avoid unnecessary duplication of instruments between groups.

491-1.4 SHOCK RESISTANCE

491-1.4.1 In recent years, switchboard instruments have been developed for naval use which are unusually resistant to damage by mechanical shock caused by the underwater explosion of mines or near-miss bombs. Switchboard instruments provided for new installations are now usually of the shock-resistant type. These instruments do suffer a loss of accuracy because of shock, but are usually capable of being recalibrated. However, many instruments now in service or provided for replacement of the earlier installations are not of the shock-resistant type.

SECTION 2.

DESCRIPTION AND SPECIAL OPERATING PRECAUTIONS

491-2.1 CURRENT MEASURING INSTRUMENTS

491-2.1.1 GALVANOMETERS. The galvanometers on naval ships are almost invariably direct-current instruments used in conjunction with a decade testing set or other equipment to indicate the presence or absence of current rather than to measure its value.

491-2.1.2 AMMETERS. Ammeters are provided for use on direct current only, alternating current, and either direct or alternating current. Any alternating-current ammeter will indicate on direct current but its accuracy may be less than on alternating current.

491-2.1.3 CONSTRUCTION OF DIRECT-CURRENT INSTRUMENTS. Switchboard and portable ammeters and milliammeters for use on direct current only are almost invariably of the permanent magnet moving-coil type. A small coil of fine wire is supported but free to move in the magnetic field of a permanent magnet. The coil is supported by either pivots in jewel bearings or by a thin ribbon held taut, under substantial tension, by springs. Current flow through the moving coil produces a magnetic field which interacts with the magnetic field produced by the permanent magnet. As a result, a deflecting torque is exerted on the moving coil which turns until the deflecting torque is balanced by the restoring torque exerted by springs attached to the stationary part of the meter. The deflecting torque is proportional to the magnetic field of the coil, and this, in turn, is proportional to the current flowing through the coil. Consequently, the position at which equilibrium between the deflecting torque and the restoring torque is reached is a measure of the current flowing through the coil. The current is indicated on a graduated scale by a pointer fastened to the coil. In jewel bearing instruments, helical springs provide both the restoring torque and a means of conducting current to the coil. In taut ribbon (called taut band) suspension instruments, there are no bearings as such; the band suspends the coil as well as providing restoring torque and a means of conducting current to the coil.

a. Direct-current galvanometers are generally similar to ammeters except that the moving coil may be either:
   1. Supported by pivots and jewel bearings as in ammeters; or
   2. Suspended on taut wires which replace the pivots and bearings and the springs used to create the restoring torque.
b. The permanent-magnet moving-coil type of instrument is useless for alternating-current measurements because the deflecting torque reverses in direction too rapidly to permit movement of the needle. Alternating current should never be connected to such an instrument. It can cause no deflection, but can burn out the coil.

491-2.1.4 CONSTRUCTION OF ALTERNATING-CURRENT INSTRUMENTS. Ammeters for use on alternating current may be either the moving-iron type or the electrodynamometer type.

a. In the moving-iron type, one or several pieces of soft iron or magnetic alloy are caused to move by the magnetic field of a fixed coil or coil system carrying the current to be measured. The value of the current is indicated by the position of a pointer when the torque caused by the current is balanced by spiral springs.
b. In the electrodynamometer type, the current to be measured is passed through two coils, one fixed and one movable. The movable coil is mounted on pivots and jewel bearings in the field of the fixed coil. The force exerted by the magnetic field of one coil on the current flowing in the other turns the moving coil until the deflecting torque is balanced by the restoring torque exerted by a spring.
c. Switchboard ammeters and portable ammeters for use primarily on alternating current are usually of the moving-iron type. Ammeters for use on both alternating and direct current may be of either type.

491-2.1.5 SPLIT CORE AMMETERS. Split-core ammeters are portable instruments that use the magnetic field around a current-carrying conductor to cause a deflection of an indicating element. Magnetic coupling between the magnetic field and the indicating element is obtained by clamping a split-magnetic core around the conductor. The split core is hinged and can be readily clamped around a conductor to measure current without making or breaking any electrical connections. These instruments are, therefore, very useful for trouble shooting and maintenance work. The accuracy of split-core ammeters is somewhat less than that of switchboard meters or other portable ammeters used by the Navy. Split-core ammeters are issued to large combatant vessels and repair ships. When using split-core ammeters, care must be exercised to see that the pole faces of the split core are clean and meet properly when making measurements as otherwise the reading may be in error.

491-2.1.6 SHUNTS. As the moving coil in direct-current ammeters can carry only a small current without injury, the greater part of the current to be measured is bypassed through a shunt connected in parallel with the coil. For switchboard instruments used in surface ships, the Navy has standardized on shunts with a resistance such that the voltage drop across the shunt is 50 millivolts for full-scale deflection of the ammeter with which the shunt is used. However, switchboard instruments used in submarines and surface ship degaussing applications generally are provided with 100-millivolt shunts. Shunts for portable instruments have 50-, 100-, or 200-millivolt drop, as approved. Shunts are normally marked with current rating and millivolt drop at that current as for example: 150 amperes, 50 millivolt.

a. Portable direct-current ammeters for 30 amperes and less, and switchboard ammeters for less than 50 amperes (30 amperes for the smaller size instruments) are usually provided with internal shunts. Instruments for larger currents are usually used with external shunts. Each ammeter to be used with an external shunt is marked to show the millivolt drop of the shunt to be used.

b. The connection between an ammeter and its external shunt should always be made with the leads furnished with or specified for the instrument, since leads of different resistance will affect the accuracy of the readings. In making these connections:
   1. Be sure that the shunt is the proper one to be used with the ammeter. Use of the wrong shunt will not only cause a false indication of current, but may also destroy the instrument.
   2. Be sure that all of the connections at the terminals of both the ammeter and the shunt are clean, tight, and well made to avoid contact resistance which would affect the accuracy of the readings.
   3. Connection of an ammeter to a shunt raises the ammeter circuit to the potential of the circuit in which the shunt is connected. The ammeter may indicate zero current but its terminals may be at a lethal potential with respect to the ships hull or structure or other equipment terminals.

491-2.1.7 CURRENT TRANSFORMERS. Alternating-current instruments with current coils are usually operated through current transformers. This arrangement isolates instruments from line potential, and produces in the secondary a definite fraction of the primary current, thereby making it possible to measure large currents with a 5-ampere ammeter.

a. The primary winding of a current transformer should be connected in the line carrying the current to be measured. The secondary winding is connected to an ammeter or the current coil of a wattmeter, power-factor meter, or some other instrument.

b. One terminal of the secondary should be grounded so that a breakdown of insulation between primary and secondary will not transmit line voltage to the ammeter with consequent danger to personnel. On all instrument transformers with metal cases, the metal case should also be grounded. A grounding terminal on the case is usually provided with a permanent internal connection to the secondary.

c. The secondary of a current transformer should never be open while the primary is carrying current. Failure to observe this precaution results in possible damage to the transformer, and the generation of a secondary voltage which may be of sufficient magnitude to injure personnel or damage insulation. Furthermore, a current transformer energized with an open-circuited secondary will overheat due to magnetic saturation of the core and even though the overheating has been insufficient to produce permanent damage, the transformer should be carefully demagnetized and recalibrated to ensure accurate measurements. The secondary should, therefore, always be short circuited when not connected to a current coil. Alternating-cur rent ammeters switches should always be of the make-before-break type so as to ensure that the ammeter is connected across the secondary of the selected current transformer prior to removing the short circuit from that transformer.

d. Polarity marks are placed on the terminals of instrument transformers to show the relative directions of instantaneous current flow in primary and secondary, information which is needed in making some connections. The direction of instantaneous current flow in the secondary is the same as if each primary conductor were detached from its marked terminal and connected to the secondary terminal with the same marking.

e. Proper consideration must be given to the ratio of the current transformer in interpreting the ammeter readings. If the ammeter is calibrated for use with a current transformer of specified ratio (usually printed on the scale of the instrument), a transformer of that ratio should be used or a suitable multiplying factor applied to the readings.

491-2.1.8 SPECIAL PRECAUTIONS IN THE USE OF CURRENT MEASURING INSTRUMENTS. Current-measuring instruments, shunts, and primaries of current transformers must always be connected in series with the line carrying the current to be measured.

a. In order to avoid damage to the instrument used, care must be taken to see that its range is greater than the line current.

b. Special care must be exercised not to connect current-measuring instruments, shunts, or primaries of current transformers directly across a line or between any two points which differ in potential by more than a very small amount. The resistance or impedance of such devices is purposely made very small in order that their connection in the line will not create an appreciable voltage drop. Connection across a line results in practically a dead short circuit and immediate destruction of an instrument, shunt, or current transformer. Consider, for example, a direct-current ammeter designed to give full-scale deflection for a 50-millivolt drop across its shunt. If either the meter, the shunt, or the parallel combination of meter and shunt is so connected in a circuit that the potential drop across the terminals is 1 volt, the current will be 20 times and the rate of heating 400 times the values corresponding to full-scale deflection. If connected directly across a 100-volt line, these figures are raised to 2,000 and 4,000,000, respectively. The effect upon the instrument, shunt, or both is immediate and disastrous.

c. The same precautions are necessary in connecting the current coils in wattmeters, power factor meters, and other instruments.

491-2.2 VOLTAGE MEASURING INSTRUMENTS

491-2.2.1 VOLTAGE TESTER. The voltage tester presently authorized for shipboard use, where a hand-held visual indicator is required, is a multi-voltage, multi-frequency, and polarity indicating instrument. This tester consists of light-emitting devices and solid-state circuitry which indicates 28-, 115-, 220-, and 440-volts ac at either 60 or 400 Hz; it also indicates 28-, 115-, 250- and 500-volts dc. The indicator will detect the presence of any voltage between 25- and 600-volts ac or dc. Separate frequency indicators will identify 60- and 400-Hz power frequencies above 90 volts. Polarity indicators provide identification of dc polarity above 90 volts.

