

Electrical Maintenance Hints

Volume 2

Industrial Equipment Maintenance

Compiled and Edited by John G. Bishop

Westinghouse Electric Corporation
Printing Division
Trafford, Pennsylvania

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Volume 2. Industrial Equipment Maintenance

- Chapter 1. A-C Control Starters and Contactors**
- Chapter 2. Maintenance of Control Components**
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Notice to the user of this book

The safe maintenance or repair of any electrical apparatus requires a thorough knowledge of engineering safety and repair techniques, and familiarity with the particular features of the apparatus involved. This book cannot, and does not deal with the numerous details of every manufacturer's apparatus necessary for safe repair or maintenance. The inexperienced electrician or unqualified layman should not expect this book to provide sufficient instructions to permit him to safely repair any electrical apparatus. Use only qualified electrical repair personnel to do any work required, and refer those workers to the manufacturers' warnings and instructions before starting any work.

Severe or fatal electrical shock or burn can result from failure to properly service or repair equipment.

Safety

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There are no understandings, agreements, representations, or warranties, express or implied, including warranties of merchantability or fitness for a particular purpose.

The information, recommendations, descriptions, and safety notations in this document are based on Westinghouse experience and judgment with respect to maintenance hints. **This information must not be considered to be all inclusive or covering all contingencies.** If further information is required, the equipment or material manufacturer must be consulted.

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Warning

Warnings, recommendations, and instructions contained in this book may not apply to equipment designed and built after the book was written. The manufacturers' applicable instructions should be consulted in all instances.

Warning: This document is not all inclusive. It does not cover all contingencies. Read and follow the manufacturer's instructions before attempting to handle, store, install, use, or service any equipment. Failure to follow these instructions can result in severe personal injury, death, or damage to property.

Warning: Hazardous voltage, vapor, hot oil, and other hazardous conditions can be present in electrical equipment and related systems. Competent trained personnel are required to handle, store, install, use, or service any equipment. Failure to follow this warning can result in severe personal injury, death, or damage to property.

Warning: Follow the safety instructions given in Volume 1 Chapter 5 and throughout the book. Failure to do so can result in severe personal injury, death, or damage to property.

Preface

This set of books is intended to provide a condensed treatment of acceptable maintenance practice on the most commonly used types of electrical equipment. Where specific references or examples were required, products manufactured by the Westinghouse Electric Corporation or components used in such products have been used.

Since this book is directed to the maintenance of electrical equipment an attempt has been made to make it applicable to older as well as new apparatus and devices.

For the user's convenience the book has been bound in four volumes, 1 General Maintenance, 2 Industrial Equipment Maintenance, 3 Power Apparatus Maintenance, 4 Reference Material and Tables and Formulas. An additional volume entitled Index, is supplied to help you locate specific topics. It consists of a volume/chapter listing, followed by a detailed index.

Page numbering reflects this organization.

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The first digit indicates the volume

The second digit the chapter

The third digit the page

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

A-C Control Starters and Contactors

Maintenance of a-c starters and contactors requires a systematic program of inspection. Experience will indicate which installations are under the most severe service conditions. These installations will require the most frequent inspections.

Inspections must be made by personnel who are trained and experienced in this type of electrical equipment and who are prepared to make quick repairs.

The manufacturer's instructions and recommendations must always be consulted and carefully followed in any inspection and maintenance programs.

Warning: Do not open covers, make interior inspections, or undertake repair work on any control equipment unless it has been de-energized. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Figure 1 shows a typical reduced voltage starter with the cover open.

1.1 General Guidelines

- A. Initial installations should be tested and proved before acceptance.
- B. Apparatus should be easily accessible for inspection and repair.
- C. An adequate supply of correct renewal parts should be available.
- D. Enclosures should be selected to fit the specific operating conditions.
- E. Starters and contactors should be kept clean and dry.
- F. Correct contact pressures should be maintained, worn, burned, or pitted contacts should be replaced. Contacts should always be replaced in pairs.

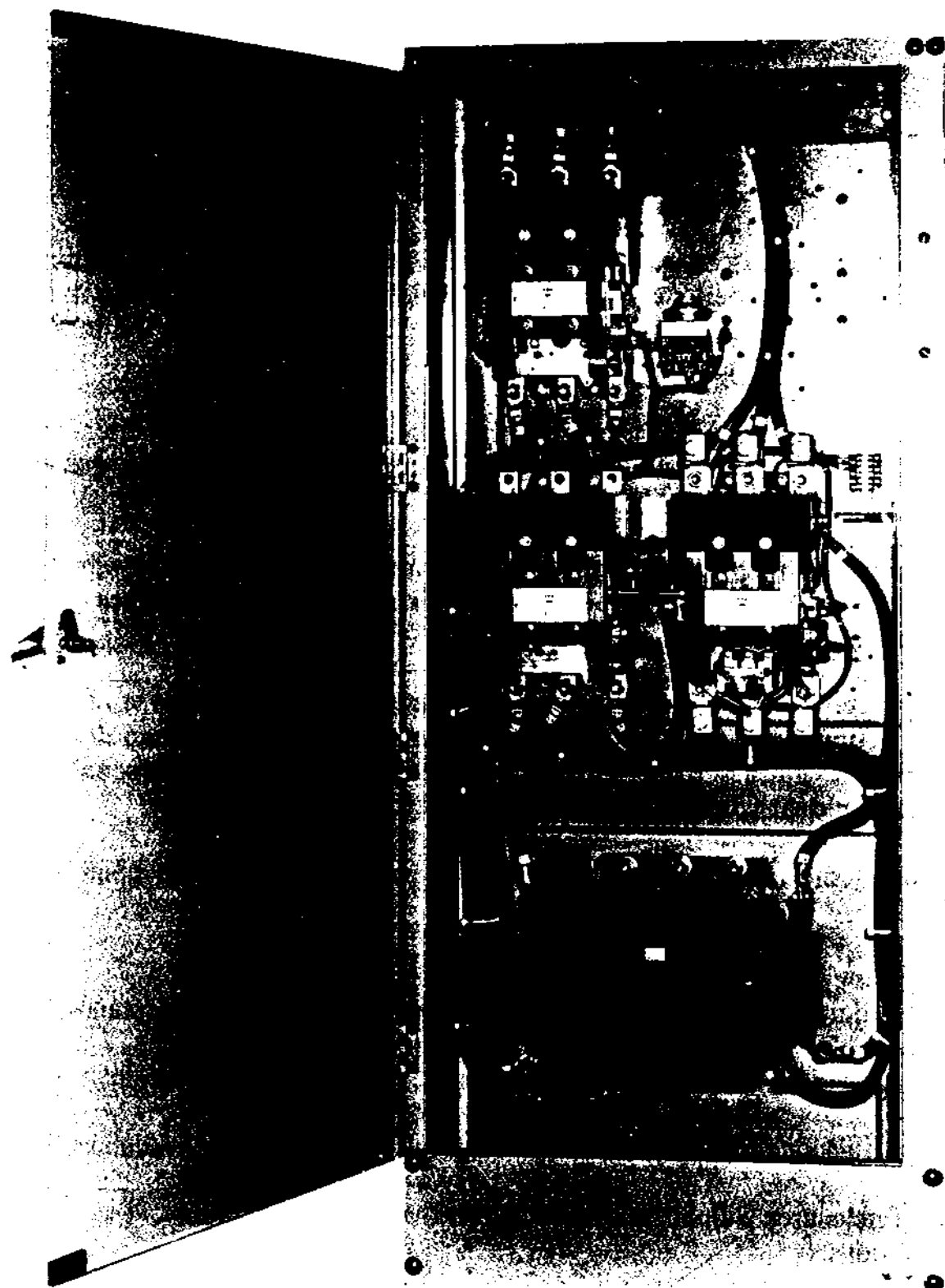


Fig. 1 - Typical Reduced Voltage Starter (Size 5 Autotransformer Type)

G. Contacts should be kept clean. The contact shape should not be altered by rough filing or grinding.

H. All contacts and connections should be kept tight.

I. Contactor or relay bearings should not be oiled. These units should be kept clean with minimum friction between moving parts.

J. Coils should be operated only at rated voltages. Overvoltage or undervoltage conditions are damaging.

K. Keep arc-quenching parts in good condition and in correct operating position.

L. Frayed or worn shunts should be replaced.

M. Dashpots should be kept clean and should contain only the correct oil.

N. High temperatures should be investigated, the cause found, and correction made. If there is any doubt, measure the temperature.

O. Inspection should be made for undesirable grounds and when found they should be immediately eliminated.

These guidelines are covered in greater detail under 1-3 in this chapter.

1.2 Personal Safety

Safety is the first consideration in any maintenance program.

A. Power must always be disconnected and the unit completely de-energized before the apparatus is touched.

B. Industry standards of safety must be observed at all times.

C. Controllers must be enclosed, guarded, or remotely located to avoid personal contact.

1.3 The Complete Maintenance Program

A. Installation

Before putting any electrical controller into operation, all installation work and wiring connections should be thoroughly checked to make certain it is correctly installed. All parts should have ample capacity and tests should be made to prove the adequacy of the equipment and its installation before final acceptance is given to the installer.

For inspection and easy repair work, all parts should be designed to be as accessible as possible. It should be possible to renew contacts, coils, springs, and other parts quickly and with few tools. Installations should be arranged so all units are accessible for maintenance work.

B. Ease of Inspection and Repair

Equipment should be designed to enable inspection and parts replacement easily, quickly without special tools, and without hazard to personnel. These considerations should be part of the purchase specifications.

C. Renewal Parts Stocks

On most electrical apparatus, normally wearing parts that will need replacement are inexpensive and easy to stock. When compared to the potentially high losses from operations shutdown for repairs, a stock of replacement parts is a good economic decision.

The equipment manufacturer can recommend a stock of parts based on the equipment, service conditions, and broad experience. Parts should be purchased from the original equipment manufacturer. If purchased from other manufacturers the parts should be thoroughly checked for dimensional accuracy and correct materials.

D. Enclosures

Most electrical controllers are mounted in some kind of metal enclosure. This is done to protect personnel from live parts, to protect the controller from mechanical damage, corrosive atmospheric conditions, and from unauthorized tampering. The most common enclosure is made of sheet metal and encloses all live parts. It may be ventilated or unventilated. Selection of a proper enclosure can greatly reduce maintenance requirements.

1. *Dusty Atmospheres*

For atmospheres containing cement dust, grain dust, coal dust, or other dusts, dust-tight enclosures will reduce maintenance requirements. These enclosures are gasketed and so constructed that no dirt or dust can enter.

2. *Wet Locations*

Weather-resistant, drip-tight, water-tight, and submersible enclosures are used when conditions indicate.

3. *Hazardous Locations*

For hazardous locations such as mines, refineries, cleaning plants, grain elevators, wherever a controller is located in an explosive atmosphere, explosion-proof enclosures are used.

These enclosures are of heavy construction and so designed that they withstand explosions of gases within the enclosure without damage to the enclosure. They will also confine the explosion, any sparks or flame to the interior of the enclosure thus avoiding general fires or explosions.

Oil immersed controllers are also used to prevent explosions in dangerous locations.

4. *Corrosive Atmospheres*

Oil immersed controllers are used in highly acid or other corrosive atmospheres. The enclosure is protected externally with a suitable resistant finish.

E. *Clean, Dry Controllers*

Few industrial controllers operate in clean places. Oil and moisture are often present as vapors or in droplets. Dust, lint, and other particulate matter are usually present as the result of the operating conditions.

These materials, individually or in combination create a maintenance requirement. They slow mechanical action, damage bearing surfaces, and reduce insulating properties.

Accumulations of dust and dirt should be regularly removed either by vacuum, the preferred method, or by blowing with compressed air. If compressed air blowing is used, care should be taken to assure that the air is dry and clean and that the blowing isn't just re-depositing the dirt in another location in the controller. In blow cleaning the air pressure

should not exceed 25 psi. Excessive pressure may drive dirt and grit into the insulation or into inaccessible places where it will be difficult to extract.

Special attention must be given to removing any metallic dust, especially if it has magnetic properties which cause it to collect on and adhere to the magnetic parts of the controller.

Warning: Wear eye and respiratory protective equipment when blow cleaning electrical apparatus; failure to do so can cause personal injury.

Moisture due to condensation may collect in an enclosure. Drainage holes are rarely acceptable as a relief method. Heaters are most frequently used to prevent moisture accumulation. When in operation, the coils and resistors in the controller usually produce enough heat to prevent condensation. When the controller is idle some form of heater, usually a small electric heater, may be required. In unusually high moisture conditions either a moisture proof enclosure or a permanent heater may be acquired.

Warning: Do not touch any controller that is wet or suspected of being wet, until it has been disconnected and completely de-energized. A high moisture level greatly reduces the effectiveness of insulation. Failure to heed this warning can cause severe personal injury, death, and damage to property.

F. Replace Worn Contacts

Every time controller contacts open or close they are subject to mechanical wear and electrical burning. The combined rolling-wiping motion of the contacts when they close cause this wear and burning. The closing action is designed to assure good contact and to confine the electrical burning to the tips of the contacts. The mechanical wear of contacts that operate at high frequency may be more serious than burning caused by arcing.

As contacts grow thinner due to the combined wearing-burning action, the pressures decrease. Reduced pressure on the contacts reduces the current carrying ability and can cause overheating. Eventually the contacts will have to be replaced.

Another cause of loss of contact pressure is damaged contact springs. If the springs have been weakened by overheating they may not be able to provide sufficient contact pressure. The controller manufacturers will

provide information on the correct contact pressure for their products. Contact pressures should be kept within the limits specified by the manufacturer.

Always replace both moving and stationary contacts. Contacts operate in pairs and a mismatched set of one old and one new contact is almost sure to operate badly. Figure 2 pictures a typical set of moving and stationary contacts. Figure 3 shows a worn contact in need of replacement.



Fig. 2 – Moving and Stationary Contacts

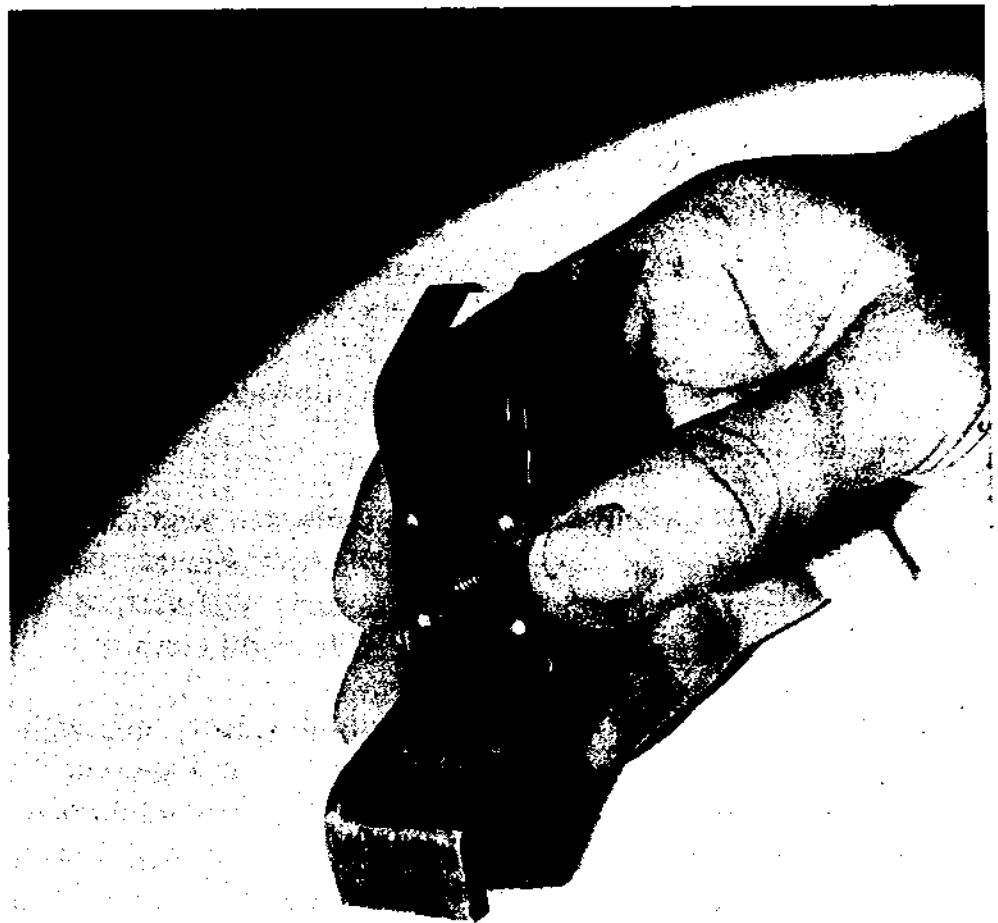


Fig. 3 – Contact Surface has been Worn Away Unevenly by Mechanical Wear. Pair of Contacts Should Be Discarded and Set Replaced

G. Clean Contacts

Warning: Do not use emery paper to clean contacts, because it is an electrical conductor. Abrasive particles imbedded in contact surfaces and emery dust in the contactor can lead to failure of the equipment and consequent severe personal injury, death, and damage to property.

The metals of which contacts are made tarnish readily. Small contacts used in small relays, electrical interlocks, pushbuttons, thermostats, pressure switches and similar devices are usually of silver. Larger contacts are generally copper. The tarnished surfaces of copper contacts inhibit electrical conductivity. The tarnished surfaces of contacts often contribute to serious overheating. The slight rubbing action and burning that occur during normal operation will generally keep the contacts clean. Contacts that infrequently open or close will develop a tarnished surface. If the contacts are copper, they should be cleaned when the discoloration appears.

Silver contacts need not be cleaned. The dense discoloration on silver is a relatively good conductor.

In cleaning contacts do not change the contact shape by rough filing or grinding.

1. *Burning of Contacts* may occur when excessive currents are opened or closed or when contact motion is sluggish. If this burning causes deep pits or craters or a very rough surface, both the moving and stationary contacts should be replaced. Figure 4 illustrates a burned contact surface.

It is not desirable to have contact surfaces completely smooth. The slightly roughened surfaces that develop under normal good operation, if clean, provide a better contact. Contacts with surfaces comparable to coarse sandpaper can be considered in good condition.

2. *Welding of Contacts.* Very few high speed contactors close without some bounce or rebound. This is due to the reaction of the contact springs as they are compressed to provide the final contact pressure. When contacts bounce they separate. At this time they are carrying current and even though the separation is small, an arc is formed. This arc, if severe, may cause sharp projections of burned or roughened contact surfaces to overheat and may weld the contacts surfaces together. Under these conditions the contacts may not open when next expected to do so. Other causes of contact welding are excessive currents when contacts

open or close, insufficient contact pressure, sluggish operation, and momentary closing of contacts with little or no pressure applied. Silver contacts weld more readily than copper.