491-2.2.2 VOLTMETERS. Both direct- and alternating-current voltmeters determine voltage by measuring the current which the voltage is able to force through a high resistance connected in series with the indicating mechanism or element.

a. Their elements, being used for the measurement of current, are similar in construction and principle of operation to those used in the ammeters described in paragraph 491-2.1.2.

b. Voltmeters for direct current only are almost invariably of the permanent magnet moving coil type; switchboard and portable voltmeters primarily for alternating current are usually of the moving iron type; and precision portable voltmeters for use on either alternating or direct current are usually of the electrodynamometer type.

491-2.2.3 MULTIPLIERS. The range of a voltmeter can be doubled by doubling its resistance, or multiplied by a larger factor by a proportionate increase in resistance. Portable direct-current voltmeters are frequently provided with built-in resistances which can be connected in series with the indicating element to permit several ranges of voltage to be measured with one instrument. External resistances, or multipliers connected in series with a voltmeter, can also be used to extend its range.

491-2.2.4 POTENTIAL TRANSFORMERS. Voltmeters and potential coils of wattmeters (in series with a high resistance inside the instrument) are connected either across the voltage to be measured or to the secondary of a potential transformer. The potential transformer steps the voltage to be measured down to a value suitable for direct application to the meter.

a. Potential transformers for Navy use are designed for a rated secondary voltage of 110 volts and for primary voltages ranging from 230 to 6,600 volts.

b. The precautions to be observed in the use of potential transformers are as follows:
   1. Make sure that the transformer ratio is correct for the instrument used and the voltage to be measured.
   2. Make connections only when the circuit is not energized.
   3. Ground one terminal of the secondary, and the metal case.
   4. Connect the primary or high voltage winding of the transformer to the voltage to be measured, and the secondary, or low voltage winding, to the instrument.
   5. Never short circuit the secondary of a potential transformer. The secondary should be closed only through a high resistance such as a voltmeter or a potential coil circuit or should be open when the primary is energized. A short-circuited secondary allows excessive current to flow which may damage the transformer.

491-2.2.5 SPECIAL PRECAUTIONS IN USE OF VOLTAGE MEASURING INSTRUMENTS. Voltmeters, in series with their external multiplier (if one is used) or the primaries of potential transformers (if used), are connected to the two points between which it is desired to measure the voltage. The instruments themselves are of high resistance to limit current flow. Care must always be exercised not to connect an instrument to a voltage higher than its range setting.

a. When using multirange instruments on a circuit of unknown voltage, start with the highest range first and work down to a range which gives a deflection on the upper part of the scale.

b. When using voltage testers (indicators) observe the following precautions:
   1. Each new indicator shall be tested by an experienced electrician on each voltage and frequency available on the ship prior to being issued to the user.
   2. Prior to each use, inspect the indicator for any signs of mechanical damage to the unit and its leads. Do not use if wet or if mechanically damaged. Test indicator on a known voltage before each use.
   3. Do not use the indicator for dc polarity indication or ac frequency indications at voltages below 90 volts.

491-2.3 POWER MEASURING INSTRUMENTS

491-2.3.1 POWER MEASUREMENTS. Electrical power can be measured:

a. In direct-current circuits by measuring the current through and the voltage across the load with an ammeter and voltmeter. The power is the product of the two.
   1. In alternating-current circuits by measuring the current through the load, the voltage across the load, and the power factor of the load, using an ammeter, voltmeter, and power-factor meter. The power can be computed from these quantities.
   2. In either direct or alternating-current circuits, by the use of a wattmeter.

491-2.3.2 WATTMETERS. Wattmeters are usually of the electrodynamometer type. In the single-phase wattmeter, which can also be used on direct current, a moving coil is mounted on pivots and jewel bearings or a taut ribbon (band) so as to be free to turn in the magnetic field of a fixed coil. The moving, or potential, coil is connected to carry a current proportional to line voltage; the fixed, or current coil, to carry a current proportional to line current. The torque exerted on the moving coil is balanced by spiral springs. A pointer fastened to the coil indicates the average power.

491-2.3.3 MEASUREMENT OF THREE-PHASE POWER WITH SINGLE-PHASE WATTMETERS. Power in a three-wire three-phase system is usually measured with a three-phase wattmeter. When one is unavailable, three-phase power can be measured with two single-phase wattmeters irrespective of whether the loads on the phases are balanced or not. The current coil of one meter is connected to measure the line current in one wire of the three-wire system, A, for example, and of the other meter to measure the line current in another wire, B for example. The potential coils of the two wattmeters would then be connected between wires A and C, and B and C, respectively.

a. If the load on the three-phase system is balanced and the power factor is greater than 0.5, add the readings of the two wattmeters; if the power factor is less than 0.5, subtract the smaller from the larger to obtain the total power. The readings will normally not be numerically equal even on a balanced system. If the load on the three-phase system is not balanced, wattmeter readings may have to be either added or subtracted to obtain correct results.

b. If the power factor is unknown or the system is unbalanced, a check can be made by turning off the power and interchanging the meters connected in wires A and B. To do this:
   1. Leave the connections from the potential coils (or their potential transformers, if used) to the common wire C unchanged, but switch the other connection from the potential coil or transformer of each meter to the other wire, A or B.
   2. Transfer the line sides of wires A and B to the wattmeter terminals (or current transformer terminals) previously connected to the line side of the other wire. The line side of each wire is one which runs from the wattmeter or its transformers to the source of power; the load side, the one which runs to the load. The load sides of wires A and B are similarly interchanged.

c. As a result of these changes, the wattmeter which originally had its current coil connected in wire A is shifted to wire B, and vice versa. Make sure that all connections are correct and turn on the power. If both instruments deflect on scale in the same direction as before, the original readings are to be added. If either deflects backward, against the stop, the original readings are to be subtracted.

491-2.3.4 THREE-PHASE WATTMETERS. The three-phase wattmeter consists essentially of two single-phase wattmeters with the moving elements mounted on a common shaft. A single pointer shows the total power, the instrument itself making the necessary addition or subtraction of the two readings automatically and correctly, provided that the connections have been correctly made. The wiring diagram furnished with the instrument must, therefore, be strictly followed in making connections.

a. The polarity marks on instrument transformers show the relative directions of instantaneous current flow in primary and secondary and furnish information which is needed in making correct connections to a three-phase wattmeter.

b. While the three-phase wattmeter should read correctly if connections are made in accordance with the wiring diagram furnished with the instrument, a check can be made as follows:

   1. Make sure that the potential coil of each single-phase wattmeter element is connected between the phase in which its current coil is connected and the common phase in which neither current coil is connected.

   2. If the load is balanced and the power factor is greater than 0.5, disconnect one potential coil, reconnect, and disconnect the other. If the wattmeter deflects in the same direction in both cases when only one potential coil is connected, the connections are correct.

   3. If the power factor is unknown or the system unbalanced, interchange the single-phase wattmeter elements as described in paragraphs 491-2.3.3, step b. If the wattmeter reading has the same magnitude as before, the connections are correct.

491-2.3.5 VARMETERS. In alternating-current circuits with resistance type of load (such as those supplying heaters) all of the power flowing in the lines is consumed in the load. On the other hand, in alternating-current circuits that are not purely resistive (such as motor circuits), some power known as reactive power is delivered to the circuit during part of the cycle and returned to the source during another part of the cycle. The reactive power does no useful work at the load but increases the current in the circuit and results in increased losses and power voltage regulation. Reactive power is measured by varmeters, the name being derived from the abbreviation of voltamperes, reactive. Varmeters are similar in construction to wattmeters except that the current through the potential coil is shifted in phase with respect to the line voltage. This is accomplished in single-phase varmeters by connecting a reactor in series with the potential coil, and in three-phase varmeters by cross connection of the potential coils. Varmeters are seldom used on naval ships, their use being limited to some of the older alternating-current power circuit analyzers.

491-2.3.6 PRECAUTIONS IN USE OF WATTMETERS. The precautions used in connecting ammeters and voltmeters must also be observed when connecting wattmeter current coils and potential coils, respectively. If external shunts, multipliers, and instrument transformers are used, they must be of the correct size and value to protect the wattmeter from excessive current flow in the coils. Extra care is necessary with a wattmeter because a pointer deflection which is on scale furnishes no assurance, as it does with ammeters and voltmeters, that the instrument is not overloaded. The pointer deflection of a wattmeter indicates only power, or the product of current, voltage, and power factor. If one of these factors is small, the current or voltage may still be of sufficient magnitude to ruin the wattmeter even though its pointer is reading on scale.

a. The current and voltage of the circuit to be tested should be measured, therefore, with an ammeter and voltmeter before the wattmeter is connected whenever there is any doubt that they come within the ranges of the instrument.

b. When the potential coil and its series resistor are connected across a line or across the secondary of a potential transformer, practically the entire voltage drop is across the resistor. Therefore, if the coil end of the series circuit consisting of the potential coil and the resistor is connected to the line in which the current coil of the wattmeter is connected, the current and potential coils will be at approximately the same electrical potential. However, if the resistor end is connected to the line in which the current coil is connected, the current and potential coils will be at potentials differing approximately by the line voltage or by the secondary voltage of the potential transformer. The correct connection is the one which places the two coils at approximately the same potential.

491-2.4 ENERGY AND AMPERE-HOUR MEASURING INSTRUMENTS

491-2.4.1 WATT-HOUR METERS. Energy, or the product of power and time, is measured by watt-hour meters. Watt-hour meters are not normally provided in naval ships of recent construction but may be found in older ships or in special applications.

a. A watt-hour meter essentially consists of:
   1. A small motor with a current circuit connected in series with the line and a potential circuit connected across the line
   2. A brake which opposes the turning of the motor
   3. A revolution counter which records the number of turns.

b. The relation between the motor torque and the opposing torque of the brake is such as to cause the motor to rotate at a speed which is proportional to the power flowing in the circuit. Energy, or the product of power and time, is proportional to the number of revolutions made by the motor, and is shown on the revolution counter.

491-2.4.2 DIRECT-CURRENT WATT-HOUR METERS AND AMPERE-HOUR METERS. Direct-current watt-hour meters are of the commutator or mercury-motor type.

a. The two types are described as follows:
   1. The commutator-type watt-hour meter is a shunt-type motor. The field coils produce a magnetic field proportional to the load current. The armature is energized through the commutator and brushes by the line voltage. This produces a rotor torque proportional to line power.
   2. The mercury-type watt-hour meters are practically all of the ampere-hour type. The meter movement consists of a copper-disc armature immersed in mercury. The pool of mercury permits the series line current to flow into the armature. The braking caused by the permanent magnet field reacts with the armature current to produce torque. The torque produced by the permanent magnet and armature is proportional to kilowatt hours at the stated supply voltage.

b. The non-mercury ampere-hour meter essentially consists of a shunt electronic circuit which samples the energy that enters or leaves a device. The electronic circuit then drives a motor whose speed is proportional to its input energy. The motor, in turn, controls a relay and readout device that indicates the number of ampere hours that have entered or left the equipment being monitored.

491-2.4.3 ALTERNATING-CURRENT WATT-HOUR METERS. Watt-hour meters for alternating-current service are of the electromagnetic induction type and include a series and a shunt coil. One coil induces current in an aluminum disk mounted so as to be free to revolve about its axis. The other coil produces a magnetic field which reacts with the induced currents to produce torque. Watt-hour meters for use on three-wire, three-phase systems have two single-phase meter elements mounted on a common shaft. Connections must be made in strict accordance with the wiring diagram, furnished with the instrument, to obtain correct results.

491-2.5 ALTERNATING-CURRENT CIRCUIT CHARACTERISTIC-MEASURING INSTRUMENTS

491-2.5.1 GENERAL FEATURES. In ammeters, voltmeters, and wattmeters, the deflecting torque exerted by a magnetic field on a moving coil or a moving iron member is balanced against a restoring torque produced by a spring. When the power is cut off, the spring returns the moving element to a definite zero position. The instruments for measuring alternating-current circuit characteristics which are described below have no spring control unless specifically noted otherwise. The measured value of the characteristic desired is indicated by the position of the moving element at which equilibrium is reached between opposing torques which are both of magnetic or electromagnetic origin. One of these replaces the spring. If the power is cut off, the moving element can come to rest at any place within its range of travel.

491-2.5.2 FREQUENCY METERS. The different types of frequency meters employ various combinations of fixed and moving coils, fixed coils and moving iron, and resonant circuits to produce a deflection of the pointer which depends upon the frequency. The design is such that a high degree of sensitivity to frequency changes and of insensitivity to waveform or changes in line voltage, temperature, or other possible disturbing factors is obtained. The vibrating-reed type of frequency meter is not used on United States naval ships except in some old installations. Frequency meters for 60-Hz circuits usually cover a frequency range of from 55 to 65 Hz. Those for the variable frequency alternating-current systems used for the electric propulsion of some naval ships are of much wider range.

491-2.5.3 POWER FACTOR METERS. In alternating current circuits, the power flowing in the lines is made up of two parts, to wit: useful (resistive) power which is expended in the load, and reactive power which flows back and forth contributing to the load carried by the conductors but serving no useful purpose.

a. The ratio of useful power to the square root of the sum of the squares of useful power and reactive power is called the power factor.
b. Power factor meters depend for their operation on the interaction between a pulsating single-phase magnetic field produced by a single coil, and a rotating magnetic field similar to that in induction or synchronous motors produced by two or more other coils. The moving element may be the single coil, the other coil, or an iron vane magnetized by the single coil. The moving element assumes a position such that at the instant when the pulsating single-phase field has its maximum value, the rotating field is alined with it. Both single-phase and three-phase power factor meters are used.

491-2.5.4 SYNCHROSCOPES. Before connecting a polyphase generator to bus bars already connected to one or more other generators, certain conditions must prevail.

a. The following are applicable:
   1. Phase sequence must be the same for generator and bus bars. (See paragraph 491-2.5.5.)
   2. Generator and bus-bar voltage must be the same.
   3. Generator and bus-bar frequency must be the same.
   4. Generator frequency must be practically constant for an appreciable period of time.
   5. The generator and bus-bar voltage must be in phase, that is, must reach their maximum voltages at the same time so that when connected, they will oppose excessive circulation of current between the two machines.
b. A synchroscope is a device for showing when these conditions are satisfied. It is essentially a power factor meter connected to measure the phase relation between the generator and bus-bar voltages. The moving element is free to rotate continuously. When the two frequencies are exactly the same, the moving element holds

a fixed position which shows the constant phase relation between the generator and bus bar voltage. When the frequency is slightly different, the phase relation is continuously changing, and the moving element of the synchroscope rotates continuously. The speed of rotation is proportional to the difference in frequency; the direction shows whether the generator is fast or slow. The generator is connected to the line when the pointer slowly approaches a mark which shows that the generator and bus-bar voltages are in phase.

491-2.5.5 PHASE ROTATION OR PHASE SEQUENCE INDICATORS. The sequence in which the currents in A, B, and C phases of a three-phase system reach their maximum values is determined by a phase-rotation or phase-sequence indicators.

a. The phase-rotation indicator presently found on a ships allowance list is a miniature three-phase induction motor which indicates phase sequence by the direction in which the moving element rotates. The instrument is marked to show relation between phase sequences and direction of rotation of the indicator.

b. Some ships have phase-sequence indicators installed in switchboards which are connected to shore-power connection boxes. The function of these instruments is to indicate whether shore power is of correct or incorrect phase sequence prior to connecting shipboard equipment (via ships distribution system) to shore power. Three-phase motors, connected to incorrect phase sequence power, rotate in the direction opposite to that intended.

c. The phase sequence indicator has three neon lamps which light when all three phases are energized. A meter connected to a network of resistors and condensers indicates correct or incorrect sequence on a marked scale.

491-2.5.6 EXCITATION INDICATOR OR STABILITY METER. The excitation indicator or stability meter is used on alternating-current electric drive naval ships which have induction motors for propulsion. The torque of an induction motor has a maximum value or pullout torque which cannot be exceeded without causing the motor to pull out and stall.

a. The purpose of the excitation indicator or stability meter is to indicate electrically an approach to conditions such that the propulsion motors could be pulled out by an increase in propeller torque caused by a shift in rudder position or motion in a seaway. The excitation indicator includes a current coil similar to that of an ammeter, connected in circuit with the propulsion motor. The instrument also includes a second coil which is connected across the generator output terminals to carry a current proportional to voltage divided by frequency. The torque produced by this second coil opposes that of the current coil, thus replacing the spiral spring of an ammeter. The higher the generator voltage, or the lower the frequency, the greater is the opposing torque of the second coil and the higher the motor current which is permissable without approaching pull-out values. When the indicator shows such an approach, the generator field current should be increased by the operating personnel. When the indicator shows operation with needlessly high excitation, the general field current should be decreased to cut down heating of the generator.

b. The amount of excitation required and the indication of the meter when a change should be made depend upon operating conditions and can be determined only be actual experience on the ship in which the indicator is installed. More excitation is required in a heavy sea and when maneuvering than when proceeding on a steady course in a smooth sea.

491-2.5.7 OSCILLOSCOPES. The cathode ray oscilloscope is a device which permits a visual presentation of some varying electrical quantity, such as voltage or current or any other quantity which can be expressed in terms of voltage or current.

a. The quantity being exhibited must be either constant or periodic. Ordinarily transients cannot be shown to advantage on an oscilloscope without special equipment which duplicates the transient periodically.

b. Essentially the cathode-ray oscilloscope consists of an electron gun which shoots a stream of electrons at a screen on the flared end of the tube. The screen consists of a material which glows when struck by the electron stream. When the stream is moved to another spot, the glow persists momentarily so that hosing the stream over the end of the tube produces a line which traces the path of the spot. Adjustments are provided for modifying the intensity of the beam and for bringing the spot into sharp focus on the screen.

c. Since the electron stream consists of negatively charged particles, it can be deflected by other electrical charges in the vicinity. A set of parallel deflecting plates is provided near the tube neck, between which the electrons shoot, so that when a voltage is applied across the plates, the positive plate will attract the electrons and the negative plate will repel. Thus the entire stream is deflected in a direction and amount which depend on the sense and voltage of the applied charge. Another set of plates deflects the stream in a direction at right angles to the first. These are the horizontal and vertical deflecting plates.

d. It is frequently desired to examine the waveform of a given alternating voltage. If this voltage is applied to the vertical plates, a vertical trace will result on the screen, the ends of which indicate the maximum voltage. The line must be spread out horizontally to reveal the wave. This is done by applying a voltage to the horizontal deflecting plates which moves the trace across the screen uniformly (say from left to right) so that the beginning and end of a cycle just fit on the end of the tube. At the end of the cycle the horizontal deflecting voltage whips the trace back to the other side of the tube and starts it forward again to trace out the next cycle. A special generator within the oscilloscope develops this sawtooth voltage.

e. Means are provided to synchronize the sweep-circuit generator with the voltage being examined so that the sweep always covers the same portion of each cycle and the trace appears motionless on the screen. It is also possible to adjust manually the sweep frequency, during which adjustment the complete wave form (or several waves) will move back and forth across the end of the tube. Provision is also made to synchronize the sweep with some external source whose frequency may be related to that of the voltage being examined.

f. Since the electron stream constitutes a current, it has a magnetic field encircling it. By locating coils near the tube and passing currents through them, it is possible to deflect the beam by magnetic means. However, this system is seldom used for test equipment because of the limitations imposed by magnetic systems. Thus a power amplifier may be required to provide the current for the coils, whereas, a voltage amplifier is ample for the electrostatic type of deflection method. Furthermore, the inductance of the deflecting coils tends to limit the response of the oscilliscope to higher frequencies.

g. Two types of general service cathode-ray oscilloscopes are provided for use of the fire controlmen in various naval ships, a three-inch scope and a five-inch scope. Both types of instruments are portable and operate from a 120-volt 60-Hz supply. The instruments are so designed that at full gain the voltage per inch of deflection on both X and Y axes of the three-inch scope and for the horizontal amplifier of the five-inch scope does not exceed 0.7 RMS volts. The voltage per inch of deflection of the vertical amplifier of the five-inch scope does not exceed 0.02 RMS volts.

h. For each instrument the input impedance of both the horizontal and vertical amplifiers is equivalent to a resistance of approximately one megohm in parallel with not more than 35 micromicrofarads.

i. The input impedance to either horizontal or vertical deflecting plates (direct) is equivalent to not more than 5 megohms or less than two megohms shunted by not more than approximately 25 micromicrofarads.

j. The input impedance to the intensity grid connection (where provided) of the oscilloscope is equivalent to a resistance of approximately 50,000 ohms in parallel with a capacitance of not more than 50 micromicrofarads.

k. The cathode ray oscilloscope is one of the most versatile general purpose testing and measuring electrical instrument available and has the following uses among others.