Contacts that are dirty or excessively rough may be cleaned with a fine file. Care must be taken to retain the contour of the contact surfaces. Changing the original shape by careless filing will leave high points or edges that may overheat.



Fig. 4 – Silver Contact Face and One Corner of this Entire Unit have been Severely Burned While Interrupting an Excessive Current

H. Tight Connections

Caution: Keep all connections on electrical components tight. Inspect and check frequently. Loose connections cause arcing and burning, overheating, and unreliable operation that can cause personal injury and property damage.

Loose connections cause heating and high resistance, this in turn causes formation of copper oxide or tarnish which further increases resistance

which increases heating and even higher resistance. The effect is always cumulative and self feeding and increases until parts overheat, deteriorate, or burn.

Other loose connections on thermally operated devices such as thermal overload relays can cause the relay to trip and stop a motor when the motor is not overloaded.

The bolts or fastening devices that hold contacts in place should always be tight. Normal expansion and contraction of metals due to temperature changes or excessive vibration will cause bolts or nuts to loosen. Frequent checking for loose contacts is advisable. Figures 5 and 6 show the method of measurement of contact force and spring length.

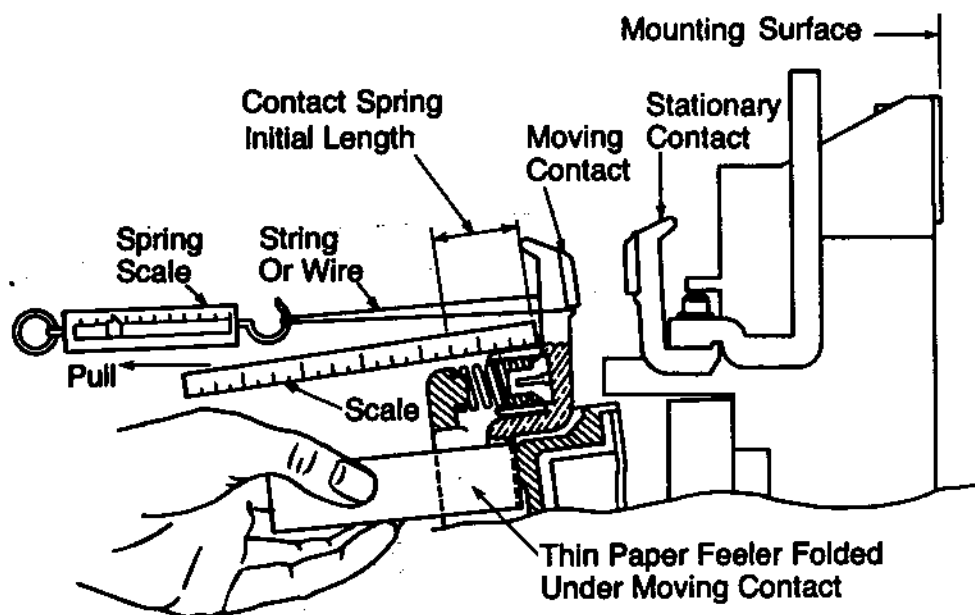


Fig. 5 - Initial Contact Force and Spring Length Measurement

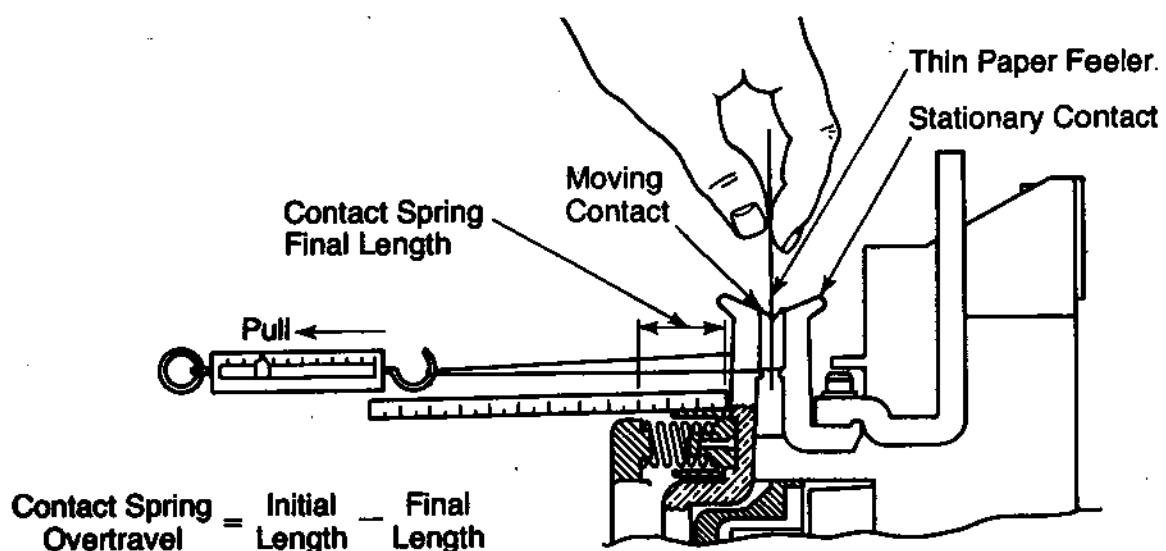


Fig. 6 - Final Contact Force and Spring Length Measurement

I. Bearings

Do not oil contactor or relay bearings but keep them clean and without friction in the moving parts. Correct operation of a contactor depends upon its being clean and free from foreign material. Any accumulation of oil and dirt may cause sluggish mechanical action that impairs the arc-interrupting capabilities of the device or causes welding of contacts. Except for bearings of master switches, drum controllers, and similar units, no lubrication of controller parts is needed. This does not apply to special controllers that are oil-immersed. Maintenance of these oil-immersed controllers is generally the same as given to oil circuit breakers of comparable voltage.

Notice: Bearing surfaces of contactors and relays do not require lubrication.

J. Maintain Rated Voltage

Coils provide the electro-mechanical pull that causes the contacts of relays and contactors to open or close. Series coils generally carry heavy currents and have relatively few turns of heavy copper. Shunt coils have many turns of insulated wire. They are generally impregnated in a vacuum or under pressure with insulating compounds and are covered with insulating tapes or materials. The impregnating compounds produce a firm but resilient binding that prevents cracks when temperature changes. The impregnation process eliminates air pockets within the winding and it makes the coil a solid mass that is less subject to mechanical injury.

1. Operating Voltages

Shunt coils for a-c devices should be designed to close contacts at 85% of rated voltage. Coils for d-c devices should close the contacts at 80% of normal voltage. Any coil is expected to withstand 110% of rated voltage without damage.

2. Open-Circuited Coils

A coil with an open circuit will not operate the contactor or relay. The questionable coil should be immediately replaced by a coil known to be satisfactory. The questionable coil can then be tested for open circuits.

3. Short-Circuited Coils

If some turns of a coil become short circuited the resistance of the coil will be reduced. More current then passes through the coil. The increased current will cause higher operating coil temperatures which will frequently result in coil burnouts.

4. *Overvoltage*

Coils must be operated only at the rated voltage. Overvoltage on coils causes them to operate at a higher temperature that shortens coil life. Overvoltage also operates the contactor or relay with unnecessary force and causes most mechanical wear and bounce when closing.

5. *Undervoltage*

Coils operating under rated voltage cause the device to operate sluggishly. The contact tips may touch but the coils cannot exert enough force to completely close the contacts against the contact spring pressure. Under these conditions the contact pressure is below normal and the contacts may overheat and weld together.

6. *Closing and Operating Currents*

Warning: Do not block contactors open when testing. This may make cut-off devices inoperable thus destroying the automatic safety protection. Blocking contacts open can cause severe personal injury or death, and damage to property.

The impedance of a magnetic circuit having a large air gap is much lower than the impedance of the same magnetic circuit having little or no air gap. The current drawn by the coil of an a-c magnet is therefore much greater at open gap than at closed gap. Since closing time is short, a-c coils are designed to withstand energizing under closed conditions. Coils will soon overheat if the magnet is blocked open or the voltage is too low to close it and the coil remains energized with a large air gap in the magnetic circuit.

Direct-current coils are not subject to these conditions because the coil currents do not vary with the gap. For certain applications d-c coils are momentarily energized at much higher than rated currents. The high momentary energizing requirement at closing of electrical devices is not damaging unless the high current is maintained.

Replace questionable coils immediately.

K. *Maintain Arc Interrupters*

When contactors are expected to open circuits carrying currents that are difficult to interrupt, they are designed with arc-rupturing (arc-interrupting, arc-quenching) features, usually in the form of a box or chute.

When these devices have been removed for inspection or renewal of contacts they must be returned to their original position to make the arc-interrupting effective.

Arc Box

Warning: The contactor must never be operated in a power circuit unless the arc box is securely bolted in place to prevent failure. To do so can cause severe personal injury or substantial property damage.

The arc box provides a mechanical stop for the moving contact assembly while maintaining the proper gap for the main contacts. The molded box also supports the arc-quenchers in the De-Ion® grid type arc interrupter. The arc box requires no maintenance except for periodic inspection for grid damage or lines burned through by fault conditions.

The arc-interrupting components generally surround the contacts so must be designed to be easily moved to allow inspection and replacement of both moving and stationary contacts. To be effective the interrupting parts must be returned to their original position relative to the contacts.

On d-c starters or contactors the arc-quenching structures generally include arc shields of molded ceramic or other heat resistant material. The arc shields should always be positioned so the arc is broken within the field of the blowout coil, otherwise the shield will not perform its function properly. Arc shields should be replaced before the molded material is burned away sufficiently to expose the metal parts to the arc.

Small a-c contactors are equipped with a De-Ion® type arc quencher which confines, divides, and extinguishes the arc almost instantly as the circuit is broken. Flash and scattering of flame is eliminated. The de-ionization action not only stretches the arc but confines and quenches it. Refer to Figure 7. As the contacts separate a magnetic reaction occurs that causes the stretching arc to rise immediately into the interrupting grids where it is broken into a series of small arcs. At the next zero point in the current cycle the air adjacent to each grid is de-ionized instantly, the voltage per grid is insufficient to re-establish the current flow and the arc is quenched.

The arc quencher is assembled over the contacts in much the same manner as the magnetic blowout coils and arc shields on a conventional d-c contactor and is easily removable for inspection and replacement of contacts. This system reduces pitting and burning of contacts and arc boxes and a longer trouble-free life is provided.

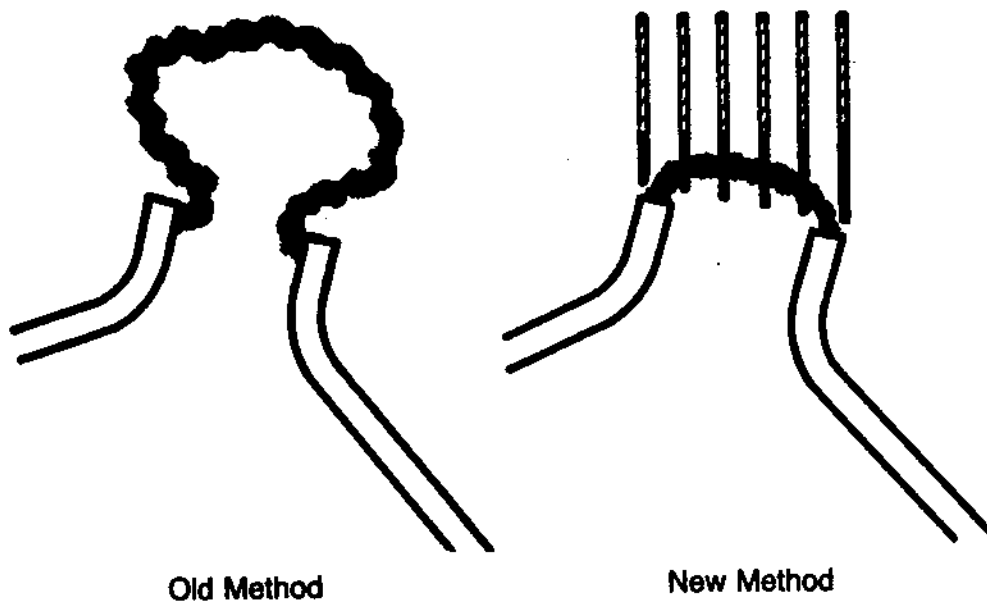


Fig. 7 – Arc Quenching by De-Ion Method

L. Maintain Shunts

Replace frayed and worn shunts. If the fine strands of shunts break, usually at bends, the unbroken strands must carry the load. If many strands break the resulting overload will cause the shunt to heat and eventually burn out.

M. Maintain Dashpots

Dashpots are used to retard motion. They are of either air or fluid type. Both types are machined to close clearances and must be kept clean and free to move. The proper type and amount of fluid should always be kept in fluid dashpots. Only fluids that meet the equipment manufacturer's specifications should be used because viscosity changes with temperature and incorrect fluid might inhibit the dashpot action.

N. Temperatures

Caution: Do not attempt to test temperatures of electrical equipment by touch. Much apparatus normally operates at temperatures high enough to burn. Testing by touch is a highly inaccurate measurement. Failure to observe this caution may result in personal injury.

High temperatures are symptoms of trouble, but it is often difficult to know when temperatures are excessive.

Resistors are operated safely at 375C above ambient but organically insulated coils are generally restricted to 85C above ambient. Most solid

contacts are limited to 65C rise and copper bus work to 50C rise above ambient. There is a growing use of high temperature insulations capable of withstanding as high as 160C rise.

Barring presense of gases, acids, or alkalis, much discolored copper parts indicate they have been or are too hot. When in doubt temperatures should be measured by thermometer. Refer to Figure 8.

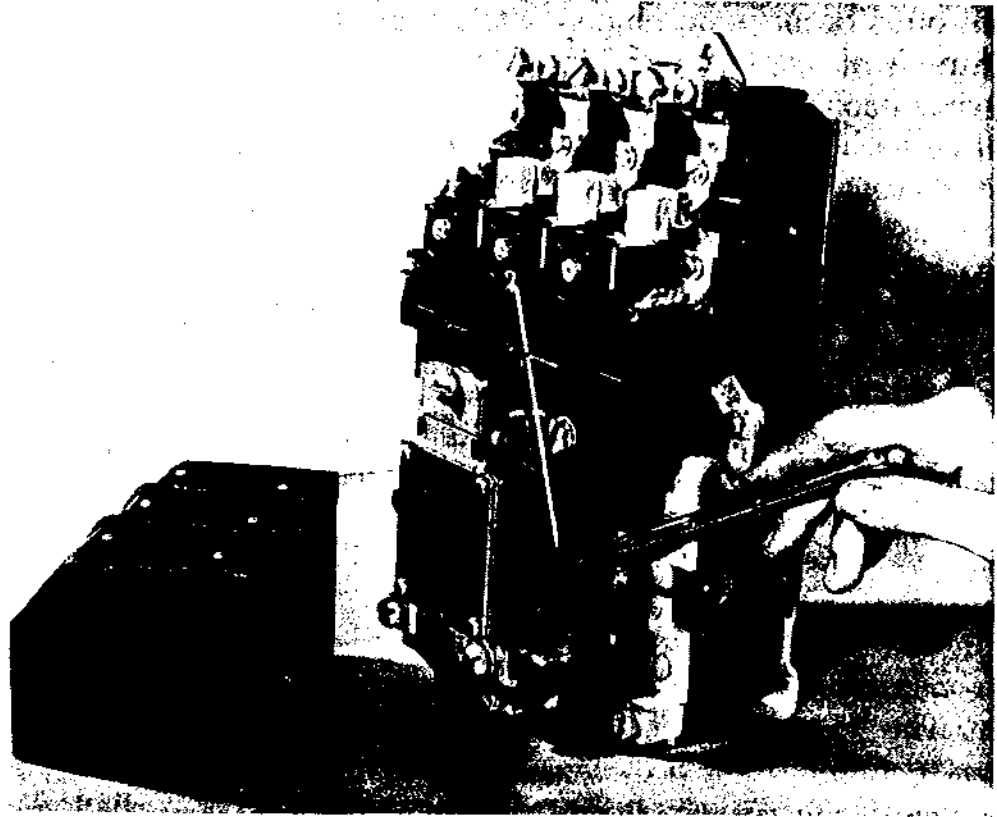


Fig. 8 – When in doubt about temperatures, secure a thermometer bulb against the hot part. Cover the thermometer bulb with putty or similar material, and leave it there until the temperature has risen to the maximum value. Be sure that no material is between the thermometer bulb and the hot surface.

The equipment manufacturer or the manufacturer's instruction literature should be consulted to find the permissable operating temperatures of electrical equipment.

Thermally operated overload relays should be in approximately the same ambient temperature as the motors they protect. If the relay is in a much higher ambient temperature than the motor it will trip when the motor is not overloaded. If the relay is in a much lower ambient temperature it may not trip in time to protect the motor. If the ambient temperatures of the motor and the thermal overload relay protecting it must be significantly different, compensation for the difference must be made by selection of the relay heaters or use of a relay that compensates for temperature differences.

O. Check for Grounds

Warning: An unexpected ground is a serious personal hazard, it can cause erratic and dangerous operating circuits, cause motors to start unexpectedly and fail to stop when they should, overload and protective features may be made ineffective. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Grounds often occur in pushbutton enclosures or similar confined spaces where stray strands of wire make contact at incorrect places. They occur when wires become chafed due to vibration on rough edges such as conduit entrances. Conduits sometimes become wet from condensation or other reasons and the insulation on the wire becomes water soaked and loses its insulation value. For this reason conduits should always be installed off-level so the water will drain away. It may sometimes be necessary to remove the wires, clean the conduit, and re-wire. Clean and dry conditions always reduce maintenance.

Desirable grounds, such as grounding for lightning protection, are easily maintained because they require only good contact connections.

P. Noisy A-C Contactors

When the voltage on the coil of an a-c contactor or relay passes through zero its magnetic pull or holding power is zero and the device will start to open. The voltage is soon effective in the opposite direction and the device is again pulled closed. This operation causes a humming noise in any alternating-current operated device, and a decided chattering noise in a defective unit.

The chattering is eliminated and the device kept closed by use of a shading coil, usually imbedded in the laminated magnetic circuit of the device. The shading coil produces enough out-of-phase-flux to provide holding power to keep the device closed during the short interval when the main flux is zero. Even with shading coils in use the air-gap surfaces must be free from dirt and well fitted to avoid objectionable noise. If a device suddenly becomes noisy a check should be made for a broken shading coil.

For quiet operation of a-c contactors it is necessary to provide well fitted surfaces at the air gap. Any dirt in this area creates a greater air gap when the unit is closed by holding the contact surfaces apart. This increases the duty imposed on the shading coil and results in a more noisy operation. The fitted surfaces at the air gap are often covered with

a light coating of grease or oil when the device is shipped, for protection. This coating may form a seal between the surfaces that will make the opening operation sluggish. To prevent this, the surfaces should be wiped clean before the units are put into service.