1. Measurement of alternating-current voltages by comparison with deflection produced by known voltage
2. Measuring of frequency by the use of Lissajous figures
3. Measurement of phase differences
4. Measurement of percent modulation. In studying various alternating-current phenomena, it is usually desirable to follow the trace with respect to time and to keep the traces running in one direction only.

l. The principal precaution to be observed in use of cathode ray tubes is not to permit the beam to remain for a long period of time on one portion of the cathode ray tube screen as this may cause the tube to become burned or streaked. To prolong tube life, the intensity and focus controls should always be adjusted for minimum readable brilliance and to produce the smallest practical spot or narrowest line.

491-2.6 RESISTANCE MEASURING INSTRUMENTS

491-2.6.1 TESTING GENERATORS OR MAGNETOS. Testing generators, also called magnetos or ringers, contain a small hand-driven permanent-magnet, alternating-current generator connected through a bell to external terminals.

a. The standard magneto is capable of giving a ring through a resistance of 50,000 ohms connected to the terminals.

b. Magnetos indicate only the existence of a high resistance or a low resistance. They are used to test for short circuits and grounds and to ring through and identify the individual conductors of a group.

c. A magneto does not give reliable results on condensers or circuits containing condensers or considerable capacity to neighboring conductors. Even when the insulation is perfect a magneto will give a slight ring through a condenser as small as 0.01 microfarad due to the charging current. For such circuits, an insulation resistance tester should be used.

d. A magneto may fail to ring through 50,000 ohms or even to ring on short circuit due to demagnetization of the generator magneto or poor adjustment of the bell. Means are provided for adjusting the bell. The magnets can be readily removed and remagnetized.

491-2.6.2 VOLTMETERS AND AMMETERS. Resistance can also be measured by using a direct-current ammeter and a direct-current voltmeter to measure the current through and the voltage drop across the resistance. The resistance in ohms is equal to the volts divided by the amperes.

491-2.6.3 RESISTANCE BOX. A resistance box is a group of resistors assembled in a case and provided with means for varying the total resistance between terminals. Resistance boxes furnish portable standards of resistance which can be used in measuring unknown resistance or checking the accuracy of ohmmeters or insulation resistance testers.

491-2.6.4 DECADE TESTING SETS. Decade testing sets contain resistances, dry cells, a galvanometer, keys, switches, and connections for measuring resistances from 0.001 to 10,000 ohms by the Wheatstone bridge method.

a. The underside of the cover has a wiring diagram and full instructions for the use of the set in making resistance measurements and Murray and Varley loop tests for ascertaining the distance to a fault in a cable or conductor.

b. Precautions to be observed in the use of the decade testing set are to secure good contact at the terminal posts where the resistance to be measured is connected; keep plugs and contacts clean; insert plugs firmly with a twisting motion; close the battery key first and then the galvanometer key to avoid inductive kicks; and keep the galvanometer key closed long enough to show which way the galvanometer deflects.

c. Binding posts are provided so that an outside galvanometer or outside battery can be used in case of need. If an external battery is used, its voltage should not exceed that of the battery originally installed in the set. Furthermore, if a battery with low internal resistance (such as a storage battery) is used, a suitable resistor should be connected in series with the battery to prevent the flow of excessive current when the low ratio arms of the bridge are used.

491-2.6.5 INSULATION RESISTANCE INDICATING INSTRUMENTS. These instruments are popularly known as ohmmeters, megohmmeters, or meggers.

a. Insulation resistance indicating instruments contain the following:
   1. A direct-current power-supply output. This is usually obtained from a small handcranked direct-current generator; if a battery or an external voltage source is used, a vibrator unit, transformer, and rectifier or suitable electronic circuit will usually be employed as an integral part of the power supply.
   2. An indicating element which reads directly in ohms or megohms.

b. In the most common types of instruments, the indicating element has a permanent magnet and a moving element which may rest at any position when the instrument is not in use. One of the coils on the moving member is connected to the source of voltage through a known resistance, the other through a circuit containing the unknown resistance to be measured. The torque exerted by one coil on the moving member is opposed by that of the other. When balance is reached, the moving element assumes a position which indicates the value of the resistance being measured. Change in voltage does not affect the reading if a pure ohmic resistance is being measured since the currents in both coils change in the same proportion. In most insulating materials the resistance is not strictly ohmic and the steady state reading tends to decrease with increasing voltage. However, this effect is small and would not be noticeable for changes in voltage as high as 20 percent.

c. In a second type of instrument the movement is similar to an ammeter and the value of the insulation resistance is determined by the amount of current flowing when a fixed voltage is applied across the resistance. In this type of instrument the voltage is maintained almost exactly constant by use of gas tubes, the voltage across which is independent of the load.

d. In measurements on large apparatus or long runs of cable it will usually be found that the megohm reading rises with time, at first rapidly, and then gradually flattens out, sometimes taking as long as 30 minutes to reach a constant value. This phenomenon consists of the inrush current due to the true capacitance charge which is large in amount and of short duration (5 to 10 seconds at most) and the dielectric absorption which slowly diminishes at a rate dependent on the nature and amount of the dielectric. The true insulation resistance is due to the constant leakage through the dielectric. If the insulation resistance reading fails to rise with time after the initial charge in rush, it may indicate that the insulation has absorbed moisture or is beginning to deteriorate. In a circuit containing inductance or capacity, fluctuations in the voltage output of the megger will introduce current transients thus making it difficult to obtain an accurate reading. Instruments which have constant voltage output are, therefore, more suitable for measurements in such circuits.

e. The navy-type GC insulation resistance indicating instruments (formerly type B and type G) have a 500-volt direct-current energy source and a range of from zero to 100 megohms. The type GC instrument has means for maintaining constant voltage, and is intended for general use in determining the insulation resistance of electric circuits and equipment without qualification as to electrostatic capacity or power output, and where reasonable accuracy and fair portability are required.

f. The navy type PC insulation resistance indicating instrument (formerly type P) is a small (pocket size) device of the hand-driven generator type with means for maintaining constant voltage. It has a 500-volt energy source and a 100-megohm scale. It is provided in certain type of ships and for applications where the small size, light-weight and reasonable portability are advantages offsetting the lower accuracy obtained in comparison with the larger type GC instrument.

g. Insulation resistance indicating instruments will indicate open, closed, or grounded circuits and approximate ohmic resistances above 500 ohms. An internal resistance in the instrument limits the current which it can deliver to a small value, thus preventing the flow of excessive current in the equipment tested or the building up of a high voltage across a low resistance. As a result instruments producing not in excess of 500 volts may be safety used for low voltage circuits and equipment except as follows: In the case of battle announcing systems the loud speaker (reproducer) and microphone voice are not required to withstand application of 500 volts to ground. Insulation measurements on wires connected to such coils shall be made only with a low-voltage ohmmeter. Also, filter condensers connected to ground may be damaged by the 500 volts produced by the insulation resistance indicating instrument and should be disconnected prior to securing insulation resistance.

h. An insulation resistance indicating instrument will indicate the condition of a condenser but not its capacity. A shorted condenser reads zero. A condenser in good condition will read varying amounts depending upon its resistance. After being charged it will give a spark when short circuited.

i. In a few cases, a bridge megger is furnished. This not only reads ohms and megohms directly on the scale, but can be used in combination with a separate dial resistance box to measure resistances from 0.01 to 10,000 ohms by a Wheatstone bridge in which the moving element of the megger serves as a galvanometer. Full instructions for use as a bridge are contained in the cover of the resistance box.

j. Low range ohmmeters (0.01 to 5 ohms) are provided for use of the fire controlmen in various naval ships for applications in which an accurate measurement of low resistance is necessary such as in the case of 5-inch mount firing circuits.

491-2.6.6 GROWLERS. Growlers are used to test for shorts, opens, or grounds in armatures or stators of electric motors or generators. A growler consists of a primary coil wound on an open iron core. When used, the growler is so placed on the armature that the iron of the armature or stator under test completes the magnetic circuit. When an alternating current is passed through the growler winding an alternating flux is established in the iron of the growler and of the portion of the armature or stator iron spanned by the jaws of the growler. If this portion of the armature or stator iron should contain a shorted coil, a feeler consisting of a hacksaw blade or a piece of soft iron held over the slot containing the shorted coil will be attracted to the slot. Opens can be detected by means of a growler by shorting the coils under the growler; an open being indicated by the absence of sparks when the short is opened. Some growlers are equipped with meters and test prods. With such growlers, a short is detected by noting the current drawn by the growler; an open is detected by measuring the voltage across the coil, and a ground is detected by measuring the voltage between the ends of the coil and ground.

491-2.6.7 CURRENT TEST SET. The current test set is used to provide variable alternating current at low voltage to test the time-current characteristics of motor overload relays and other current actuating devices. The current test set consists of a continuously variable auto transformer which supplies a voltage to an output transformer. Integral metering, timing, and control circuitry in the test set are provided to meter the current and determine the elapsed time of the test. Power to the test set is provided through a cord and plug which can be plugged into any convenient 115-volt 60-Hz single-phase convenience receptacle. A suitcase-type enclosure with appropriate handle makes the test set portable.

491-2.6.8 ELECTRIC TOOL TESTER. The electric tool tester presently authorized for shipboard use is used to check for open equipment grounds, faulty equipment grounds, power grounds, and short circuits on electric tools such as drills, riveters, grinders, saws, nut runners, soldering irons, and extension cords.

a. The tool tester consists of a transformer, sensing relays, indicator lights, audible warning buzzer, and leads suitable for tool or appliance connections; all components are housed in a compact enclosure.
b. The presence of a dangerous **power ground** (caused by carbon, moisture paths, or insulation breakdown) should be checked at a 500-volt potential. Other conditions are checked at 10 volts.