Direct-current coils are not subject to a zero voltage condition, so d-c operated devices of this type are always quiet, and contactors carrying alternating current but equipped with d-c operating coils will operate quietly.

Q. Magnetic Sticking

Warning: Magnetic sticking can cause dangerously slow opening of contactors. Any condition of magnetic sticking should be corrected immediately. Failure to heed this warning can cause severe personal injury or death, and damage to property.

When operating coils are de-energized, some residual magnetism remains in the magnetic circuit. This residual magnetism is sometimes strong enough to hold the device closed after the coil is de-energized. The condition is most frequently found in small devices on which contact spring pressures are light. Magnetic sticking causes erratic, unsatisfactory, and sometimes dangerous operation. It can be avoided by adding a non-magnetic shim in the magnetic circuit.

R. A-C Squirrel Cage Induction Motor Starters

Starters for a-c squirrel cage induction motors are the most commonly encountered. There are four basic types. Figures 9-14 illustrate some of the many variations of these four basic types:

1. Manual Across-the-Line Starters

Manual starters are available in sizes up to 10 hp at 600 volts. They are used to connect small motors directly to the line. Maintenance personnel will encounter some oil-immersed drum type manual starters which were at one time used extensively in locations where corrosive gases or explosive atmospheres were encountered such as textile mills, flour mills, woodworking plants, and some chemical processes. This starter was also used for reversing service and for smaller multi-speed squirrel cage motors. Manual starters have now been superseded by magnetic starters in most applications.

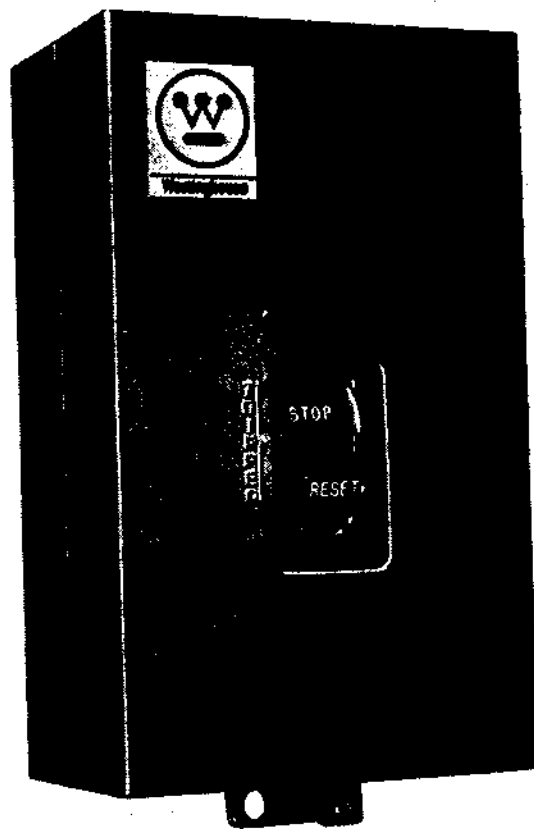


Fig. 9 – Typical Manual Starter

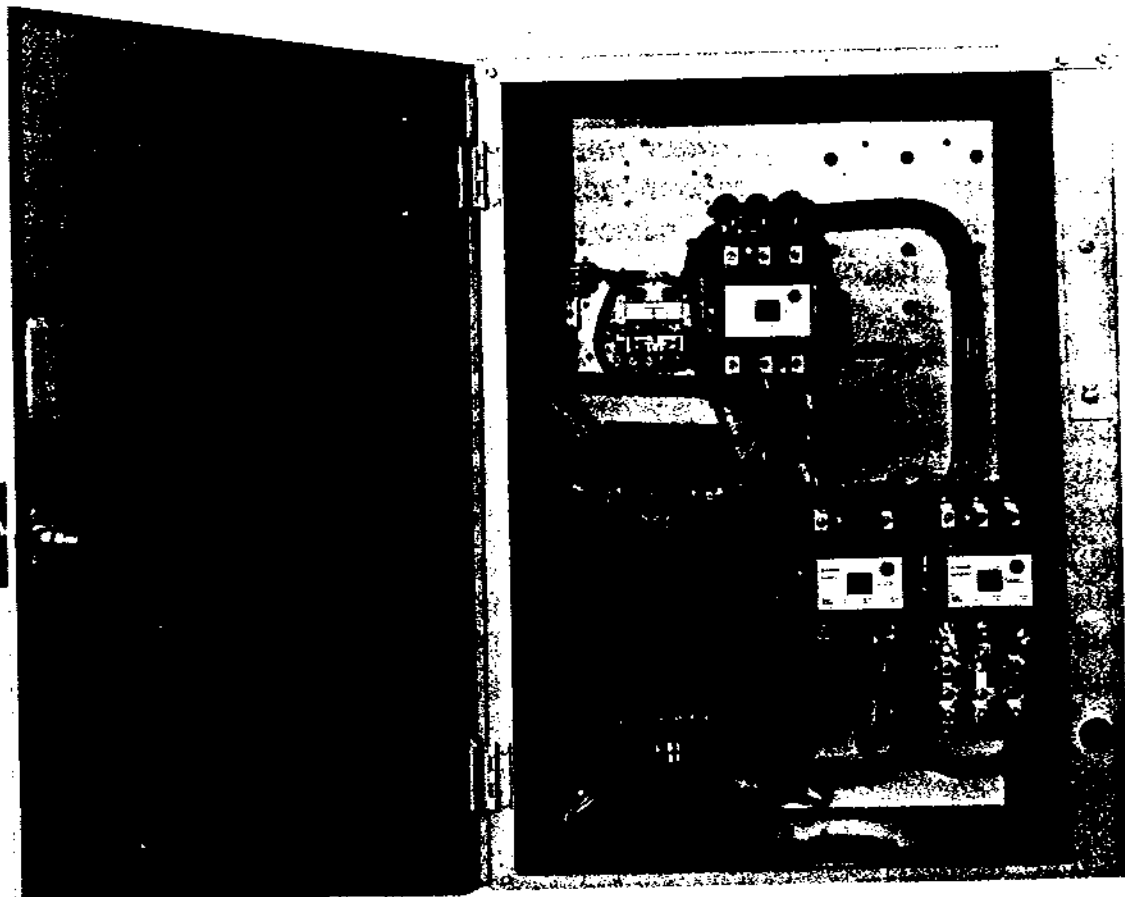


Fig. 10 – Transformer Type Reduced Voltage Starter

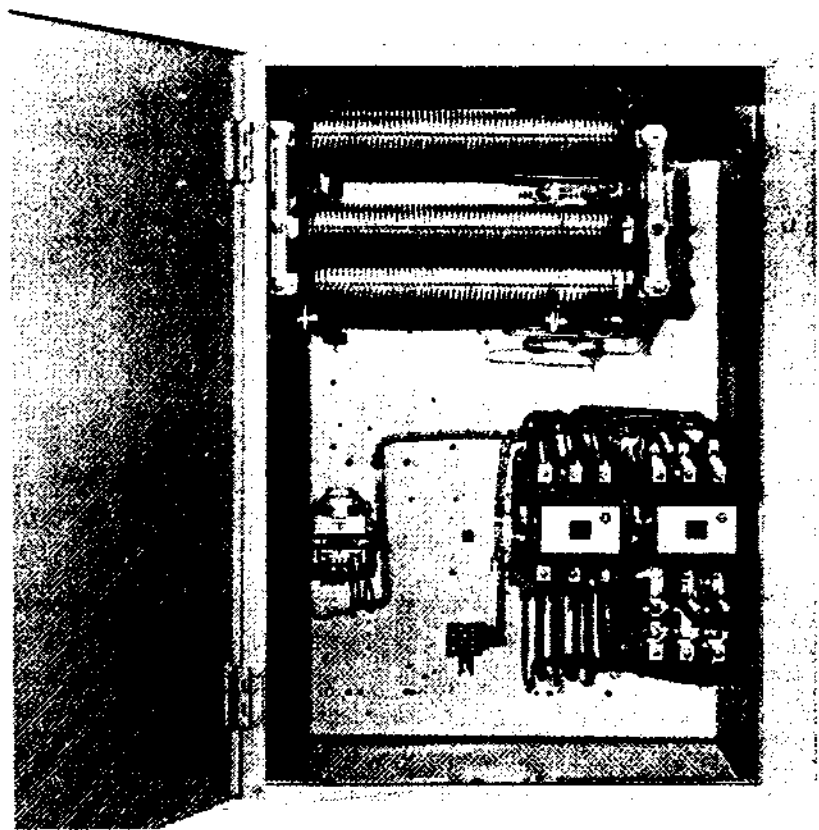


Fig. 11 – Resistance Type Reduced Voltage Starter

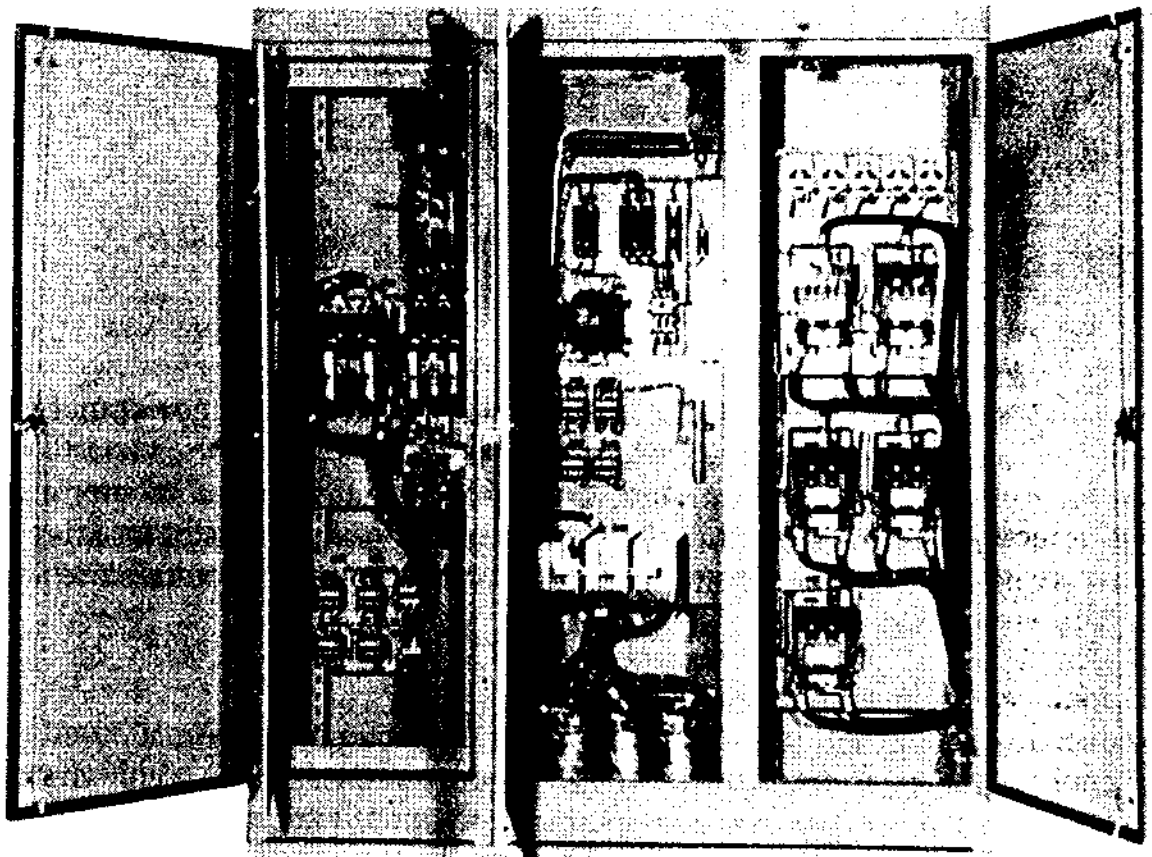


Fig. 12 – Typical Wound Rotor Motor Control NEMA Size 6 – Reversing with Braking

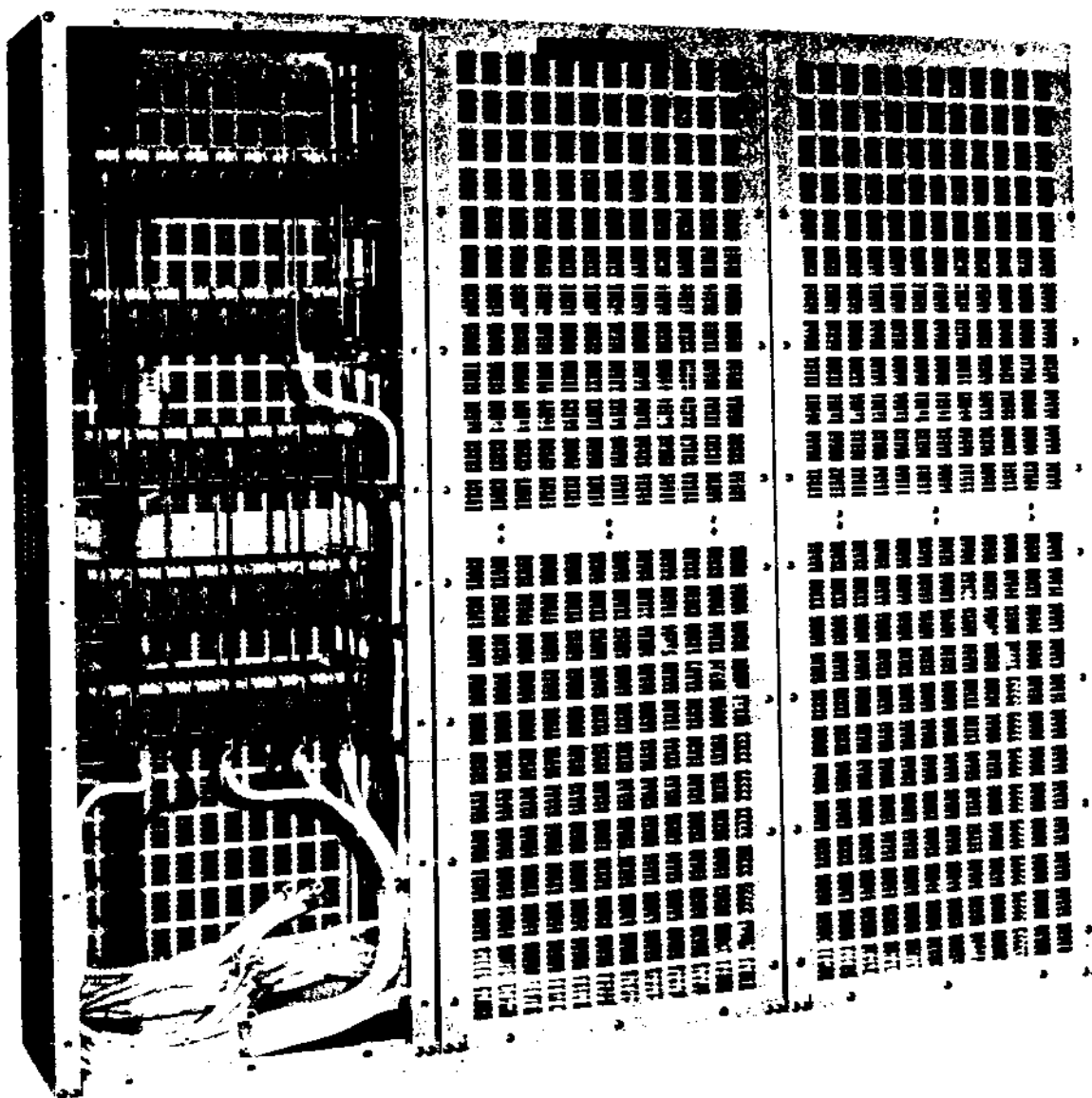


Fig. 13 – Wound Rotor Secondary Resistor Bank

2. *Magnetic Linestarters*

Magnetic linestarters are suitable over a wide range of horsepower and voltages. Linestarters are used wherever the design of the motor and the capacity of the circuit permit, and where the advantages of simplicity and remote control are desired. These starters may also be used as primary switches for wound-rotor motors in combination with suitable secondary controllers.

3. *Reduced Voltage Starters*

Reduced voltage starters, both manual and magnetic have a broad range of application. Auto-transformer starters are extensively used where motor size or design, or restrictions of supply circuit requires starting at reduced voltage. The auto-transformer type of starter provides greater torque per ampere of starting current drawn from the line than any other reduced voltage starter.

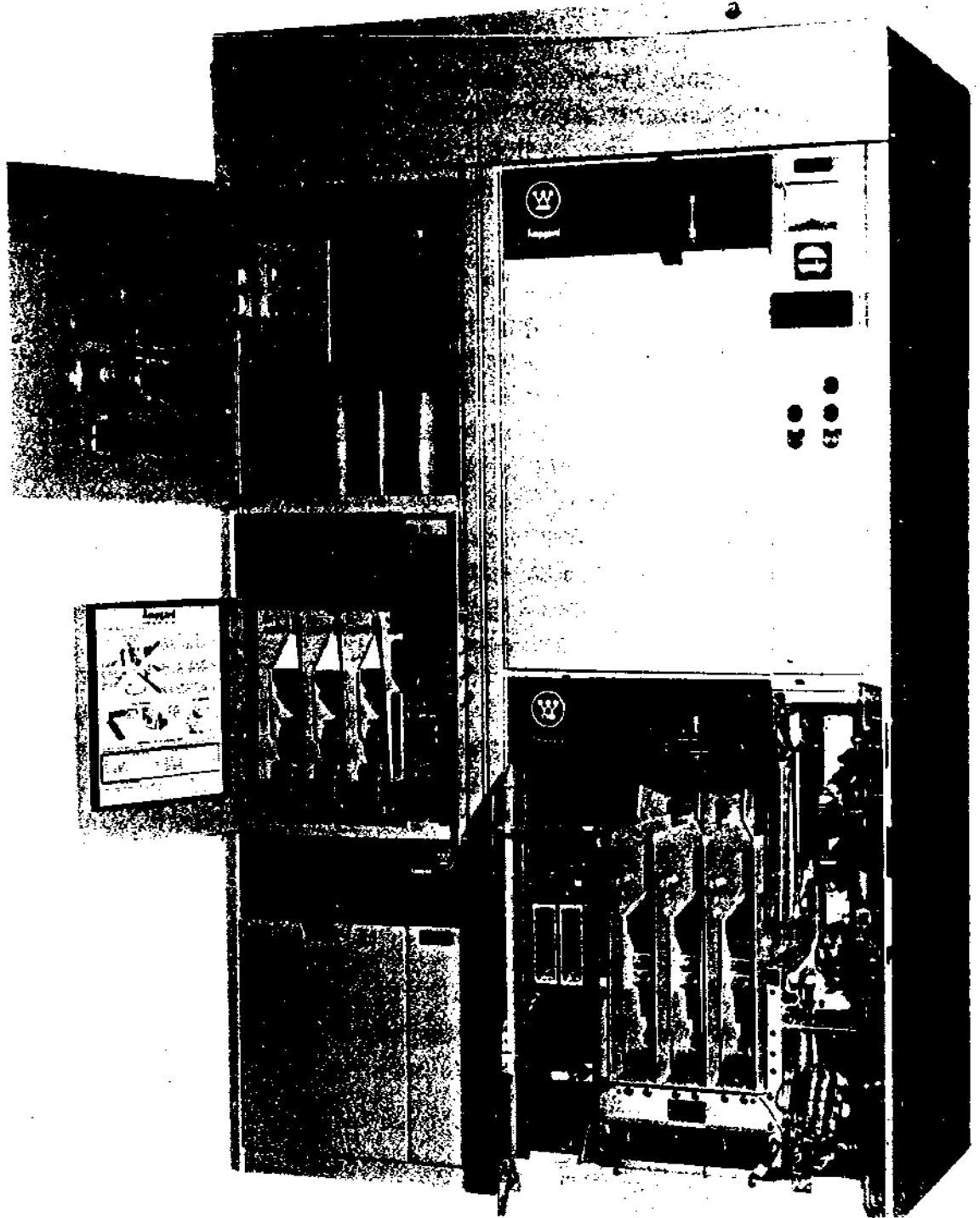


Fig. 14 - Front View, High Voltage Westinghouse Ampgard® Starter

4. Resistance Type Starters

Resistance starters are particularly desirable to avoid sudden mechanical shock to the driven load. They are normally applied where it is necessary to keep starting currents within limits. These starters are sometimes applied on network distribution systems where power company regulations require that the circuit not be open during the transition from reduced to full voltage.