491-2.7 SPECIAL INSTRUMENT ASSEMBLIES

491-2.7.1 PORTABLE INSTRUMENT ASSEMBLIES. Several portable instrument assemblies containing a number of different instruments in a single case are provided for use in the analysis of electrical loads and circuit characteristics.

491-2.7.1.1 Alternating-Current Power-Circuit Analyzer. The alternating-current power-circuit analyzer is composed of a voltmeter, an ammeter, a three-phase wattmeter, and a power factor meter. The range extends up to 75 kilowatts, 600 volts, and 125 amperes. Older models also have a varmeter.

491-2.7.1.2 Volt-Ohm-Milliammeters. Volt-Ohm-Milliammeters are combination instruments with versatile applications. They are particularly useful for circuits involving electronic elements.

a. General purpose. This instrument provides for reading direct-current voltages up to 1,000, alternating-current voltages up to 500, direct-current milliamperes up to 750, resistances in ranges from 1,000 ohms up to 1 megohm--on several convenient scale ranges. The alternating-curren t and direct-current voltage ranges have a sensitivity of not less than 1,000 ohms per volt. The milliampere readings are provided for direct current only in order to read the average current in vacuum tube plate output circuits. This instrument is energized from self-contained batteries.
b. Electronic type volt-ohm-milliammeter. This instrument is especially intended for use on high-frequency circuits (up to at least 100 megacycles) and is designed to present a very high input impedance so as to cause as little disturbance as possible in the circuit being tested. A diode-capacitor probe is provided for alternating-current measurements and presents an input impedance equivalent to a resistance of 1 megohm in parallel with not more than 8 micromicrofarads.
    1. The direct-current input resistance is at least 10 megohms and is constant for all ranges.
    2. The following readings are provided:
        (a) The alternating-current voltage ranges are between 0 and 250 volts.
        (b) Direct current ranges--between 0 and 1,000 volts.
        (c) The direct-current ranges are between 0 and 1,000 milliamperes.
        (d) As an electronic ohmmeter, the instrument incorporates ranges between 0 and 1,000 megohms.
    3. The instrument is operated from a 120-volt, alternating-current 60-Hz single-phase supply.

491-2.7.1.3 Stroboscopic Tachometer. The stroboscope is a device that permits rotating or reciprocating objects to be viewed intermittently, thus producing the optical effect of slowing down or stopping motion. If, for example, an electric fan revolving at 1,800 revolutions per minute is viewed under a light which flashes 1,800 times per minute, the fan will appear to be standing still. A slight decrease in the flashing rate will make the fan appear to revolve slowly in the direction of its actual rotation and a slight increase will produce a similar effect in the reverse direction. Because the eye retains images for an appreciable fraction of a second (so-called persistence of vision), no flicker is seen at very low speeds.

a. When mechanisms operating at high speeds are viewed as if in slow motion by using stroboscopic light, irregularities of the motion present in the original motion are made visible, thus making it possible to observe high-speed mechanisms under actual operating conditions. When the speed of flash is adjusted to coincide with the speed of the machine under test (so that the machine appears in stroboscopic light to be standing still), the speed of the machine is then read on the tachometer dial; this dial controls the flashing rate of the stroboscopic light and is calibrated directly in revolutions per minute.

b. The stroboscopic tachometer is a small, portable stroboscope calibrated to read speed directly in revolutions per minute. The light source is a strobotron neon lamp mounted in a parabolic reflector. The frequency of a self-contained electronic pulse generator determines the flashing speed, which can be adjusted, by means of a direct reading dial, to any value between 600 and 14,400 revolutions per minute.

c. The instrument operates from a 120-volt 60-Hz alternating current supply. When using the instrument for accurate speed measurements, care should be taken to ensure that the power supply is actually 60-Hz, since the instrument is calibrated for this supply frequency. Any change in this frequency will affect the flashing speed, and hence, the accuracy of the instrument calibration.

d. For speed measurement, the stroboscope has one outstanding advantage over other types of tachometers; no contact with the mechanism under measurement is required, and hence, no power is absorbed.

e. The stroboscope can be used for measuring the speed of rotating, reciprocating, or vibrating mechanisms and for observing their operation in slow motion. The operation of motors, fans, pulleys, gears, cams, and other machine elements can be examined in slow motion. Speed measurements for overload and underload tests can be made.

WARNING

In stroboscopic light, a rotating machine will appear to stand still, not only when its speed matches the flash rate of the stroboscopic light but also when its speed is two or three times faster. For example, a machine rotating at 1,600 r/min or 2,400 r/min will appear to be standing still in stroboscopic light when the instrument dial reads 800 r/min.

f. **Precautions -** In addition to taking extreme care to read each complete scale revolution and following the operating instructions, users of stroboscopic lights shall take the following precautions.

1. Use only stroboscopes on which there is a single range or on which only a single range is viewable at any one time. Multiple scale or range stroboscopes in which more than one scale is in view at the same time shall not be used.
2. Use a backup instrument for speed verification before making any adjustments to equipment. The backup instrument must be a nonstroboscopic device. If the design of the component permits, use a hand-held mechanical tachometer with a single scale and range. Multiple scale or range portable tachometers are not to be used. The backup instrument must be used at the same time as the stroboscope, so that both instruments measure the same speed.

g. A tag, NAVSEA Form 9491/2 (1-78), which contains a reminder to use the mechanical tachometer as a check of the stroboscope, must be attached to every stroboscope. The tag may be ordered under Navy stock number 0116-LF-094-9105, unit of issue-EA, available from Cog "11″ in accordance with NAVSUP 437 and 2002. The tag is shown in Figure 491-2-1.

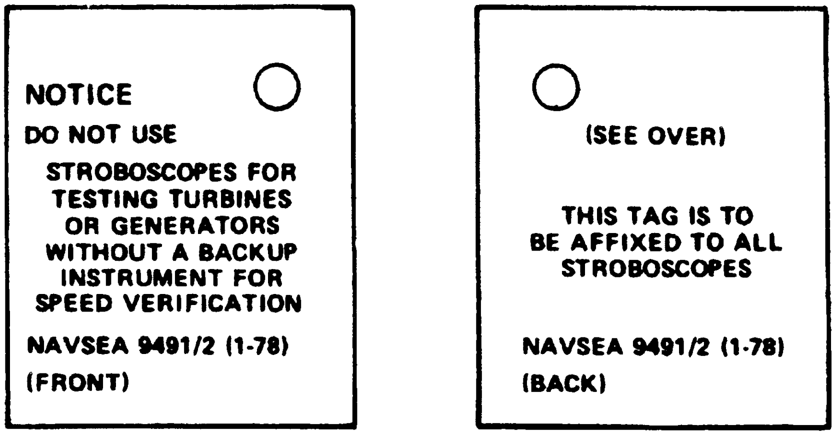

Figure 491-2-1 Tag for Stroboscopes

SECTION 3.

MAINTAINING ACCURACY OF ELECTRICAL INSTRUMENTATION

491-3.1 BACKGROUND

491-3.1.1 Sophisticated electrical systems can be maintained at the required state of readiness only if sufficient precision test equipment is carried on board each ship. Because test equipments are complex sensitive instruments, they must be calibrated periodically to ensure their acceptability as tools to support equipment repair actions. Department of the Navy Metrology and Calibration (METCAL) requirements were established by SECNAVINST 4355.11 and are coordinated and controlled under the centralized policy direction of the Chief of Naval Material in accordance with NAVMATINST 4355.67A.

491-3.2 POLICY

491-3.2.1 GENERAL. Periodic calibration of all portable and installed electrical and electronic test and measuring equipment used as shipboard standards or in support of shipboard maintenance and repair is mandatory and will be performed at the lowest level of activity authorized to effect required calibration or field calibration action.

491-3.2.1.1 Each equipment will be recalibrated at the interval established by Planned Maintenance System (PMS) directives. In the event PMS coverage is lacking, calibration will be as established in the Metrology Requirements List (METRL) (NAVAIR 17-35MTL-1/NAVELEX 0969-LP-133-2010/ NAVSEA OD 45845).

491-3.2.2 DEFINITIONS. Pertinent terminology is defined as follows:

a. Accuracy. The degree of correctness with which a measured value agrees with the true or nominal value.

b. Calibration. The comparison of a measurement system or device of unverified accuracy to a measurement system or device of known and greater accuracy to detect and correct any variation from required performance specifications of the unverified measurement system or device.

c. Calibration Interval, Period, or Cycle. The maximum length of time between calibration services during which each standard and test and measuring equipment is expected to remain within specific performance levels under normal conditions of handling and use.

d. Calibration Procedure. A procedure which outlines the steps and operations to be followed by standards and calibration laboratory and field calibration activity personnel in the performance of an instrument calibration.

e. Calibration Schedule. A documented schedule distributed periodically by cognizant scheduling activities listing standards and test and measuring equipment that each participating activity will submit to a designated facility for calibration servicing.

f. Field Calibration. A calibration process performed at authorized Navy activities other than Navy standards or calibration laboratories by specifically trained personnel utilizing authorized standards, procedures, and equipment. The standards must be calibrated periodically by a calibration or standards laboratory in order for a field calibration to be valid.

g. Field Calibration Activity Metrology Requirements List (FCA METRL). A publication prepared for use by personnel concerned with the field calibration segment of the METCAL program.

h. Fleet Electronic Calibration Laboratory (FECL). A calibration laboratory on board tenders, repair ships, and selected shore activities to provide calibration services for Fleet electrical and electronic test and measuring equipment. Standards from these laboratories are submitted to high echelon laboratories for calibration.

i. Metrology. The science of measurement for determination of conformance to technical requirements including the development of standards and systems for absolute and relative measurements.

j. Metrology Requirements List (METRL). A publication that provides test equipment information regarding model number or nomenclature, NSN description or manufacturer’s code, calibration procedures, and approved calibration intervals. Data contained therein is authorized for the Navy METCAL program.

k. Navy Field Calibration Activity (FCA). An activity located at organizational and intermediate maintenance facilities ashore or aboard ship in which calibration is performed by specially trained personnel utilizing specially authorized standards, procedures, and equipment. Standards used by the FCA are submitted to a higher echelon laboratory for calibration.

l. Standards. Laboratory-type devices which are used to maintain continuity of value in the units of measurement embodied by periodic comparison with higher echelon or national standard. They may be used to calibrate a standard of lesser accuracy or to calibrate test and measuring equipment directly.

m. Test and Measuring Equipment (T &ME). All devices used to measure, gage, test, inspect, diagnose, or otherwise examine materials, supplies, and equipment during research, development, test, evaluation, production, quality assurance, maintenance, and operation to determine compliance with requirements established in technical documents.