5. Multi-Speed A-C Motor Starting

Alternating-current motors, both squirrel cage and wound-rotor inductive, and occasionally synchronous motors, may be arranged with windings that provide two or more speeds. Two-speed motors may have two separate windings or a single winding capable of rearrangement or pole changing. Four-speed motors usually have two-speed windings. However the motor is designed, the different speeds require different switching set-ups. Wound-rotor and synchronous motors require switching or pole changing in both primary and secondary (field) windings. Multi-speed motor starters may consist of manually operated drum switches or magnetic contactors.

Notice: When servicing multi-speed controllers, actual connections and markings should be obtained from the manufacturer's wiring diagram or from the motor connection plate.

Standards for connections and markings have changed over the years and have varied with different motor manufacturers and motor designs.

S. Maintenance Requirements

In addition to the general guidelines given in 1.1, there are specific requirements for each type of starter.

1. Manual Starter Maintenance

- a. Check tightness of all connections. Assure that heaters for overload relay are tight.
- b. Replace worn contacts. Refer to manufacturer's recommended maintenance schedule.
- c. See that all parts are clean and move freely. Do not lubricate unless manufacturer's instructions call for it.

2. Magnetic Linestarter Maintenance

- a. Do not lubricate contact tips or bearings.
- b. Magnet sealing surfaces should be occasionally wiped with an oil-moistened cloth to prevent rust.

- c. Assure tightness of all connections, particularly connections to overload relay heaters. A loose connection at this point will cause local heating that will affect the calibration of the relay.
- d. Make sure there are no broken or frayed shunts and that none are touching other parts.
- e. Contacts should be adjusted so all meet at the same time.

Warning: Do not use emery paper to clean contacts because emery dust is an electrical conductor. Abrasive particles imbedded in contact surfaces and emery dust in the contactor can lead to failure of the equipment and consequent severe personal injury and property damage.

- f. Contact maintenance does not require action unless the contact becomes excessively rough or burned in service. If this happens the contact can be dressed with a fine file. Care should be taken not to change the contour of the contact surface.

Contact tips should be replaced when approximately two-thirds of their thickness has been worn away, or as directed by the manufacturer's maintenance requirements. Contact tips are removable and only simple tools are needed to make the change.

- g. Arc boxes should be kept free of excess deposits especially on the inside adjacent to the contacts. Cracked, broken, or burned arc boxes should be replaced.
- h. Assure that all moving parts are clean and working freely.
- i. With the motor disconnected, manually test the start button, stop button, overload relay, and reset. Overload relays should be checked for tripping at current values.
- j. Overload relays vary in form and design. Most overload relay action depends on the movement of a bi-metallic element under heat. On very small motors the bi-metallic element actually carries the motor current. On larger motors a separate heater carrying the motor current is placed near the bi-metal. On very large motors a current transformer reduces the motor current to a value that can be handled by the heater.

3. Overload Protection

Thermal relays do not protect against short-circuit currents. They provide excellent protection against overloads and momentary surges due to their inverse time limit action which means the greater the overload the shorter the time of tripping. For protection against short circuits, fuses not exceeding four times the motor full-load current, or time limit circuit breakers set at no more than four times the motor full-load current,

or maintenance trip circuit breakers should be installed ahead of the linestarter. Where fuses are used it is good practice to use a disconnecting switch as well.

Heaters for thermal relays are made with different current ratings. This means that within its limits any starter can be used with different sized motors and still provide proper protection. By selecting the size of heater corresponding to the full-load current of the motor, a starter can be made to fit any motor within the rating limits of the starter. Tables showing the ampere ratings of heaters can be obtained from the manufacturer. In general the ampere rating of the heater should be approximately 120% of the motor full-load current.

Some relays have a calibration lever which offers another adjustment. When the relay is set at 100%, the rated current of the heater (stamped on the heater) will just trip the starter after several minutes. For tripping at a smaller current the relay calibration lever can be moved toward 90%, for larger current tripping the lever can be moved toward 120%.

4. Reduced Voltage Starter Maintenance

The maintenance requirements given for linestarters apply to reduced voltage starters (frequently referred to as auto starters) as well. Additionally the following apply:

- a. Assure that the moving portion of the low-voltage release mechanism works freely.
- b. Many past reduced-voltage starter designs need a magnetic overload relay having an oil dashpot to prevent tripping on momentary overloads. Take care that the dashpot piston is free to move and that the dashpot is filled to cover the piston with the proper grade of dashpot oil. Dashpot oil is specially refined to have a flat viscosity - temperature curve. Refer to the manufacturer or the manufacturer's literature for the recommended oil.
- c. The overload relay should be set at 125% of motor full-load current at least.
- d. Many older autostarters above 35 hp at 25 cycles, and above 50 hp at 60 cycles, 550 volts and above used insulating oil in a pan designed so the contacts make and break under oil. On these starters the pan should be kept filled with oil to the oil level mark. If the oil becomes badly discolored or carbonized from service, it should be replaced with new oil after carefully cleaning the pan.
- e. In reduced-voltage starters a definite time delay is used to control the time on the starting tap. The timing on this relay should be checked. If the relay is a type using an oil dashpot, the oil level should be checked and maintained. This relay dashpot uses a very light oil with a

low pour test, suitable for low temperatures. The manufacturer or the manufacturer's literature should be consulted for the recommended oil.

f. The starting transformers in these starters are provided with taps by which the starting voltage can be changed. The proper taps to use are those that bring the motor up to speed in 20 seconds or less for motors up to 100 hp. On 220 hp motors the starting period may be as long as 30 seconds. Longer starting times may seriously overheat the transformer.

5. Resistance-Type Starter Maintenance

Resistance starters are usually designed to short circuit the resistor in one to ten seconds, and for starting not more than once every 80 seconds. They are called resistance type starters because resistance inserted in the primary circuit is cutout gradually by the starter as the motor comes to speed. These starters employ drum controllers in the smaller sizes and contactors in larger sizes. The maintenance requirements are as covered for across-the-line starters.

6. Heavy Duty Contactor Maintenance

Heavy duty contactors are functionally the same as those used for low voltage applications. They are sturdily built and designed for long life as they are subject to severe duty and usually interrupt full-load currents and voltages. Their application creates a wide range of maintenance requirements. Figures 15 and 16 show two types of heavy duty contactors.

Large industrial motors are applied in situations where they may be started and stopped infrequently or they may be employed in a rolling mill, on traction duty, or mine hoists or elevators where they are required to start, stop, and reverse many times an hour. Often entire sections of control boards are devoted to an arrangement of contactors remotely located from the motors they control. The operation of these contactors is accomplished by manual and automatic control devices such as drum controllers, speed regulators, reversing, jogging, and limit switches, and other controls. These controllers usually operate at voltages lower than the main contactors due to safety requirements and the high utilization voltages and currents at which the contactors must operate.

The main contactors, operating to interrupt actual motor currents and voltages, require more than routine maintenance. The manufacturer usually provides instructions for the required maintenance and the procedures to be followed to obtain maximum performance and service life. Heavy duty contactors usually require special consideration when establishing a realistic program for effective preventive maintenance.

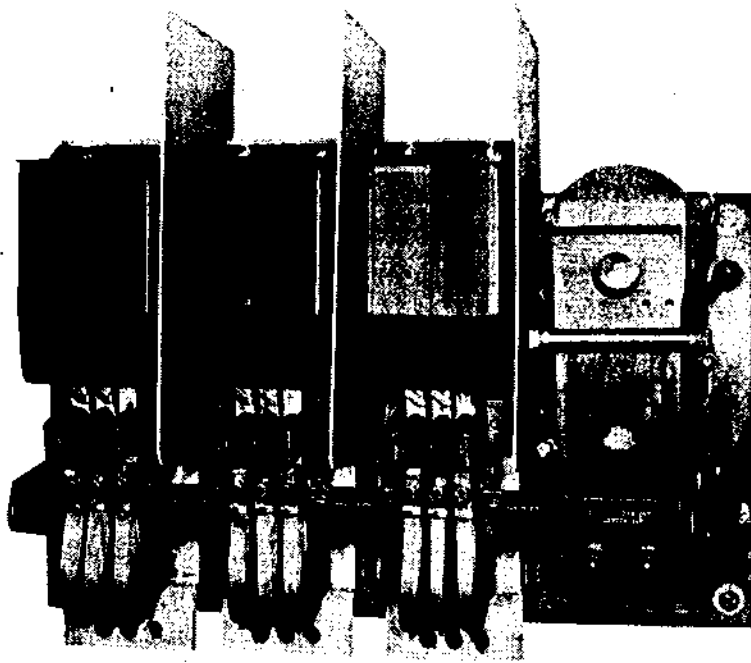


Fig. 15 - Typical Heavy Duty Contactor - Size 8 AC

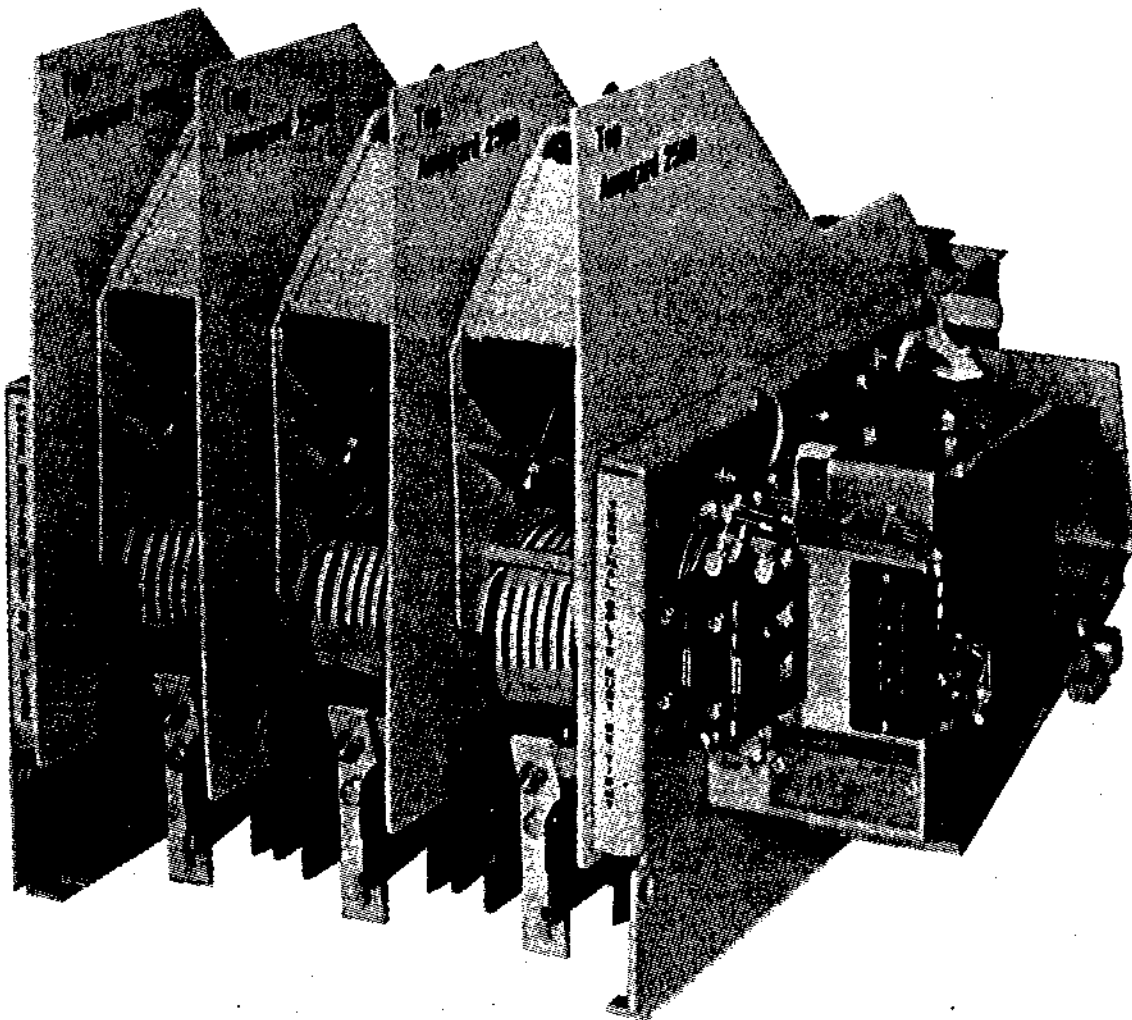


Fig. 16 - High Voltage Airbreak Contactor

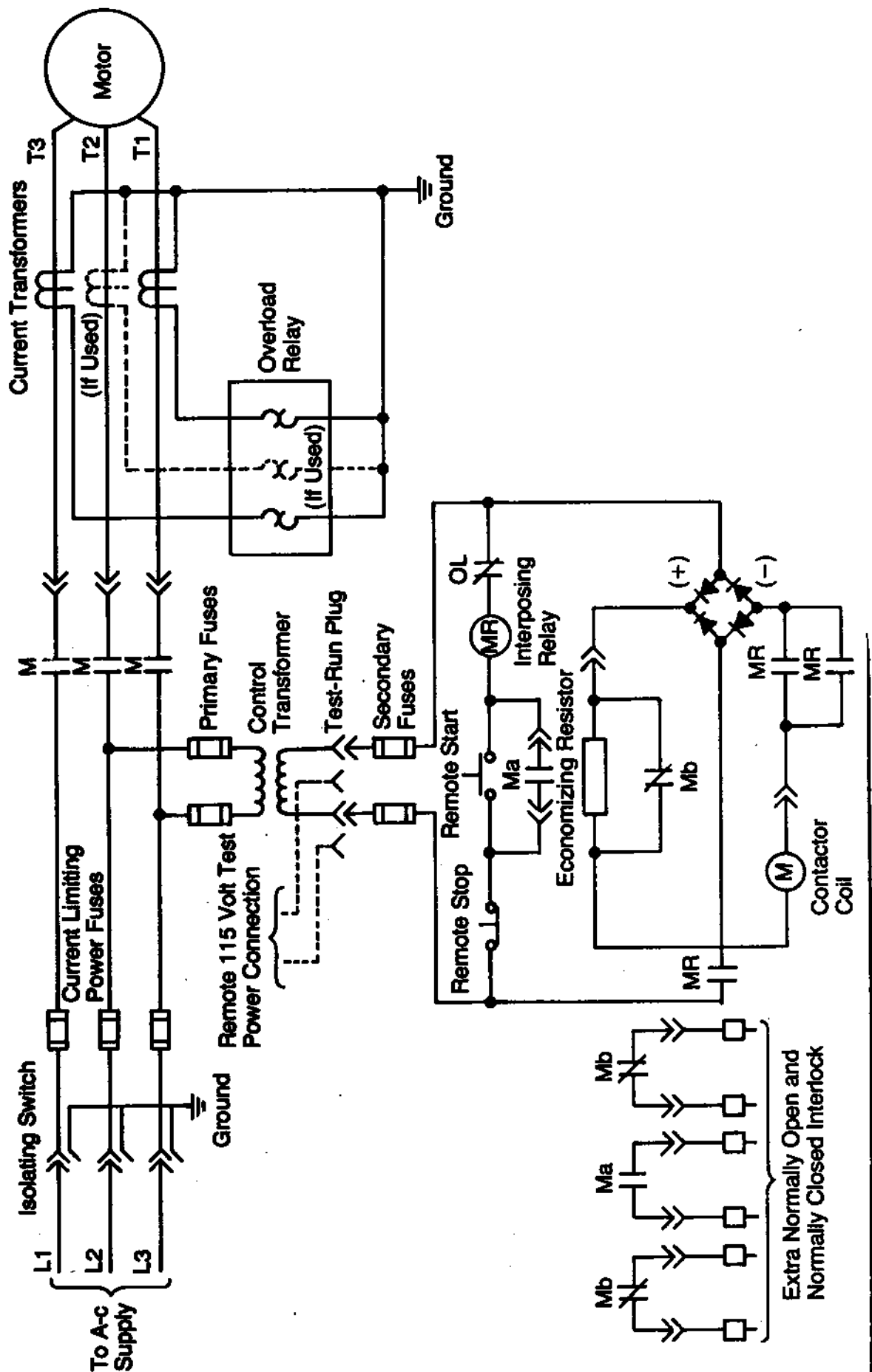


Fig. 17 - Typical Wiring Diagram, Ampgard® High Voltage Starter

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Maintenance of Control Components

The great variety of control systems, assemblies, and components makes specific, detailed coverage of maintenance requirements impossible here. For specific instructions regarding any control component the manufacturer's instruction literature should be consulted.

There is a great similarity between the various control equipment manufacturer's products, so general maintenance requirements can be established, but when excessive maintenance requirements are encountered, or a high failure rate is experienced, the manufacturer or the manufacturer's instruction literature should be consulted.

The most effective insurance of proper equipment operation and service is adequate maintenance. The conditions under which control components must operate vary greatly, consequently the maintenance requirements vary greatly. Maintenance schedules and programs should be established based on local experience.

The state of the art in control components is in a highly volatile condition with change and development coming rapidly. Much of the traditional electro-mechanical control is being replaced by solid state devices which tend to call for replacement rather than repair in the event of failure, and which have minimal maintenance requirements. Much of the control used in industry is still of the electro-mechanical type which requires regular maintenance.

2.1 Contactors

Contactors are a basic control device. They function to open and close circuits and are often used as accessories to other equipment. A contactor may be required to operate at infrequent intervals, perhaps once a shift to open and close a circuit, or the same type of contactor may be required to operate many times an hour continuously. These variations in duty require similar variations in maintenance. There are many types and sizes of contactors performing many types of duty, but there are some types of maintenance requirement common to all.

Warning: Do not attempt to do any service or inspection work on a contactor or starter unless it has been de-energized and will remain so during the work period. Failure to heed this warning can cause severe personal injury or death and substantial damage to property.

A. Welding of Contacts

Few high speed contactors close without bounce. This rebound is due to the action of the contact springs as they are compressed to provide final contact pressure. The separation of the contacts at the bounce is small, but it occurs when the contacts are carrying current so an arc is formed. If this arc is severe the metal may melt which may cause sharp projections of burned or roughened contact surfaces and may weld the two surfaces together. This would prevent the contacts opening when next called upon to do so. Other causes of contact welding include excessive currents, insufficient contact pressure, sluggish opening or closing, or momentary closing without pressure. Silver contacts will weld more readily than copper. Figure 1 shows how severely contacts can burn and the loss of the contact metal that can result.

If inspection reveals frequent or severe contact burning, an investigation into the cause should be made and corrective action taken in addition to replacing the damaged contacts.

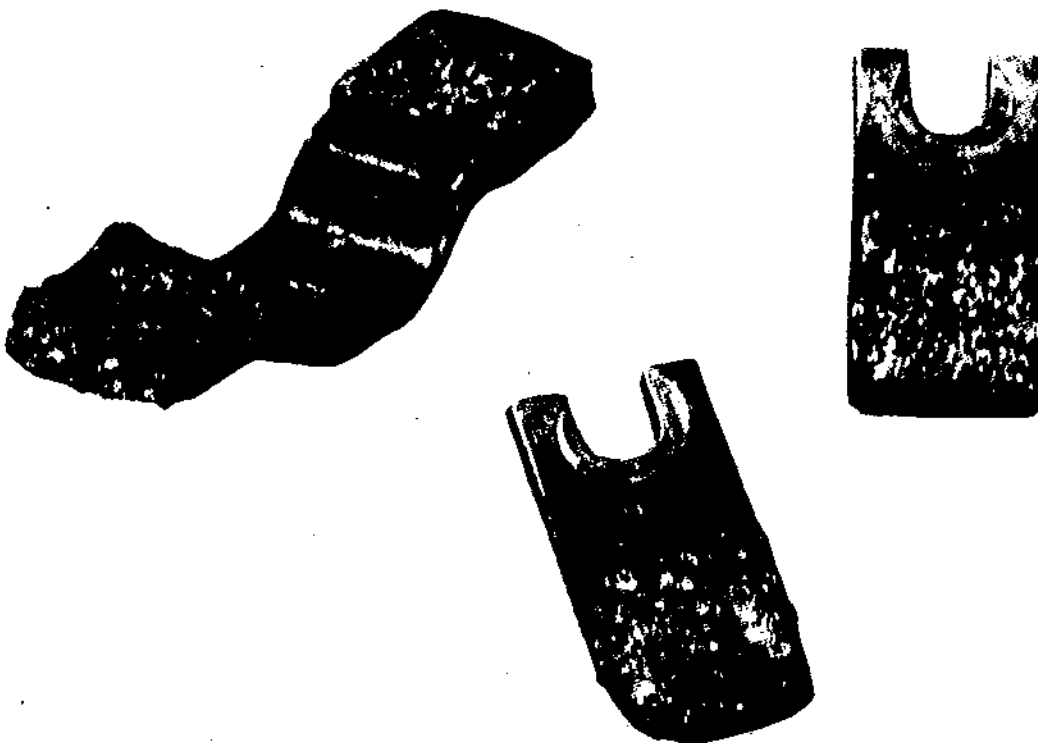


Fig. 1 – Severely Burned and Eroded Contacts

B. Contact Pressure

Warning: Make sure the contactor is de-energized before attempting to make spring pressure readings and assure that it will stay de-energized until the readings have been completed. To attempt to work on a live contactor can result in severe personal injury or death and substantial damage to property.

Contact pressure can be checked by using a spring balance scale as shown in Figure 2. It is not necessary to remove the contactors to check the spring pressures. The spring balance should be exerting a force directly in line with the contact spring when pressures are read.

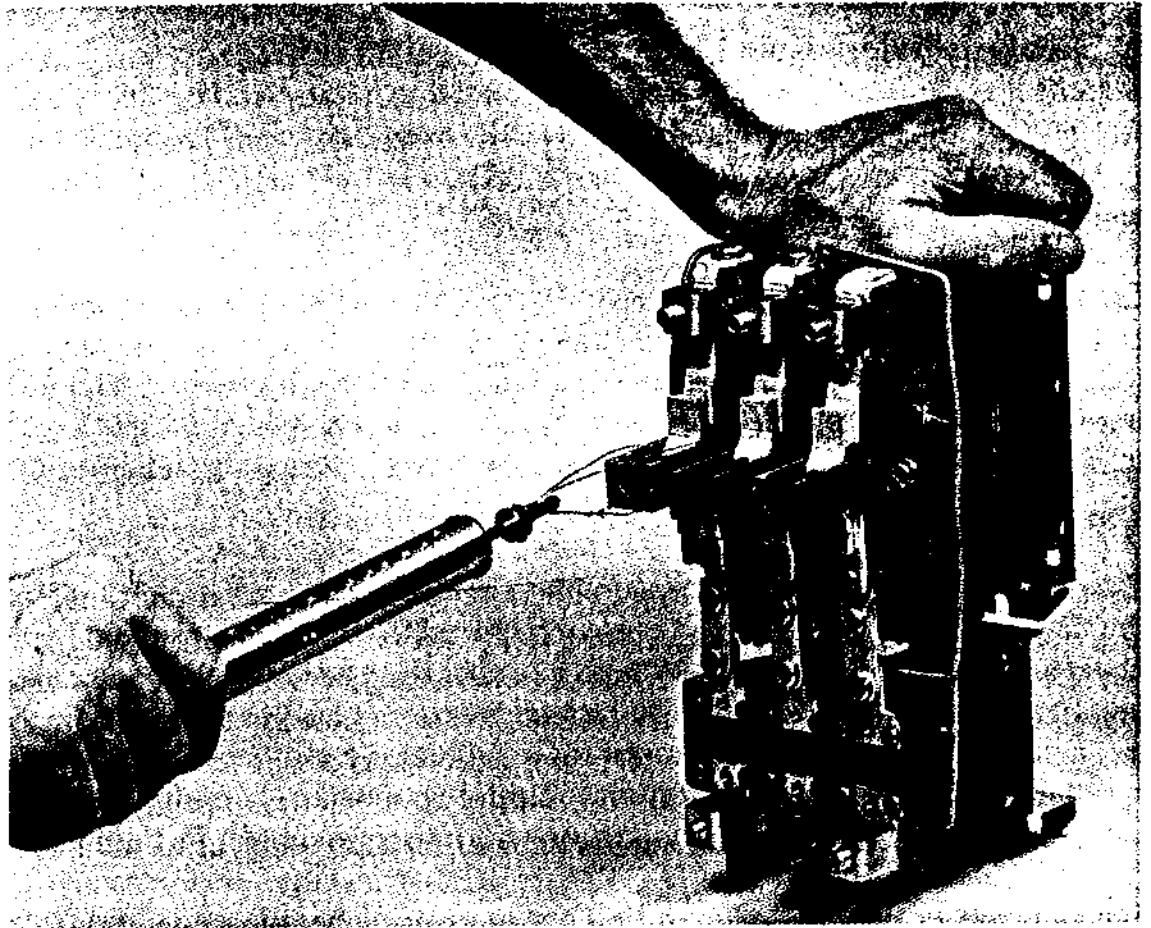


Fig. 2 – Contact Pressures can be Checked Using a Spring Balance

In most contactors it is necessary to remove arc boxes to gain access to the contacts. The moving armature must be held in a closed position on normally open contactors; it is not necessary on normally closed spring loaded contactors. Each pole should be checked individually and the pressures compared with the manufacturer's recommended pressures.

Caution: Do not bend any part, moving or stationary, or compress or stretch springs to increase or decrease contact pressure. To do so may cause malfunction or failure of the contactor on subsequent operations. Personal injury and damage to property could result.

The most common causes of loss of contact pressure are erosion of contact materials, or weak contact springs. When too much current is carried, or there is poor contact, the resulting heat may have an annealing effect on the springs causing them to lose tension.

If one contact seems to be burning more than the others it could indicate a broken contact spring, an overloaded phase, or misalignment or mechanical obstruction. Causes of improper contact pressure should always be determined and corrected immediately.

C. Contact Materials and Replacement Requirements

Silver alloy contacts are generally used on across-the-line starters, control relays, electrical interlocks, and pilot control devices. Discoloration of silver alloy contacts is a build-up of silver oxide which breaks down and need not be removed.

Contacts for other devices are generally copper. These contacts should be kept clean because the copper oxide on copper is not a good conductor. It increases the contact resistance and causes heating with resultant burning, eroding, and welding of contacts. When contacts are replaced it is important to be sure the new contact and the surface to which it is mounted are clean.

Provision is made for changing contacts on all equipment except the throw-away devices which are completely replaced. Contacts should always be replaced in sets and on all poles. Factory set adjustments and pressures will be maintained if all contacts are replaced at once. Replacing a single contact or the contacts on a single pole will upset the simultaneous make-break action on multipole contactors, spring pressures will be uneven and the contactor will be more subject to failure.

Contacts are critical and should be kept in proper operating condition. The following list covers the common trouble points:

Excessive contact burning is an indication of trouble. Look for too high current, sluggish operation.

Badly burned and poorly mating contacts are more likely to overheat due to higher resistance. Excessive heating damages springs and can warp and deform metal parts.

A certain amount of contact maintenance is desirable. Contacts should not be allowed to operate and deteriorate until they must be replaced. An occasional touch-up with a file or smoothing with fine sand paper will add greatly to the contact life, if properly done. See *L.3 Contacts*, below.

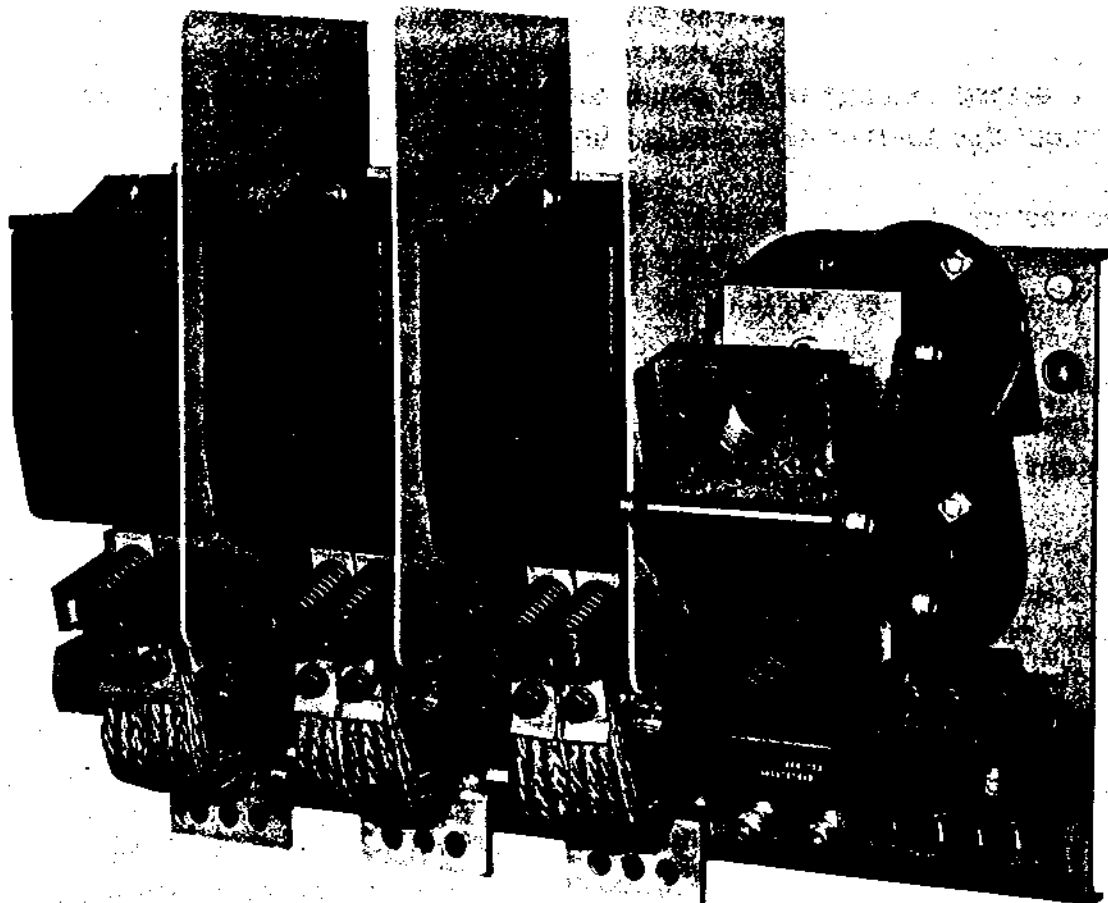


Fig. 3 – Typical Heavy Duty Contactor. Coils and Armature which Hold Contactor Closed are at the Right Side

Warning: Do not use emery cloth in reconditioning contacts. Emery dust will contaminate and destroy contactor bearing surfaces and pivots. This can lead to failure of the contactor, and possible electrical or mechanical failure and personal injury and property damage.

When reconditioning and cleaning contacts, care should be taken to remove only a minimum of material and not to change the contact radius or shape. Removal of excessive amounts of material or changing the contact shape may cause improper operation and require early replacement.

Replace contacts only in sets. If one pair of contacts in a multiple contactor is consistently burning, determine the cause, probably either load or mechanical problems.

If arc intensity is significant and of a long duration during contact opening, it is possible that the contact separation distance can be bridged. When this happens, ionization and arc continuance can lead to severe damage of the contactor and the served circuit and equipment due to excessive arcing current values.

Contactors should be included in any time allotted for general inspections. Periodic inspections and cleaning by wiping and blowing out are recommended.

Warning: Do not allow damaged or deteriorated contacts to remain in service. To do so can cause failure which can result in severe personal injury or death, and damage to property.

D. General Maintenance Requirements

Since correct operation of a contactor depends largely on the unit being clean and free from foreign material, oil or other lubricants of any kind should not be used on the bearings unless the manufacturer's instructions direct lubrication. Except for bearings of master switches, drum controllers, and similar units, no lubrication of controller parts is necessary. This does not apply to oil-immersed contactors which should be maintained in the manner required for oil circuit breakers of comparable voltage.

Coils should be operated only at rated voltages. Coils provide the electro-magnetic pull that causes the contacts of relays and contactors to open or close. Coils of series devices have relatively few turns of heavy wire and can carry heavy currents. Other devices are shunt devices and have coils with many turns of insulated wire. These coils may be impregnated in a vacuum or under pressure, with insulating compounds, and covered with insulating tapes. Many coils are encapsulated in epoxy or glass polyester molding compounds. Coils must withstand temperature and humidity cycling without cracking, and endure extended mechanical stress without damage.

E. Operating Voltages

Coils, at operating temperatures, must close alternating-current devices at 85% of rated voltage and direct-current devices at 80% of rated voltage. All coils can be expected to occasionally withstand 110% of rated voltage without damage. Measurement of operating voltages should be made at the coil terminals, not at the source of the supply voltage.

1. *Overvoltage*

Coils should be operated at their rated voltages. Overvoltage on coils causes higher operating temperatures that shorten coil life. Overvoltages also cause opening and closing of the device with unnecessary force resulting in greater mechanical wear and bounce.

2. *Undervoltage*

Undervoltage can be even more damaging, causing sluggish operation. The contact tips may touch but at undervoltage the coil may not be strong enough to completely close the contacts against the spring force. When this happens, contact pressure is below normal and the contacts may overheat and weld together. At the same time it is possible for the coil to overheat and burn out because the magnetic actuator is still in an open gap condition.

F. Open-Circuited Coils

A coil with an open circuit will not operate the device. Any questionable coil should be replaced immediately by one known to be operational.

G. Short-Circuited Coils

If any turns of a direct-current coil become short circuited, the resistance of the coil will be reduced and more current will pass through the coil. The increased current will cause higher operating temperatures that will eventually result in insulation failure and coil burn-out.

Short circuited turns in an alternating-current coil result in a transformer action which permits high current to flow at the point of short circuit. Immediate burn-out usually results.

H. Closing and Operating Currents

The impedance of a magnetic circuit having a large air gap is much lower than the same magnetic circuit with a small air gap. The current drawn by the coil of an alternating-current magnet is much greater at open gap than at closed gap. Since closing time is relatively short, a-c coils are designed to withstand being energized under closed conditions. If the magnet is blocked open, or the voltage too low, or any other factor holds the energized coil with a large air gap, it will quickly overheat.

Direct-current coils are not subject to this because coil currents do not vary with the air gap. For certain applications d-c coils are momentarily energized at much higher than rated currents. This is not damaging unless the high current is maintained.

For these reasons, contactors should not be blocked open when testing since cut-off devices may be made inoperable.

I. Arc Quenching

When contactors are expected to open circuits that are difficult to interrupt, they are designed with arc interrupting capability. This is usually in the form of an arc box or chute surrounding the contacts. Figure 3 gives an external view of arc boxes in place. The arc boxes are bolted or snap fastened in place and can be removed for inspection of contacts and the ceramic and metal parts that make up the extinguishing device in the arc box.

Warning: Always reposition and properly secure arc chutes or arc boxes after inspection. Do not operate arc-rupturing contactors without the arc chutes in place. To do so could cause severe personal injury and damage to property.

On direct-current starters the arc quenching system consists of a molded ceramic shield, or other heat resisting material, and a blow-out coil. The shields should always be kept in place when the starter is in operation.

Alternating-current contactors are equipped with arc quenchers. The arc splitting action confines, divides, and extinguishes the arc almost instantly as the circuit is broken. There is no flash or scattering of flame outside the arc box when operating properly. Figure 4 illustrates how the de-ionizing action not only stretches the arc but confines and quenches it. As the contacts separate a magnetic reaction forms and stretches the arc which rises into the metal grids where it is broken into a series of arcs. At the next zero point in the current cycle, the air adjacent to each grid is de-ionized instantly; the voltage per grid is not strong enough to re-establish the current flow and the arc is extinguished. This arc quenching system provides for reduced pitting and burning, and a longer trouble-free life for the device.