Table 491-3-1 FLUKE 760A SPECIFICATIONS

FUNCTION	RANGE	RESOLUTION	OUTPUT LIMITATION	TOLERANCE
DC Voltage	.001-1000V	0.1mV	20mA	(0.1% of ± setting +25uV)
AC Voltage 60 amp; 400Hz	.001-1000V(RMS)	0.1mV	20mA	(0.25% of ± setting +25uV)

Table 491-3-1 FLUKE 760A SPECIFICATIONS - Continued

FUNCTION	RANGE	RESOLUTION	OUTPUT LIMITATION	TOLERANCE
DC	1.0uA-10A	1uA	1.0V	(0.25% of ± setting +0.025uA)
AC 60 amp; 400Hz	1.0uA-10A (RMS)	1uA	1.0V	(0.25% of ± setting +0.025uA)
Resistance	1.0-10.0M ohm	1 ohm	0.25W	(0.1% of ± setting +0.5 Ω)

491-3.2.3 FACTORS WHICH AFFECT ACCURACY. Extraordinary measures are taken by the manufacturer to keep the errors from all sources within the required limits of accuracy. Equal care should be exercised in the installation, use, and care of instruments to avoid exposure to influences which may temporarily or permanently affect their accuracy.

a. The accuracy of direct-current instruments is affected more or less by the following factors:
   1. Temperature
   2. Vibration and shock
   3. Stray magnetic fields at the instrument which affect the torque exerted on the moving coil
   4. Exposure to intense magnetic fields which may permanently affect the strength of the permanent magnet
   5. Moisture, dirt, and corrosion
   6. Overloads
   7. Lack of proper mechanical balance of the moving element
   8. Bent pointer, or warping, or displacement of the scale
   9. Electrostatic deflections caused by wiping off the glass face of an instrument.
b. The accuracy of alternating-current instruments is affected by:
   1. All of the above factors except that item d. may have a negligible effect on some instruments
   2. Variation in voltage and frequency
   3. Variation in power factor
   4. Abnormal waveforms of voltage being in measured
   5. Variation in instrument transformer characteristics.
c. In instruments employing electronic tubes, erratic operation may sometimes be experienced when a tube is replaced due to the variation in characteristics between tubes of different manufacturers or even between tubes of the same manufacturer. In such cases the manufacturer’s instruction book should be consulted. For example, in certain rectifier circuits, two matched tubes must be used and, if one tube fails, both tubes must be replaced. The Naval Sea Systems Command (NAVSEA) endeavors to minimize the use of such special circuit requirements.

491-3.2.4 FIELD CALIBRATION ACTIVITIES. Most larger surface ships have been designated as Field Calibration Activities (FCA). This field calibration segment of the METCAL program was developed to provide certain Navy fleet and shore activities with the capability to calibrate specific designated electrical and electronic test equipment, thereby reducing calibration turn-around time and reducing the workload at FECLs. The test instruments which are included in the FCA designated phase A-1 package will permit field calibration of any panel, switchboard, or portable electrical meter whose functions and ranges are compatible with the meter calibrator and whose tolerance is ±1% or greater. Table 491-3-1 is a representative description of specifications for one test instrument; the Fluke 760A Meter Calibrator. The test instruments included in the phase A-1 package are as follows:

Manufacturer			
Model Number	**FSC**	**MEC**	**Description**
760A or	89536	FLA	Meter Calibrator
MC10C	14558	ABY	
W10MT3A or	24655	GEB	Auto-transformer
W8MT3-VM or W8MT3A			

491-3.2.5 INITIAL ACCURACY. The initial accuracy required of portable and switch instruments for Navy use is provided in Table 491-3-2.

Table 491-3-2 INITIAL ACCURACY REQUIREMENTS

Instrument Accessory	Initial Accuracy	Instrument Accessory	Initial Accuracy
Voltmeters and ammeters: Switchboard, direct current 4-1/2 inch and larger Switchboard, direct current, smaller than 4-1/2 inch	1 percent 2 percent	Volt-ohm-milliammeter (electronic type)	Direct current voltage (up to 250 volts), 4 percent; direct current voltage (250 to 1000 volts), 5 percent; alternating current voltage, 5 percent (exclusive of frequency error which is small below 100 megacycles); resistance, 3 percent of arc length; current, 3 percent
Switchboard, alternating current, 4-1/2 inch and larger	1 percent	Vacuum tube analyzer	Direct current voltage, 3 percent; alternating current voltage, 5 percent; current, 3 percent
Switchboard, alternating current, smaller than 4-1/2 inch	1-1/2 percent	Power analyzer	Over-all error of instruments in the assembly, 2 percent except 3 percent error permitted for polyphase wattmeter
Switchboard, H.I. shock class[1]		Stroboscopic tachometer	1 percent (at frequency of 60 cycles)
Wattmeters: Switchboard Power factor meters	1 percent 1 unit of power factor, 0.01	Capacitor analyzer	5 percent
		Shunt	1/4 percent

Table 491-3-2 INITIAL ACCURACY REQUIREMENTS - Continued

Instrument Accessory	Initial Accuracy	Instrument Accessory	Initial Accuracy
Frequency meters	3 percent of frequency range covered or 0.3 cycle for a range from 55 to 65 cycles.	Current Transformers Navy Primary Service (NPS)	If current in primary is 10% 100% 1/2 1/4
Insulation resistance indicating instrument, type B	1-1/2 percent		
Insulation resistance indicating instrument, type G	1 percent	Navy Secondary Service (NSS)	1 1/2
Insulation resistance indicating instrument, type P	2-1/2 percent	General Usage (GU)	21
Ohmmeter, low range Volt-ohm-milliammeter	3 percent Voltage, 3 percent; resistance	Potential Transformers	
(general purpose)	3 percent, current, 2 percent	NPS	1/2 percent
Volt-ohm-milliammeter (highly portable submersion proof)	Direct-current voltage, 3 percent; alternating-current voltage, 5 percent; resistance, 3 percent of arc length; current, 3 percent	NPS NSS Resistors	1/2 percent 1 percent 1/2 percent

[1]The accuracies listed above are usually specified for room temperature (25°) only. Any appreciable change in temperature will usually result in increase of error.
These are switchboard voltmeters and ammeters, 4-1/2 inches and larger, which are of the HI (high impact) shock class. Except for these, the initial accuracies given in the above table for switchboard instruments apply irrespective of whether the instrument is of the HI shock class or not.

491-3.3 PERIODICITY

491-3.3.1 The test instruments provided as standards with the FCA phase A-1 package should be calibrated at least once a year at a higher echelon calibration laboratory. A description of the field calibration program and identification of items specifically approved for field calibration may be found in the FCA METRL (NAVAIR 17-35MTL-2/NAVELEX 0969-LP-133-2020/NAVSEA OD 45854). Navy activities not receiving this manual may be placed on distribution by specific request to Metrology Engineering Center, Naval Plant Representative Office, Pomona, CA 91766.

491-3.3.1.1 If no FCA phase A-1 package is allowed a ship, an instrument of higher accuracy can be used to verify the calibration accuracy of electrical panel and switchboard meters. The instrument used for this interim check should have current calibration decal attached and should have at least a 4:1 accuracy ratio in relationship to the meter to be checked.

491-3.3.1.2 Whether a panel or switchboard meter requires calibration depends on the use of the meter in the equipment or system in which it is installed. If the parent equipment or system is not included under PMS or is not listed in the FCA METRL the following general guidance should be used for establishing calibration interval for meters requiring calibration-panel meters, 9 months; switchboard meters, 12 months. By NAVSEA directive, selected submarine battery instruments are calibrated at least every 3 months.

491-3.3.1.3 NAVSEA has established an order of precedence for determining the appropriate calibration interval in instances where there is a conflict between documents. This order of precedence can be found in the METRL.

491-3.4 CHECKS AND ADJUSTMENTS

491-3.4.1 ZERO ADJUSTMENT. Indicating instruments with spring control have an external adjustment for bringing the pointer to zero when the instruments are not in use. The zero adjustment should be checked and corrected, if necessary, each time a portable instrument is used, and as frequently as found necessary on switchboard instruments. The zero adjustment can always be made with out opening the enclosure about the instrument. Except for a few adjustments on magnetos and the generators in insulation resistance testers, it is the only adjustment which should be made by anyone except a qualified instrument repair man.

a. The zero adjustment should not be used in an attempt to correct for a bent pointer. An instrument with a bent pointer will read incorrectly to a greater or lesser extent depending upon its construction and should be repaired by a competent instrument repair man at the first opportunity.
b. Manufacturer’s instruction books, which are furnished with the equipment, should be carefully studied for detailed information.

491-3.4.2 PIVOT FRICTION. Severe mechanical shocks or vibration often damage jewels or pivots. Pivot friction on switchboard instruments can usually be checked by gently tapping the case. If the jewel bearings and steel pivots are intact, the pointer will move slightly. Portable instruments are checked by holding the meter firmly in the hands and rotating it about the axis of rotation of the moving element. If the jewels and pivots are intact, the pointer will be momentarily deflected.

491-3.4.3 MECHANICAL BALANCE. Meter movements are carefully balanced by the manufacturer, but under severe service conditions may receive injuries which disturb the balance. There is no way of checking the balance of movements in switchboard instruments without removing the instrument from the board. Balance is checked by tilting the axis of the instrument from its normal position. When spring controlled instruments are tilted 60° from their normal position, in any direction, the tip of the pointer should come to rest within 1° of the zero position for portable instruments, and within 2° for switchboard instruments. The moving elements in some instruments have no spring control and, if balanced, should rest indifferently in any position within the limits of movement.

491-3.4.4 VOLTMETERS AND AMMETERS. A voltmeter is checked against a standard by connecting both instruments to the same points on a source of variable potential. The voltage is varied and comparative readings are taken at a number of points on the scale. An ammeter is checked by connecting it in series with the standard so that the same current flows through both instruments.

a. Direct-current voltmeters and ammeters must be checked on direct current.
b. Alternating-current instruments are preferably checked on alternating current against an alternating-current standard but can be checked on direct current against a direct-current standard. When this procedure is used, it must be remembered that many alternating-current instruments operate through instrument transformers.

Although the scales of such instruments are marked with line volts or amperes, the actual values measured by the instrument are smaller by a factor which depends upon the instrument transformer ratio. The instrument transformer must be disconnected from the alternating-current instrument which is then connected to carry the same current or measure the same voltage as the direct-current standard with which it is compared. In order to eliminate error due to stray magnetic fields, two readings of the alternating-current instrument should be taken at each comparison point, one for each direction of current flow through the instrument. The mean of the two can be taken as the indication at that point if the two readings do not differ by more than a few percent. The effect of stray magnetic fields on the readings of the direct-current standard can be checked by measuring the same current or voltage with the instrument turned about its axis to four different positions 90° apart. If the readings are all the same, the instrument is unaffected by stray fields.

c. A check of an alternating-current instrument on direct current obviously furnishes no check on the accuracy of the instrument transformers normally used with the alternating-curr ent instrument.

491-3.4.5 WATTMETERS. Direct-current wattmeters can be checked by comparison with a standard direct-current wattmeter, or with a voltmeter and ammeter.

a. Single-phase wattmeters can be checked on alternating current by comparison with a standard wattmeter, or on direct current by comparison with a direct-current wattmeter, or a voltmeter and ammeter. If the check is made on direct current, precautions similar to those for checking alternating-current voltmeters and ammeters on direct current (paragraph 491-3.4.4) must be observed. In order to eliminate errors from stray magnetic fields when checking with direct current, two power readings should be taken on both wattmeters at each comparison point, one with current and voltage in one direction, and another with both reversed. If the readings are considerably different, the instruments should be moved to a region where stray fields are smaller.

b. Three-phase wattmeters are most conveniently checked on alternating current by comparison with a similar standard.

491-3.4.6 WATT-HOUR METERS. A watt-hour meter can be given a rough check by connecting it to a constant load and comparing its indication with the energy input determined by a watch and a wattmeter or a voltmeter and ammeter.

491-3.4.7 FREQUENCY METERS. A frequency meter can be readily checked by comparing its indication with the true frequency as determined from the number of poles and speed of the alternating-current generator which energizes the meter. Frequency is equal to the total number of alternator field poles multiplied by the revolutions per minute divided by 120.

491-3.4.8 POWER FACTOR METERS. The simplest method of checking the accuracy of a power factor meter is to compare its readings with those of a standard power factor meter of known accuracy connected to the same circuit. In order to obtain checks at a number of points, it will be necessary to provide some means of changing the power factor to the circuit. In the absence of a standard power factor meter for comparison, the power factor meter reading can be compared with the power factor of the circuit as determined from simultaneous readings of an ammeter, voltmeter, and wattmeter connected to the circuit.

a. In a single-phase circuit, the power factor is given by the expression:

Power facter = P/(EI)

where P = power in watts as read from the wattmeter

E = volts

I = amperes

b. In a balanced three-phase circuit, the power factor is given by the following expression:

Powere factor = P/(3EI)

where P = the three-phase power in watts as determined by two single phase wattmeters or a three-phase wattmeter. (See paragraphs 491-2.3.3 and 491-2.3.4)

E = line to line volts.

I = amperes in one line.

For the determination of power factor in this way, it is necessary that the voltages and loads be balanced. The power factor is indeterminate in an unbalanced three-phase circuit.

491-3.4.9 INSTRUMENT TRANSFORMERS. The design of instrument transformers is such that their accuracy is not appreciably affected by normal service. It is considered good practice to check the accuracy of all instrument transformers at least once in 5 years. Instrument transformers which have been subjected to overload or other abuse that may affect their accuracy should be checked as soon as possible after such an occurrence. This includes:

a. Current transformers with primaries connected in a circuit in which a short circuit occurred.

b. Current transfomers which have had their secondaries open while the primary was carrying current.

c. Potential transformers which have had their secondaries shorted while the primary was carrying current.

d. Current and potential transformers which have had either primary or secondary inadvertently connected to direct current.

491-3.4.10 RESISTANCE STANDARDS AND DECADE TESTING SETS. Resistance standards and decade testing sets should be checked for accuracy at intervals of not longer than 18 months.

491-3.4.11 OHMMETERS AND MEGGERS. The pointer of an ohmmeter or an insulation resistance indicating instrument (megger) may stand at any point on the scale when the instrument is idle because there is no spring control over the moving element. When the instrument is energized, the pointer should stand at zero if the terminals are shorted, and at infinity if no resistance is connected between them. The instrument can be considered fairly accurate if it reads correctly at these two points. A check of the accuracy at intermediate points can be made by measuring different known resistances, either in resistance boxes or a high-range direct-current voltmeter or multiplier of known resistance.

491-3.4.12 VACUUM TUBE AND CAPACITOR ANALYZERS. These analyzers should be checked by comparison with measurements made by other analyzers on board and by testing of tubes and capacitors which are known to be in good condition.

491-3.4.13 STROBOSCOPIC TACHOMETERS. These instruments may be checked by comparison with a mechanical tachometer.

SECTION 4.

PRECAUTIONS

491-4.1 GENERAL

491-4.1.1 OVERVIEW. The use of electrical measuring instruments is largely a matter of observing certain precautions to avoid damage to the instrument and errors in reading. When these are observed, electrical measuring instruments give very little trouble.

491-4.1.2 USE OF INSTRUCTION BOOKS. Instructions and wiring diagrams are furnished with instruments whenever the manner in which they are to be used is not obvious. Such instructions are either attached to the instrument case or cover, or are given in separate instruction books. These should be consulted freely for specific instructions and precautions in addition to those which follow.

491-4.1.3 NEED FOR PRECAUTIONS. The operating forces involved in electrical measuring instruments are extremely small. The instruments themselves are necessarily of delicate construction and require certain precautions in handling and use to obtain accurate results and to avoid injury by:

a. Mechanical shock

b. Exposure to strong magnetic fields

c. Excessive current flow.

491-4.1.4 AVOIDING MECHANICAL SHOCK. Although the moving element in most electrical instruments is light in weight, the bearing pressure at pivots and jewel bearings is high because the bearing area is made extremely small in order to reduce friction. Mechanical shocks increase the bearing pressure and may injure the pivots and bearings and destroy the usefulness of an instrument. The obvious precautions are:

a. Never handle an instrument roughly or carelessly.

b. Never hammer or pound or do heavy drilling, filing, or other work which will result in shock or excessive vibration at a table, bench, or switchboard on which instruments are placed or mounted.

491-4.1.5 AVOIDING EXPOSURE TO STRONG MAGNETIC FIELDS. Exposure to strong magnetic fields may permanently impair the accuracy of an instrument by leaving permanent magnetic effects in the magnet of permanent magnet moving coil instruments, in the iron parts of moving iron instruments, or in the magnetic materials used to shield instruments from disturbance by external magnetic fields. Electrical measuring instruments, therefore, should never be placed in or carried through a strong magnetic field. Among the positions to be avoided are the bedplates and pole pieces of electrical machinery and regions near degaussing coils, main storage battery leads in the submarines, and conductors in the main propulsion circuits in electric drive ships. A heavy short circuit in conductors near an instrument, even though of extremely short duration, may partially demagnetize the magnet of a current instrument. After such an occurrence, instruments near the short circuited conductors should be checked for accuracy even if they have suffered no visible injury.

491-4.2 CONNECTING AND USING INSTRUMENTS

491-4.2.1 GENERAL. The coils of electrical measuring instruments are of limited current-carrying capacity and can be burned out with startling rapidity by excessive current. To avoid such an occurrence and errors due to loose or dirty connections, the following points should be kept in mind when connecting and using instruments:

a. Whenever possible, connections should be made only when the circuit is not energized.

b. All contacted surfaces should be clean.

c. All connections should be tight, and in switchboard or permanent installations, provided with suitable means for keeping them permanently tight.

d. An ammeter or the current coil of a wattmeter or other instrument must be connected in and never across the line carrying the current to be measured. If an external shunt or current transformer is required, the shunt or the primary of the current transformers must be connected in the line.

e. A voltmeter or the potential coil of a wattmeter or other instrument must be connected across the voltage to be measured, in series with an external multiplier if one is needed, or across the secondary of a potential transformer. If a potential transformer is required, the primary is connected across the voltage to be measured.

f. The secondary of a current transformer should be connected to its ammeter or current coil or short circuited, but never open circuited, when the primary is energized.

g. The secondary of a potential transformer should be open circuited or closed through a voltmeter or potential coil, when the primary is energized; it should never be short circuited or closed through a low resistance.

h. One terminal of the secondary of each instrument transformer should be grounded. If an instrument transformer has a metal case, this should also be grounded.

i. The coils of wattmeters, varmeters, frequency meters, power factor meters, synchroscopes, and excitation indicators may be carrying an excessive current even when the deflection of the pointer is on the scale. Extra care is necessary in connecting such instruments to avoid excessive current in the coils since the reading of the instrument does not necessarily give warning of an overload.

j. An instrument should never be left connected with its pointer deflected off scale nor deflected in the wrong direction.

k. Never connect alternating current to an instrument intended for use on direct current only. Alternating current cannot deflect the pointer of such an instrument but can burn out the coil.

l. Never connect direct current to an instrument transformer.

m. When using multiple-range instruments to measure unknown or doubtful values of current or voltage, always start with the highest range first and work down to a range which gives a deflection on the upper part of the scale.

n. Check all connections carefully to make sure that no instrument will be overloaded before turning on the current.

o. Before measuring resistance, observe these precautions:

   1. If the equipment being tested employs batteries or other power, shut off all power and disconnect batteries.
   2. Discharge all capacitors in the equipment under test.