Arc shields and arc boxes should be replaced before the molded material is burned away sufficiently to expose metal grid parts to the arc.

J. Older Designs

Many contactors are in service that have been serving for years. They will, with proper maintenance, continue to give good service for years to come. These designs have many features and aging problems not encountered in new equipment.



Fig. 4 – Arc Quenchers Extinguishing an Arc

1. Dashpots

Air or liquid dashpots are used to retard motion. They are machined to close tolerances and must be kept clean and free to move. The proper amount and type of fluid should always be kept in fluid-using dashpots.

Warning: Do not use substitute oils in oil dashpots. The viscosities of many oils change with temperatures. Use of improper oil could hamper action of the dashpot and cause failure of the contactor which could result in severe personal injury and property damage.

If overheating is encountered, the causes should be determined and corrected. If consistent high temperatures are encountered and are not correctable, the contactor manufacturer should be consulted for recommended substitute dashpot oil that will not change the timing characteristics of the contactor or damage parts such as gaskets and seals.

2. Temperatures

All contactors should be checked for overheating. This is especially true for older equipment which may exhibit some signs of aging and wear such as deteriorating insulation, arc chute erosion, and burned contacts. These conditions are in part a result of, and contributors to, elevated temperatures.

Overheated parts always indicate trouble, but it is often difficult to know when temperatures are excessive. Resistors are operated safely at 360 C above ambient, but insulated coils made with class A wire are

restricted to 85 C above ambient. Solid contacts and copper bus are limited to 55 C rise. Field wiring terminals are limited to 50 C or 65 C above ambient depending on the wire temperature rating specified by the manufacturer^①.

When there is uncertainty about temperatures or where there appears to be excessively high temperature associated with any part or assembly it is best practice to make an accurate temperature measurement.

Warning: Do not attempt to estimate temperatures by feel. Temperatures can get high enough to fuse metal. Attempting to determine temperature by hand can result in severe personal injury.

The best method of determining temperatures of electrical equipment is to use a precision thermometer, or an electronic heat sensing instrument, as shown in Figures 5 and 6.



Fig. 5 – A Precision Thermometer may be Held in Place with Electrical Putty

^① Values from Standards for Industrial Control Equipment, UL 508.

Barring the presence of gases, acids, or alkalis, discolored copper parts are a sign of overheating.

If overheating is evident or suspected, and after the temperature has been accurately measured, the equipment manufacturer should be consulted for advice on whether the temperature is above permissible levels.

Motor starters equipped with thermally operated overload relays should be located in approximately the same ambient temperature as the motors they control. If the relay is in a much higher ambient temperature than the motor it may trip when the motor is not overloaded. If the relay is in a lower ambient temperature, it may not trip in time to save the motor. If ambient temperatures for motor and starter must be different, some compensation for the different temperatures can be made by proper selection of the overload relay heaters, or by providing a relay that is ambient compensated. The starter manufacturer's heater tables are a source of the necessary information.

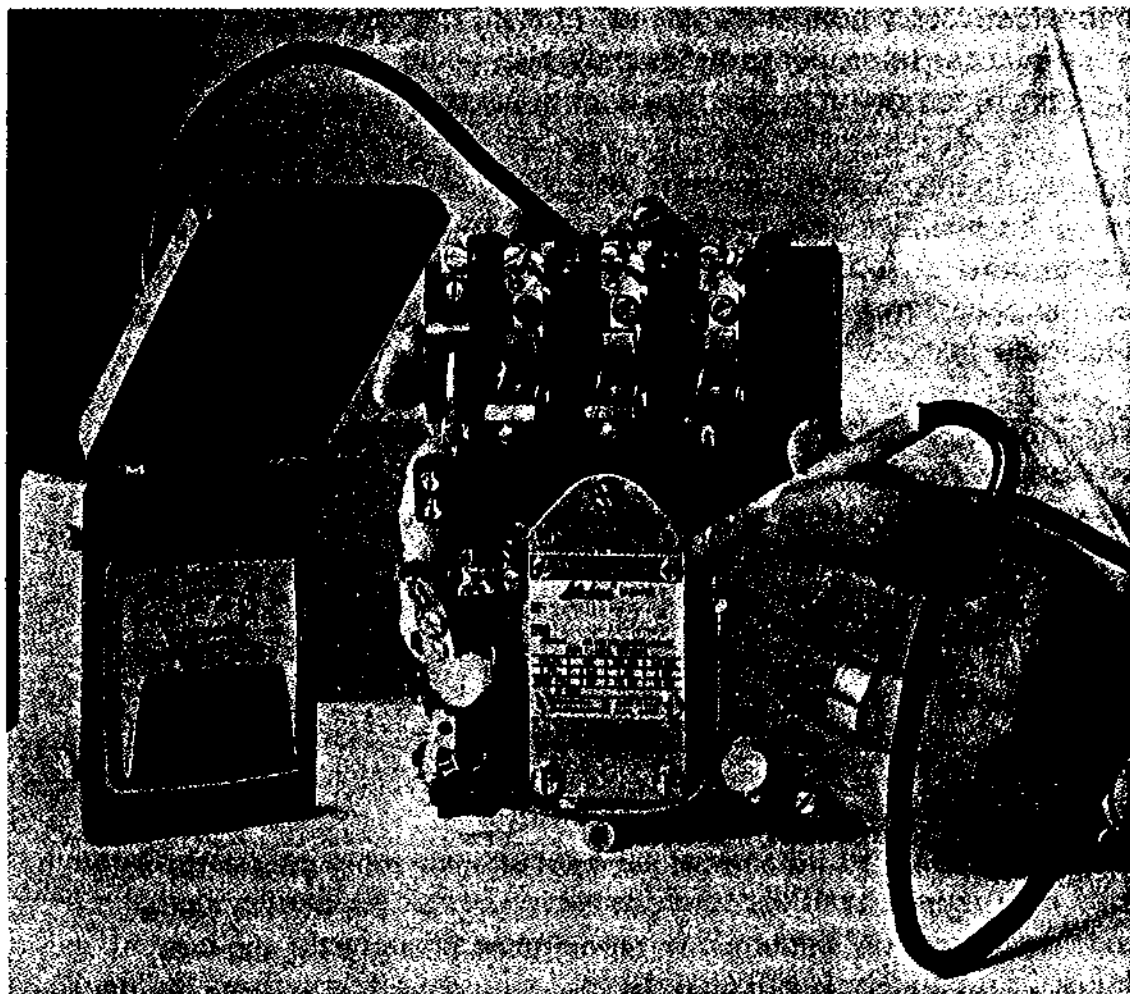


Fig. 6 – Using an Electrical Contact Thermometer to Determine Operating Temperature

3. Equipment Grounding

Required grounds are useful and necessary. They are easily maintained because they require only good contact connections. Working on an ungrounded system is a serious personnel hazard. Refer to *Westinghouse Electrical Maintenance Hints, Volume 1, Chapter 8. Current Grounding Practice.*

Warning: Be alert for undesirable grounds and eliminate them when discovered. Failure to do so can subject personnel to severe personal injury or death.

Constant vigilance is required to prevent and eliminate undesirable grounds. These grounds can cause operating troubles and erratic and dangerous circuits. Improper grounds may cause motors to start unexpectedly or fail to stop when they should; overload and other protective schemes may be made ineffective by a poorly made or undesirable ground.

Unintentional grounding often occurs in pushbutton stations or similar confined spaces where stray strands of wire may make contact at the wrong places. Improper grounds may also occur when insulation on wires is chafed due to vibration, such as at conduit entrances.

Moisture is also a possible cause of ground faults. Conduits should always be installed so moisture will drain away. If enough water collects in conduit, flooding or condensation are usual causes, it may become necessary to remove the wires, clean the conduit, provide drain holes, and install new wiring.

Warning: Always make sure circuits are de-energized before working on any conduit or part of a device suspected of containing water, as dangerous ground fault currents may occur. Failure to heed this warning can cause severe personal injury or death, and damage to property.

K. Additional Maintenance Considerations

1. Noisy A-C Contactors

When the current in the coil of an a-c contactor or relay passes through zero, the magnetic pull or holding power is zero so the device has a tendency to open. This tendency is momentary because the current almost immediately is effective in the opposite direction and the device is again pulled closed. This action causes a humming sound in any a-c device and a decided chattering in a defective unit.

This objectionable chattering is eliminated and the device kept quiet by the use of a shading coil, usually imbedded in the laminated magnetic circuit of the device. The shading coil produces enough out-of-phase-flux to provide holding power to keep the device closed during the short period when the main flux is zero. Even with shading coils, the air gap surfaces must be free from dirt and well fitted to avoid noise. Any dirt on the pole surfaces introduces a greater air gap when the unit is closed which increases the duty on the shading coil. Any rust preventive grease placed on the pole surfaces for protection during shipment and storage must be wiped clean before the units are put in service, or sticking may result.

There are two commonly used types of magnet, the E magnet and the U magnet, see Figure 7. The E magnet uses a single coil positioned around the center pole. This magnet has an air gap formed by grinding the center pole shorter than the two outside poles. This air gap tends to close as the pole faces wear with repeated operation. When wear reduces the air gap to zero the unit will become very noisy and will tend to be held shut by residual magnetism. If this occurs the magnet and armature should be replaced.

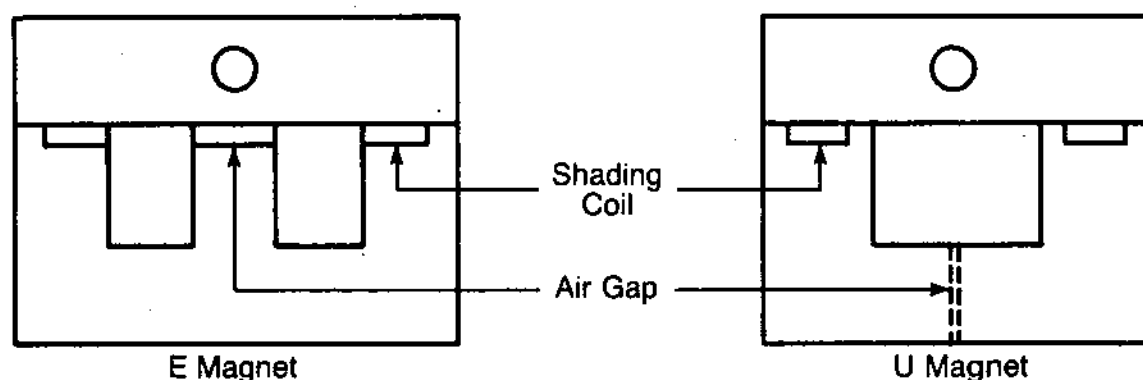


Fig. 7 -- Magnet Construction

The U magnet is assembled with the air gap away from the pole faces. There is no mechanical wear involved with air gap. The structure is usually two coils, one on each leg, which may be connected in series or in parallel for dual voltage convenience. Both are usually encapsulated in a single unit.

With either type of coil, a broken or missing shading coil will cause a noisy unit and both magnet and armature should be replaced.

Magnet noise can also be caused by loose laminations when rivets are not properly headed, or by improper grinding of pole faces, or laminations that have shifted after grinding. (This may occur if the magnet is

dropped.) In these instances the magnet and armature should be replaced.

Direct-current coils are not subject to a zero current condition so d-c devices are not noisy. A-c contactors equipped with d-c operating coils will operate quietly.

2. *Magnetic Sticking*

When operating coils are de-energized, there is a residual magnetism in the magnet. This residual magnetism is sometimes strong enough to hold the device closed. Magnetic sticking occurs most frequently in small devices having light spring pressures and moving parts. Magnetic sticking causes erratic, unsatisfactory, and sometimes dangerous operation. It can be corrected by providing a permanent air gap. A non-magnetic shim is inserted in the magnetic circuit at the time of manufacture.

Warning: Do not permit a condition of magnetic sticking to continue. Immediate correction is required. Failure to do so can cause equipment to remain energized, which can cause severe personal injury and damage to property.

3. *Braided Shunts*

Many control devices have single break contacts and use flexible shunts to carry current. These shunts are made from many strands of fine wire. These fine strands sometimes break where the shunt bends. The remaining unbroken strands must then carry the entire current load and overheating and burnout result. Frayed or damaged shunts should be replaced immediately.

4. *Overload Relays*

Often contactors are equipped with overload protection. This is commonly true when the contactor functions as the primary contacting device in a starter.

Built-in overload protection provides vital protection against sustained overloads. It also is possible to provide low level fault protection from short circuits and ground faults.

Overload relays may be of several types:

- a. Single pole bimetallic with removable heaters, either ambient compensating or non-ambient compensating.

Operation may be either automatic reset, manual reset, or convertible.

Operating current is adjustable $\pm 15\%$

b. Block type rating is sometimes bimetallic which provide two or three phase protection. All the variations for **a.** above may be available on these relays.

c. Both single pole and block type overloads may be manufactured with direct heated bimetal operating elements, in which case the adjustment is indicated on the adjustment mechanism. All the variations indicated above (**a.** and **b.**) are available on these devices.

d. Both single pole and block type melting alloy use a eutectic solder to release a spring loaded ratchet when the alloy melts. Eutectic alloy overload relays are manual reset only and are not available with ambient compensation, although they can be designed with a high melting temperature alloy to make them relatively ambient insensitive.

L. Routine Contactor Inspection

A maintenance program should be established as soon as a contactor is put into service. After a contactor has been inspected a number of times at weekly or monthly intervals, the frequency of inspection can be established based on this experience.

Warning: De-energize the contactor before attempting inspection. Assure that it will remain de-energized until inspection is completed. Failure to do so can result in severe personal injury or death, and damage to property.

1. General Inspection

Check for loose, missing, broken, or corroded hardware. Inspect pivot pins, cotter pins, and other mechanical parts. See Figure 8.

Do not lubricate moving parts, this will only accelerate collection of dust and dirt.

2. Arc Boxes

Check arc boxes for broken or eroded ceramic insulating parts and steel grid plates.

Check for excessive deposits of contact material, carbon, or foreign material on the surface of insulating parts.

Replace broken or badly eroded parts.

Clean or replace all parts having excessive build-up of conducting matter.

3. *Contacts*

Remove excessive oxide and beads of contact material from the faces of copper contacts using a fine file or sandpaper.

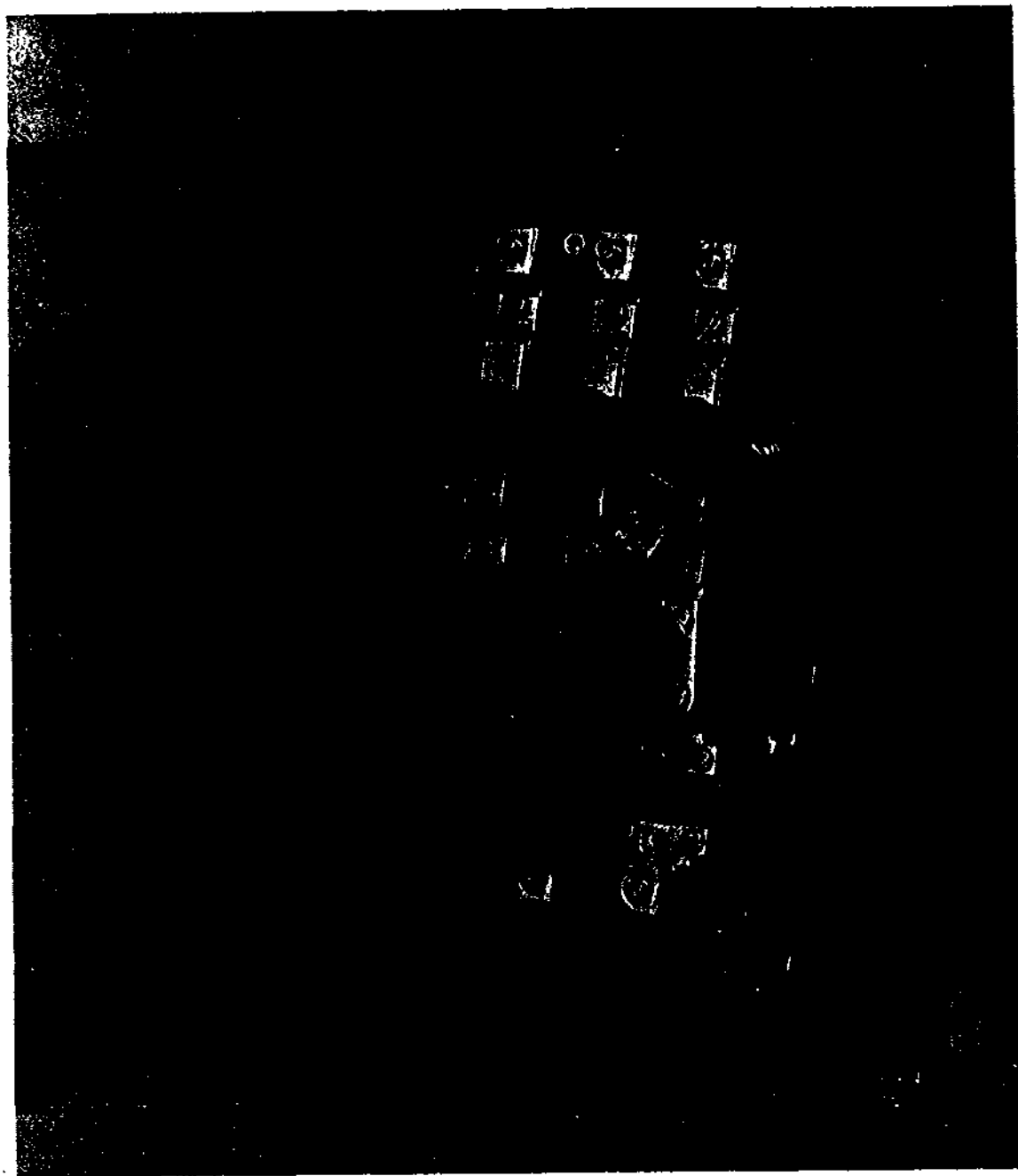


Fig. 8 – Inspect and Clean Contacts Frequently. Replace When There Is Significant Loss of Material or Contacts are Badly Burned

Warning: Do not use emery to clean contacts. This material can become imbedded in the surfaces and cause improper contact. It will also quickly destroy bearing surfaces. These effects can result in failure of the contactor, severe personal injury and property damage.

Do not file or sand silver or alloy contact surfaces unless considerable oxide or foreign matter has collected on the surfaces. When replacing contacts or other current carrying parts, clean the surfaces that are to be bolted together.

Re-align contacts and set overtravel when necessary and if adjustments are provided.