3. Do not test devices such as thermocouples, meters, or sensitive relays which might be damaged by the current. In such cases a special bridge circuit must be used.

p. When measuring an alternating-current potential, one line of which is grounded or low in potential with respect to ground, this line should be connected to the terminal of the instrument which is marked LO or otherwise designated for low potential connection. Similarly the connection to the highest in potential should be connected to the instrument terminal marked HI. This procedure places the least dielectric stress between the instrument circuits and the instrument case.

q. When using portable instruments (except zero-center type), the correct polarity or direction of reading should be ascertained, if possible, before attaching test leads.

491-4.3 OBTAINING ACCURATE RESULTS

491-4.3.1 GENERAL. While a modern electrical measuring instrument can be expected to give reasonably accurate results under almost any conditions in which it is likely to be used, certain precautions, in addition to those to protect the instrument, are necessary in order to obtain the most nearly accurate results, either in making tests or checking instruments. These are:

a. Instruments should be used at a distance from motors, generators, transformers, and conductors carrying large currents in order to avoid errors from stray magnetic fields. Unshielded instruments should not be placed too close together as stray field errors can be caused by neighboring instruments whether they are connected in the circuit or not. A test of the effect of stray fields on an instrument placed on a table can be made by determining whether the readings are unchanged when the meter is rotated into four different position, 90° apart. In making this test, it is obviously essential that neither the stray field nor the quantity measured change between the readings in the different positions.

b. For most nearly accurate results, instruments should be used in the positions in which they were calibrated. Portable instruments are nearly always calibrated with the scale in a horizontal plane; switchboard instruments in the position in which they will be installed.

c. In wattmeters and other instruments with both current and potential coils, a large difference of potential between the coils gives rise to electrical forces on the moving element which may cause errors. Connections should be made in such a way that both coils are at nearly the same potential.

d. Avoid wiping the glass cover over the pointer of an instrument before taking readings, because the electrostatic charge left on the glass will attract the pointer. Large errors from this cause are possible with some types on instrument. If, for any reason, the glass has recently been rubbed, breathe on it to dispel the charge.

e. Never use an instrument which sticks at any part of its scale or has a zero error.

f. Avoid the use of instruments in extreme temperatures whenever possible. Even though no permanent injury to the instrument may result, its indication is affected to some extent by temperature and the accuracy is less than at normal temperatures.

g. If an instrument has been roughly jarred, overloaded, or exposed to extreme temperature conditions or strong magnetic fields, it should be checked for pivot friction and balance and compared with a standard or a similar instrument not so exposed to test the accuracy of its indication.

h. Avoid parallax errors when taking readings by placing the eye on a line through the pointer and perpendicular to the scale. Portable instruments are usually provided with a mirror. When the pointer and its image are in alinement, the eye is in the proper position for reading the instrument.

i. Several ammeters and current coils may be connected in a series to the secondary of a current transformer;

and several voltmeters and potential coils may be connected in parallel to the secondary of a potential transformer, if the total burden on the transformers does not exceed their rating. For the most nearly accurate results, however, it is preferable that each instrument have its own transformer or transformers, the one with which it was calibrated or checked.

j. For each measurement with multirange instruments, check the zero adjustment on the range being used to obtain accurate measurements.

491-4.4 USING PORTABLE INSTRUMENTS

491-4.4.1 GENERAL. The following precautions should be kept in mind when using portable instruments:

a. Wires attached to the instruments should preferably extend back over the bench or table on which the instruments are placed and away from the observers. Wires draped over the front of the table are sometimes accidentally caught by the observer and throw the instrument to the deck. If it is impossible to avoid placing wires in this way, they should be clamped to the bench or table near the instruments.

b. When instruments must be used at places where vibration is unavoidably present, they should be placed on pads of folded cloth, felt, or similar material.

c. When the tests being conducted are to last for several hours, switches should be provided to bypass the current around ammeters and the current coils of other instruments. The switches are opened when readings are taken. Switches should also be used to disconnect voltmeters and the potential coils of wattmeters if the instruments themselves do not have keys. The switches used to short circuit ammeters connected to measure the current taken by a motor should always be closed during the starting period of the motor in order to avoid damage to the instrument by the starting current.

d. Voltmeters should be disconnected from field circuits or other highly inductive circuits before the circuit is opened as otherwise the inductive kick may bend the pointer.

e. Volt-ohm-milliammeters should not be left with the selector switch on the OHM setting after use, as on some instruments this places a drain on the small battery serving as source of direct current supply with a consequent shortening of battery life. The selector switch should preferably be left on the highest voltage scale. This setting assists in avoiding damage in the event the instrument is inadvertently connected to potentials exceeding the lower range settings. Some volt-ohm-milliameters have OFF positions on their selector switches. Store such instruments with the switch OFF.

491-4.5 INSTALLATION OF SWITCHBOARD INSTRUMENTS

491-4.5.1 Switchboard instruments should be installed: where they are well lighted; can be easily read without parallax errors; and are not exposed to undue vibration or shock, abnormally high temperature, an extreme range of temperature, or to stray magnetic fields from neighboring instruments or from other sources. Instruments should not be installed until all heavy pounding, hammering, or drilling in the vicinity of their mounting has been completed.

491-4.6 ELECTRONIC TYPE INSTRUMENTS USING HIGH VOLTAGES

491-4.6.1 The following instructions apply to electronic-type instruments employing high voltages.

a. Although interlock protection is not employed, the operation of the equipment involves the use of high voltages which are dangerous to life. Operating personnel must at all times observe all safety regulations. Do not change tubes or make adjustments inside equipment with high voltage supply on. Always shut down motor generators or other power equipment. Under certain conditions dangerous potentials may exist in circuits with power controls in the OFF position due to charges retained by capacitors. To avoid casualties always remove power, discharge, and ground circuits prior to touching them.

b. Since the use of high voltages which are dangerous to human life is necessary to the successful operation of the equipment covered by these instructions, certain reasonable precautionary measures must be carefully observed by operating personnel during the adjustment and operation of the equipment. It should be borne in mind that interlocks are not provided, and, therefore, removal of the case or rear cover will not cause interlocks to function and will thereby allow access to circuits carrying voltages dangerous to human life.

c. While every practicable safety precaution has been incorporated in the equipment, the following rules must be strictly observed.

   1. Keep away from live circuits. Under no circumstances should any person other than authorized maintenance personnel be permitted to reach within or in any manner gain access to the enclosure when the power supply line switches to the equipment are closed, or to approach or handle any portion of the equipment which is supplied with power, or to connect any apparatus external to the enclosure to circuits within the equipment or to apply voltages to the equipment for testing purposes while any portion of the shielding or enclosure is removed or open. Wherever feasible in testing circuits, maintenance personnel should check for continuity and resistance rather than directly checking voltage at various points.
   2. Do not service or adjust alone. Under no circumstances should any person reach within the enclosure for the purpose of servicing or adjusting the equipment without the immediate presence or assistance of another person capable of rendering aid.
   3. An approved poster illustrating the rules for resuscitation by the latest method shall be prominently displayed in each compartment in which the above equipment is normally used.

SECTION 5.

MAINTENANCE

491-5.1 ESSENTIALS OF CARE

491-5.1.1 GENERAL. The essentials in caring for instruments are:

a. Keep the outside of the enclosure clean and dry.

b. Store instruments not in use in a clean, dry place where they are not exposed to shock, vibration, strong magnetic fields, or extremes of temperature, and are securely stowed to prevent shifting in heavy seas.

c. Never allow the enclosure around an electrical measuring instrument to be opened except by a qualified instrument repairman. This rule applies to both switchboard and portable instruments of all kinds except magnetos and insulation resistance testers. The outer cases of these may be opened for replacement of brushes or minor repairs to magneto or generator by a skilled electrician.

491-5.2 LUBRICATION

491-5.2.1 The pivots and jewel bearings of electrical measuring instruments require no oiling at anytime and should never be lubricated.

a. No provisions are made for oiling the generator bearings in meggers from the outside of the case. The original assembly provides lubrication for several years of use.

b. The bearings on magnetos should be lubricated as necessary at the oil holes provided for this purpose.

491-5.3 SWITCHBOARD INSTRUMENTS

491-5.3.1 Before a start is made on any repairs which involve pounding, hammering, riveting, or drilling on a switchboard or near enough to cause vibration and shock, the switchboard instruments should be carefully removed and stowed where they cannot be damaged. Instrument leads should be tagged and marked to facilitate reconnection without error.

491-5.4 REPAIRS

491-5.4.1 GENERAL. It is intended that instrument repairs be made on tenders and repair ships to the extent permitted by shipboard instrument shop facilities and personnel. In general, this includes such repairs as: adjusting and installing springs and moving elements; rewinding and installing electrical coils; fabricating small shafts and bearing holders; recharging magnets; adjusting air gaps; repairing and recalibrating shunts; straightening and installing pointers; and installing jewels and pivots. Also, repairs to equipment requiring qualified technicians and the use of sensitive-type (Instrument Shop) tools and instruments such as movie projectors, sound equipment, degaussing indicating gear, voltage regulator elements, and so on are included. The number of instruments to be repaired and the extent of repairs are matters affected by local shipboard considerations such as utilization of repair personnel and availability of repair parts. For this reason, ships of the fleet must determine on the basis of prevailing local circumstances whether instruments are to be repaired shipboard or transported to appropriate shore activities for repairs.

491-5.4.2 REPLACEMENT OF CATHODE RAY TUBES. In replacing cathode ray tubes in oscilloscopes, it is necessary to aline the new tube in the shield with respect to the vertical and horizontal axes of the scope. The directions in the instruction book should be followed.

491-5.4.3 REQUISITIONING OF REPLACEMENT METERS. When requisitioning replacement meters, the meters should be selected from the Ship Portable Electrical and Electronic Test Equipment Requirements List (SPETERL). If a meter with the exact characteristics desired is not listed, an instrument having a scale with the next higher or lower range to that desired which would be serviceable should be selected. An instrument listed in SPETERL should be requisitioned; submittal of a request for a special instrument is not recommended under ordinary circumstances.

REAR SECTION

NOTE

TECHNICAL MANUAL DEFICIENCY/EVALUATION EVALUATION REPORT (TMDER) Forms can be found at the bottom of the CD list of books. Click on the TMDER form to display the form.