Warning: Do not substitute contacts of a material different from the original without approval from the contactor manufacturer. To do so may change the operation of the contactor which could cause equipment malfunction, severe personal injury, and substantial damage to property.

Replace contacts when there is significant loss of contact material or if they are badly burned, eroded, or pitted.

4. *Shunts*

Replace shunts having broken strands.

Clean shunt connection points if current carrying parts are discolored. If silver or tin plated terminals are provided, brighten with steel wool before installing. Remove loose steelwool particles. Do not use acids or corrosive metal polishes.

5. *Blowout Coils*

Inspect blowout coils for discolored connections, shorted turns, and loose hardware.

Examine turn insulation and coil spacers, replace if burned, cracked, or brittle.

6. *Terminals, Contact Blocks, Bus Bars, and Connectors*

Discolored metal at connections usually indicates heat, present or past. This is most commonly due to loose connections.

Clean connection points and tighten all hardware. Do not use corrosive cleaners, emery, acids, or files. If steel wool is used all particles must be removed. Fine sandpaper or neutral compounds containing pumice are preferred abrasives.

7. Insulators

Remove dust and dirt from all insulating parts. Use clean rags or wiping cloths. Avoid use of commercial solvents except neutral spirits and solvents meeting requirements of U.S. Bureau of Standards for Commercial Standard (53-40).

Warning: Avoid contact with or breathing vapors of cleaning solvents. These substances are highly toxic and readily absorbed into the system. Failure to do so can cause severe personal injury or death. Follow the solvent manufacturer's directions.

If carbonized tracks, cracked, or broken insulators are found, replace defective parts immediately.

As a last resort, until replacement parts can be made available, carbonized tracks may be scraped clean and covered with insulating varnish. Before any repaired insulating part is put into service it should be given an overvoltage test in which it is subjected to rated voltage plus 50%. This is an accepted proof-test value for used apparatus.

8. Magnet Assembly

Check the magnet for dirty or corroded pole faces, pivot points, and other moving parts. Clean and dress as necessary.

Check for loose iron, broken or damaged shading coils, and hardware. Repair, tighten, and replace as required.

Inspect the operating coil for evidence of electrical or mechanical damage. If condition is questionable, replace.

Operate the armature by hand and check for mechanical interference and friction. It should operate freely and not bind in any position. Figures 8 and 9 show a typical starter disassembled for inspection.

9. Electrical Operation

Operate the contactor electrically without load and observe magnet operation to be sure it opens and closes properly and that the armature is fully sealed in the closed position. If an a-c magnet is used check for abnormal noise (see under K, 1, Noisy A-C Contactors, above).

Test oil sample from oil immersed contactors. Keep the oil tank filled with manufacturer recommended oil. Use 25 kV dielectric test value or higher.

Measure insulation resistance with a megohmmeter; between phases, to ground, and to the control circuit. Do not use a megohmmeter on equipment rated lower than 600 volts. A 500 volt megohmmeter is recommended for control equipment.

Warning: Close all doors enclosing a contactor or provide adequate shielding or remote operation. Never permit personnel near an exposed contactor when testing under load. Failure to heed this warning can cause severe personal injury and substantial damage to property.

Operate the contactor under load and check for an excessively loud report and arcing on both opening and closing. A loud report on closing is usually due to bounce (see under A-welding of contacts, above). The magnitude of the report and arcing found on opening and closing will depend upon the type of contactor, operating load, and phase angle at which the contacts separate or touch.

There are no absolute standards covering this problem so it is necessary to rely on experience and judgement. Comparison with similar equipment under similar conditions, or comparisons with new equipment of the same style may be helpful. Excessive noise and arcing under normal conditions of operation is not acceptable and investigation should be made as to cause. A larger contactor may be required. If the installed contactor size is deemed adequate, a new contactor should be tried. If the condition persists, the contactor should be given frequent and thorough maintenance inspections.

2.2 Other Control Components

A-c control is covered in Chapter 1 so coverage here will be restricted to small manual a-c starters, rheostats, drum controllers, and control relays.

A. Manual Starters

Manual starters are used where only manual starting and stopping and automatic overload are desired. These starters must be manually reset after tripping just as magnetic starter breakers. Servicing this kind of starter is relatively simple and usually thoroughly covered in the manufacturer's instructions. The maintenance requirements are basically those for contactors. A schematic wiring diagram is usually mounted inside the cover of the starter enclosure. Figure 9 illustrates a typical manual starter of the NEMA size 1 to 5 range.

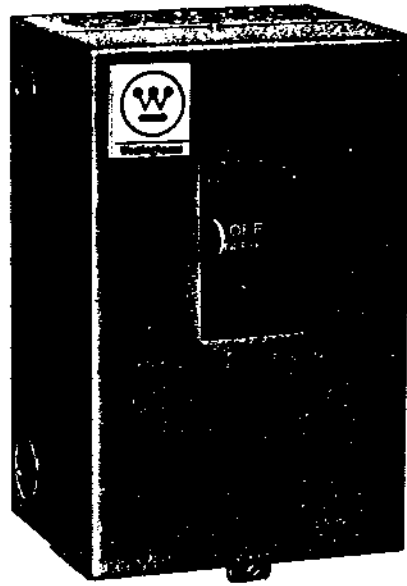


Fig. 9 – Typical Manual Starter

B. Starting and Speed Regulating Rheostats for D-C Motors

Rheostats are used for starting and speed regulating of series, shunt, and compound wound motors in non-reversing service. Specific applications are fans, blowers, pumps, machine tools, and similar d-c motor duties.

Little maintenance is required; periodic inspection, cleaning and dressing of the contacts with a file is usually all that is needed. The low maintenance requirement is due to magnetic blowout devices, high contact pressures, contacts raised above the surface of the face plate, sturdy moving parts, and easy access to serviceable parts. See Figures 10 and 11.

Warning: Do not use emery cloth to smooth contact-making parts. Emery is an abrasive and can cause mechanical and electrical hazard. Failure to heed this warning can cause severe personal injury or death, and substantial damage to property.

Some arcing and burning of the contact-making parts is unavoidable and servicing will be necessary. Contacts should always be smooth. (A file should be used, *never* emery cloth)

After each dressing, contacting surfaces should be thoroughly cleaned, including the areas between the contacts. The contacts may be lightly greased with petroleum jelly, but care should be taken not to over grease. If there are abrasive particles in the air, the contacts should not be greased as grease will cause the particles to adhere to the contacts and cause scoring.



Fig. 10 – Starter Disassembled for Inspection. Few Tools are Required

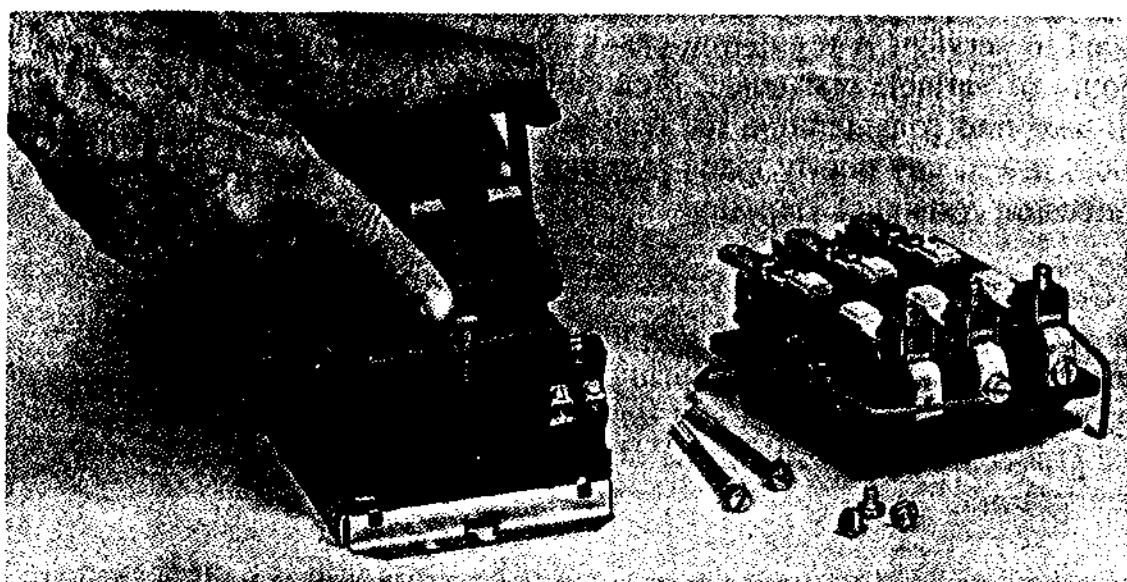


Fig. 11 – Proper Operation Often Depends on a Small Part. Note the Critical Kick-Out Spring

1. Servicing Rheostats

Warning: Do not attempt to service a rheostat unless it has been completely de-energized and will remain so during the work period. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Many rheostats are made with reversible contacts. Both movable and stationary contacts can be turned over and used on the reverse side, thus giving them double life. Reversing of contacts should be resorted to only when the burning-dressing sequence has made the opposed contact surfaces uneven. It is generally advisable to turn all the contact buttons at the same time. This will maintain the firm even pressure between moving and stationary contacts, necessary to prevent arcing. Uneven pressure between the moving contact and stationary contacts as it moves from one to another can result in irregular increments in speeds or voltages due to poor regulation of resistance. This is less critical on larger rheostats or those equipped with compensating contacts.

Oxides will form on the unused copper surfaces. These oxides should not be allowed to accumulate. They should be removed at regular maintenance periods. The unused contacts should be thoroughly cleaned and protected from re-oxidation by a light coating of petroleum jelly.

When load application requires use of previously unused portions of the rheostat, the added resistance should be measured. A check should be made to assure that the additional travel of the moving contacts is not restricted by the height of the previously unused stationary contacts, and that these contacts are properly connected to obtain the desired resistance.

Contact surfaces of a rheostat should always be cleaned before it is placed in service. A regulation check should be made measuring the amount of variable resistance, preferably at the controlled motor. This will take into consideration the resistance value of the motor leads and should reveal any poorly made terminal connections and any irregularity or erosion resistance stepping.

2. Contact Pressure Settings

The proper pressure between moving and stationary contacts must be maintained by adjustment of spring tension, to minimize pitting, heating, and oxidizing contacts and to assure good electrical contact. Specific procedure values should be obtained from the rheostat manufacturer.

The recommended moving contact spring pressure will usually be indicated in pounds or ounces per square inch of contact and can be

checked with a spring tension scale. The force required to separate the contacts should be determined and compared with the manufacturer's recommendations. The manufacturer's recommended pressure is calculated to establish good conductivity without causing damage to the surfaces of the contacts. In setting contact pressure, care must be exercised not to create frictional forces that would prevent resetting the arm on rheostats with low voltage release and automatic reset. The turns of the pressure spring should never touch. This is an indication of a weak or improperly applied spring which must be replaced.

3. Magnet Coils and Low Voltage Release Devices

Starting rheostats of low horsepower ratings normally have a magnetic holding coil as a part of the low voltage release mechanism. This coil is connected across the line and the release is adjusted to hold the operating handle in the last running position as long as the line voltage remains normal.

The release may or may not be adjustable. If it is adjustable, its holding characteristics may be changed over a prescribed range of undervoltages. If it is not adjustable the device may be rendered inoperative by filing, bending, shimming, or otherwise altering mechanical parts in attempting adjustment.

The operating arm of a rheostat should never be held in the running position by force.

A rheostat that does not operate as intended should be thoroughly checked for mechanical defects and the possibility of misapplication. It is more economical to replace the rheostat operating mechanism than to risk damaging the controlled motor by excessive starting or running current.

The control rheostat should not be used to stop the motor; a motor starter, safety switch, or circuit breaker should be provided for this purpose.

The maintenance requirements established by the rheostat manufacturer should be observed when servicing, and regular inspections should be made to insure long service and proper operation.

4. Resistor Replacement

Abnormal starting or operating conditions may burn out a section of resistance. Plate resistors must be replaced with parts of equal value. If resistance is the wire wound bobbin type covered by ceramic glaze, it must be replaced by a unit of equal or adjustable value. Edgewound resistance supported on a ceramic core can be temporarily repaired by

welding or clamping the burned out sections together until a replacement resistor of equal value can be obtained.

To replace burned out resistors, partial or complete disassembly of the rheostat may be required. In most types of industrial rheostats, the field resistors are removable from the mounting without disconnecting the wiring at the face plate, or disassembly of the operating mechanism. Large motor applications frequently use remotely located frame mounted resistors. See Figures 12 and 13.

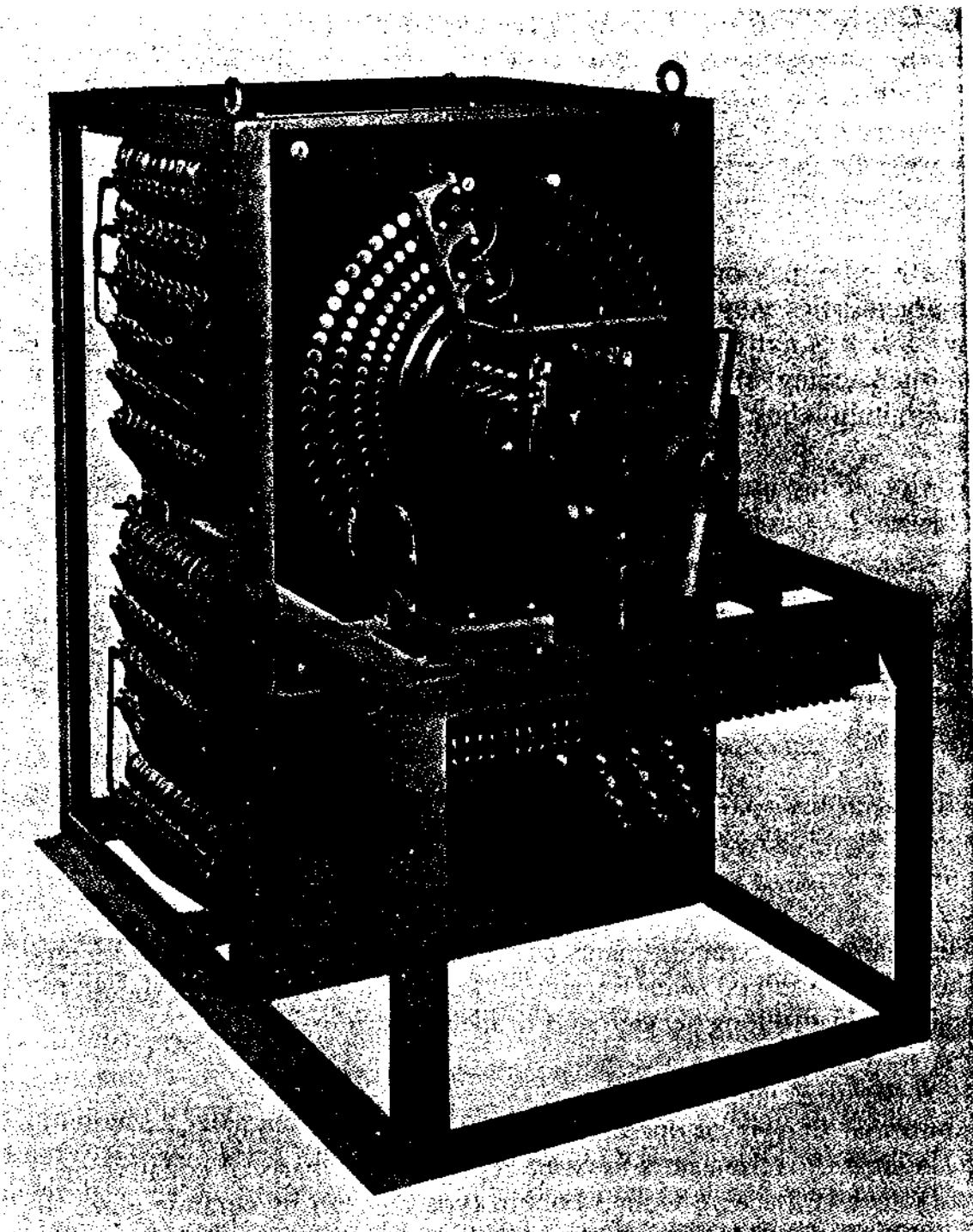


Fig. 12 - Typical Industrial Class, Motor Operated Resistor

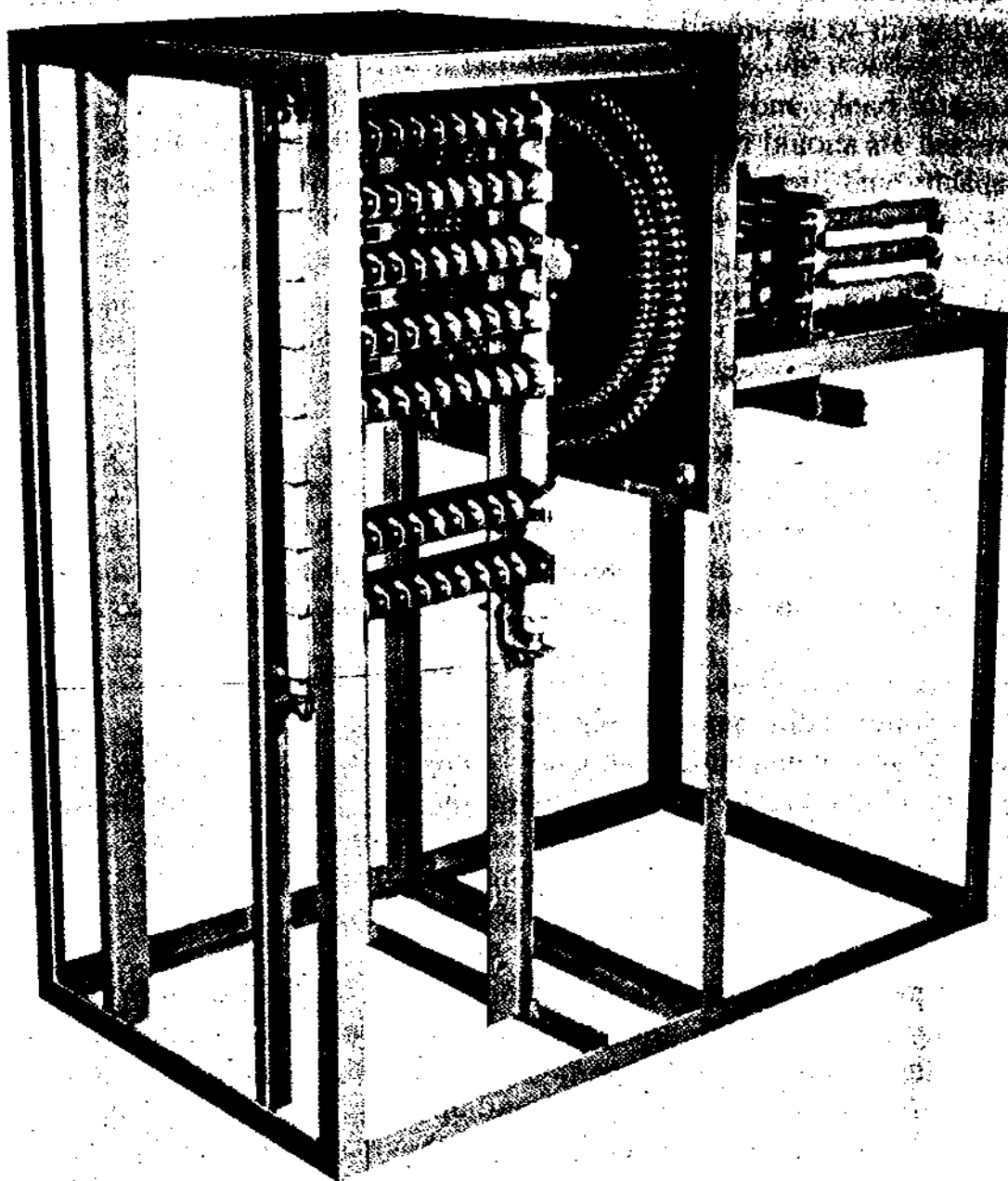


Fig. 13 – Partial Assembly of Edgewound Resistors in a Back-of-Board Frame on a Motor Operated Rheostat

5. Locating and Installing Rheostats

The primary consideration in locating rheostats and resistors is adequate ventilation. Rheostats should be installed with ventilating hoods at the top. If resistors are stacked in racks, the accepted practice is to limit the height to four frames with ample separation between frames. At least one foot of free space should be provided between the floor and the bottom frame and an equal minimum space between the top frame and the ceiling.

In most instances the rheostat manufacturer specifies the necessary requirements for remote mounting of field resistors and the volume of cooling air to be provided if forced air ventilation is necessary.

Resistor banks and rheostats must be kept clean and dry. Dry compressed air should be used to blow out accumulated dust. Since both capacity and life of resistors are dependent largely on heat dissipation, they should always be adequately ventilated. If not properly ventilated, there may be undesirable variations in resistance and addition of forced ventilation may become necessary. It is recommended that temperatures be kept well below maximum, although some resistors may operate at temperatures high enough to cause them to glow.

Warning: Do not store or leave combustible material near or in the area of resistors. Keep cooling air free of oil mist, lint, or explosive vapors. The operating temperatures of resistors are high enough to ignite these materials and start fires and explosions. Severe personal injury, death, or substantial damage to property can result.

6. *Loose Connections*

The cyclic heating and cooling of resistors tends to create loose connections. Loose connections can cause many annoying delays, are difficult to locate, and create operating conditions that are potentially hazardous. They are very difficult to find unless arcing or burning occurs. To guard against loose connections developing from cyclic heating and cooling, frequent checks of all resistor connections should be made.

When placing a rheostat or field resistance in service for the first time, it is important to check the resistance value before attempting operation. After the equipment is placed in service and during the initial observation period, terminal connections and all interconnections should be inspected at least twice to determine if they have loosened due to heating.

It is good maintenance practice to occasionally compare current resistance values with the manufacturer's data. Incremental values and total values should be measured as a guard against shorted resistors which affect total resistance values. One of the best devices for checking continuity and regulation of a rheostat is an ohmmeter. It is convenient, of sturdy construction, and small in size. The ranges on the ohmmeter dial indicate whether it can be used for high or low resistance circuitry. If extremely accurate measurement is required a Wheatstone Bridge or similar resistance reading instrument should be used.

Warning: Never use a measuring device which is not properly rated for the measurement being taken. Failure to heed this warning can cause severe personal injury or death and damage to property.

When using a direct reading ohmmeter to check resistances, changes between two points of resistance will cause a fluctuation in the position of the instrument pointer. Most resistors are manufactured with an accuracy range of ± 10 percent, so it is important to know the resistance requirements for both checking and replacing resistors.

If a portion of a resistance bank or rheostat has open circuited or burned out, there may be considerable change in motor performance. This is also true if a portion of the resistance has been improperly replaced.

Always check the motor and application data when replacing rheostats. The manufacturer's resistance data and resistor connection drawings should be available when re-stacking or changing-out resistors.

Arcing at the contacts or burning of contacts on the faceplate of the rheostat are sure signs of trouble:

There could be shorts or open resistance at these points.

There could be a lack of resistance at that step.

Substitute field rheostats must never be used if current requirements exceed the nameplate rating and value of the rheostat.

7. Secondary Control

Special attention should be given to the maintenance of the secondary control of wound rotor motors, particularly those used in speed regulated service. In contrast with primary circuit faults which require immediate correction, regulating problems can develop in secondary circuits without causing immediate shutdown or failure to start.

The motor will continue to start and run, even though an open circuit or serious unbalance of resistance may exist in a secondary circuit or at specific points on the controller. This condition can lead to serious consequences, such as the roasting out of the rotor windings, burning out of resistors, undue stress on equipment due to loss of smooth steps of acceleration because of poor contact or no contact at certain points on the controller. Operators should be alerted to report when they have to change normal settings or if operation is not smooth at all steps.

Because rheostats and resistors are simply designed and of strong construction, they are largely troublefree, which may lead to their being neglected. A regularly scheduled thorough inspection is essential for this equipment.

C. Hand Operated Rheostats and Potentiometers

The function of hand operated rheostats and potentiometers is regulation by introducing resistance into circuits to maintain steady state conditions or to provide vernier regulation.

1. Hand Operated Rheostats

Three types of hand operated rheostats are illustrated in Figure 14, a single unit, a double, and a triple stacked array. Each plate has a resistance element which has increments of total resistance brought out through the ceramic glaze and connected to contact buttons similar to those in a motor operated rheostat, see Figure 12.

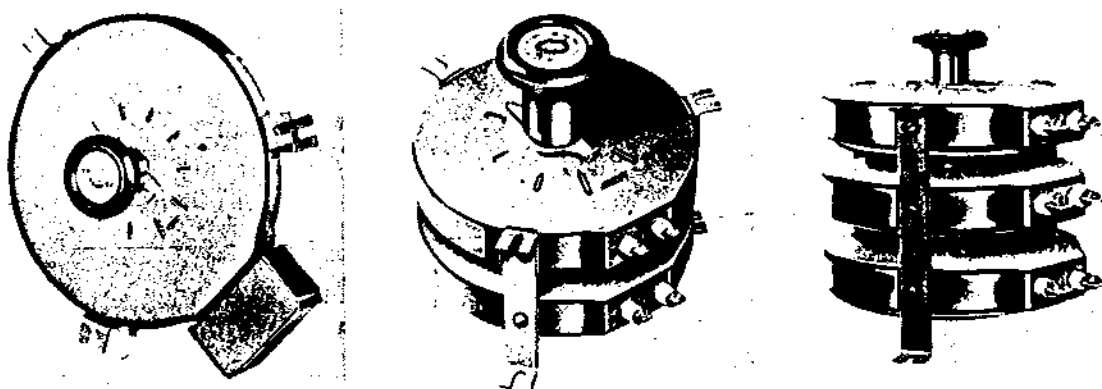


Fig. 14 – Three Types of Hand Operated Industrial Class Rheostats:
Single Pole, Double, and Triple Stacked Array

2. Potentiometers

A potentiometer is a variable resistor which has a continuously wound element on a circular ceramic core. The continuous winding is connected to a terminal at each end of the potentiometer and a moving contact is centered in the potentiometer core. It can be rotated from zero to full resistance by positioning the moving contact at any point along the wound wire resistance. Potentiometers generally have much lower ohmic values than rheostats. They are used principally for low resistance vernier control and are not used to handle high currents. They are generally low wattage, low voltage components.

3. Maintenance

The maintenance requirements for hand operated rheostats and potentiometers are closely parallel to those outlined for motor operated rheostats. They can become inoperative from excessive use, lack of maintenance, or overloading. Heating is not a sign of distress, but excessive heating should be investigated. Heat losses are normal and ample ventilation should be provided. If overloading or a partial burn-out is suspected, the unit should be tested for total resistance. A check

should also be made for good contact throughout the full range. If the unit is a button type rheostat, each step should be measured for proper contact. Excessive wear in shaft bearings or bushings and loss of moving contact pressure can cause arcing and burning in either device. Most hand operated rheostats have a tightly fitting rear cover to keep out dirt, but full enclosure will inhibit air circulation and cooling.

2.3 Controllers

Automation is rapidly phasing out the manual controller, however, there are still many operations requiring manual starting, stopping, and speed control, and there are still many controllers in service.

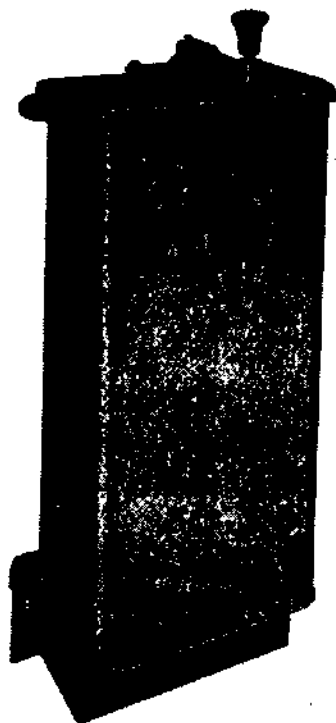
There are two common types, drum controllers and drum contactor controllers. Except for different drum assemblies the construction is similar. See Figure 15. Low current rated controllers have contact supporting discs assembled on an insulated steel shaft, with contacts bolted directly to the supporting discs. Larger ratings in the 150 to 300 ampere sizes have heavy curved copper segment plates supported by molded insulated pieces bolted to a steel shaft. These copper segments are reversible so as they wear, they can be reversed, the old trailing edge becomes the new leading edge when turned 180 degrees. This not only doubles the life but offers a real advantage in simplifying maintenance. As in all drum controllers, as the shaft is rotated the moving contacts change position, thus changing the resistance.

The drum contactor type is made up of a series of contactors closed by cams on the rotating shaft and opened by positive spring pressure. The contacts are the same as those used on corresponding sizes of magnetic contactors. They are usually of the rolling type. The rolling action limits arcing and burning to the contact tips. This quick-make, quick-break action results in only momentary arcing which leaves the current carrying contact surfaces in good condition. The contacts need replacement only when they are so burned that the rolling action is severely reduced. When installing new contacts, care should be taken to obtain proper rolling action.

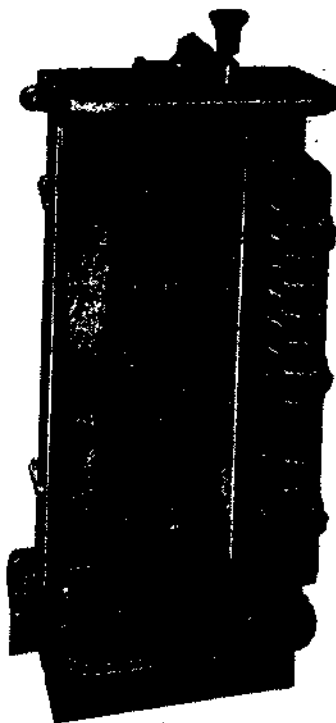
In all instances, consult the manufacturer's instructions for complete maintenance information before undertaking any service work.

2.4 Direct-Current Relays and Timing Relays

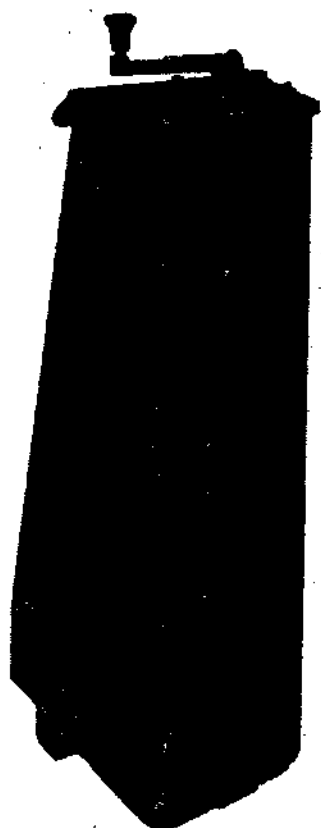
Notice: These descriptions of relays design and their operation are based on Westinghouse design. Relays built at other times and by other manufacturers may vary. Always consult the manufacturer's instructions before attempting to service or adjust a relay.



50 Ampere Drum



75 Ampere Drum



300 Ampere Drum

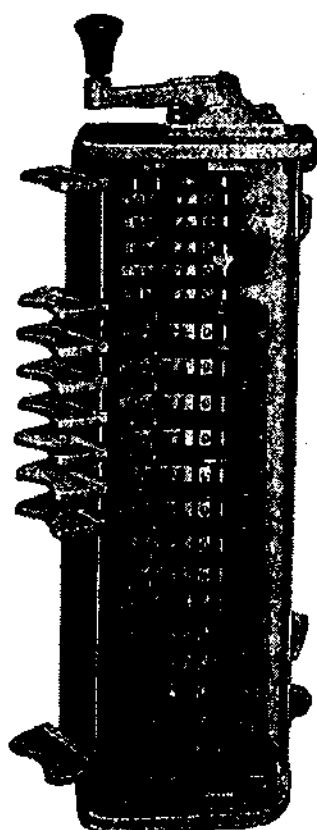


Fig. 15 – Typical Drum Controllers for Speed Control of Variable Speed Motors –
Reversing and Non-Reversing

Warning: Do not attempt any work on a relay unless it has been de-energized and will remain de-energized during the work period. To do otherwise could result in severe injury or death, and damage to property.

Proper maintenance of d-c control relays and timing relays requires an understanding of the operating principle of these devices. Relays and timing relays have great similarity of parts and appearance but can vary widely in function with minor changes in magnetic circuits.

There are many applications which require drop-out limits (pick-up and drop-out within a specific range) usually between 80 and 110 percent of rated coil voltage for pick-up and drop-out when the coil is de-energized. Modification of the relay magnetic circuit is accomplished by controlling the thickness of the non-magnetic spacer in the armature end of the core, which changes the drop-out characteristic. Pick-up is controlled by the air gap between the core and the armature in the open position, plus the force exerted by the kick-out spring in the open position. Drop-out characteristics are controlled by the air gap between core and armature in the closed position, plus the contact force and the kick-out spring force. For the effect of the non-magnetic shim thickness plus the adjustment of the kick-out spring tension, refer to Figure 16.

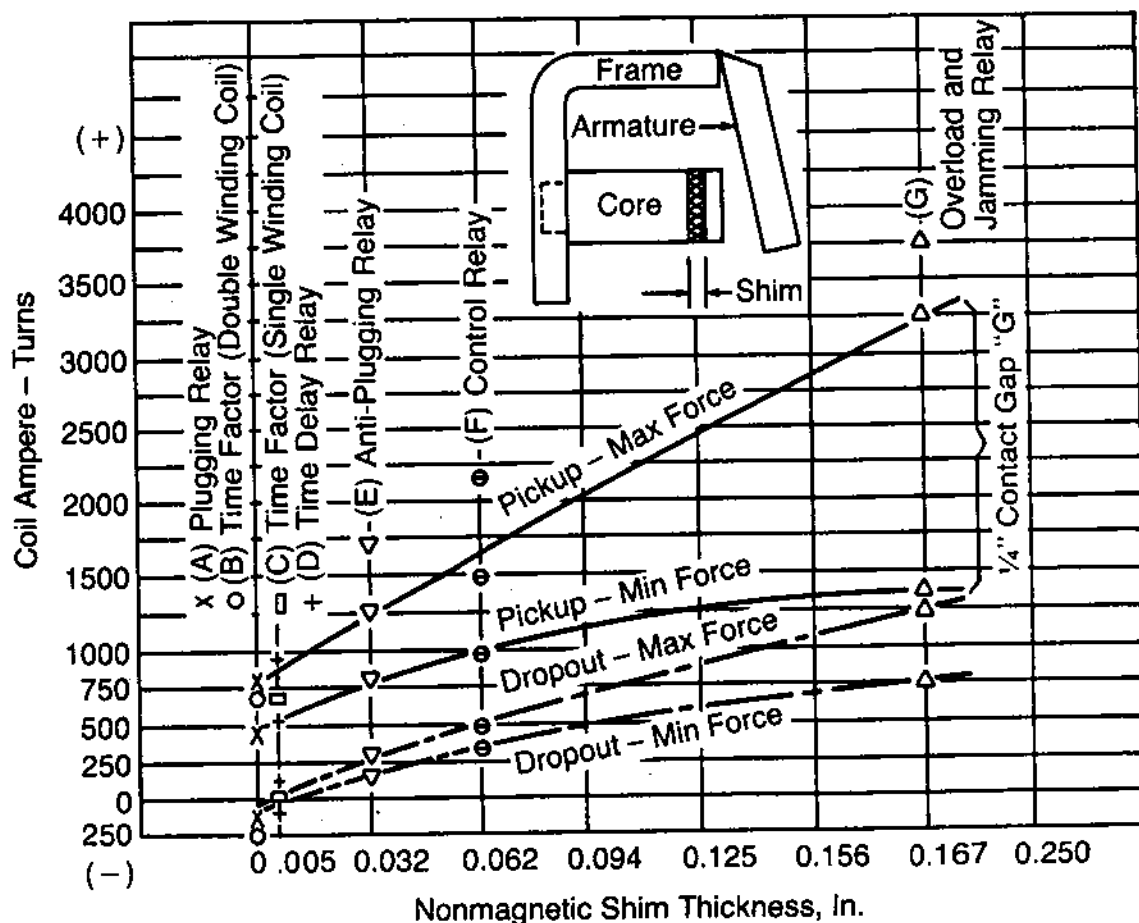


Fig. 16 - Effect of Non-Magnetic Shim Thickness and Adjustment of Kick-Out Spring

A. Relay Operation

When direct-current voltage is applied to the operating coil of a relay, the product of the current flowing and the number of turns in the coil winding is equal to the magnetic force. Refer to Figure 17. With the armature in the open position (point 0) the rate of rise of the flux is nearly proportional to the magnetizing force. When the ampere-turn value reaches approximately 35 percent of the ampere-turns, the armature is picked up (point 1) and rapidly sealed against the core (point 2). Since the reluctance has simultaneously greatly reduced, the flux will increase to approximately 85 percent of the available total. As the coil current reaches its steady state, the iron reaches saturation (point 3) and the rate of increase of flux decreases. When the coil is de-energized, the flux decay does not retrace curve 3-2-1-0, but generates a descending curve along points 3-4-0.

Unless some delaying means is deliberately introduced, the flux decreases immediately from the maximum value (point 3) to the armature release point (point 4). The increase in reluctance due to opening of the armature drives the flux point to zero (point 0). If the armature were

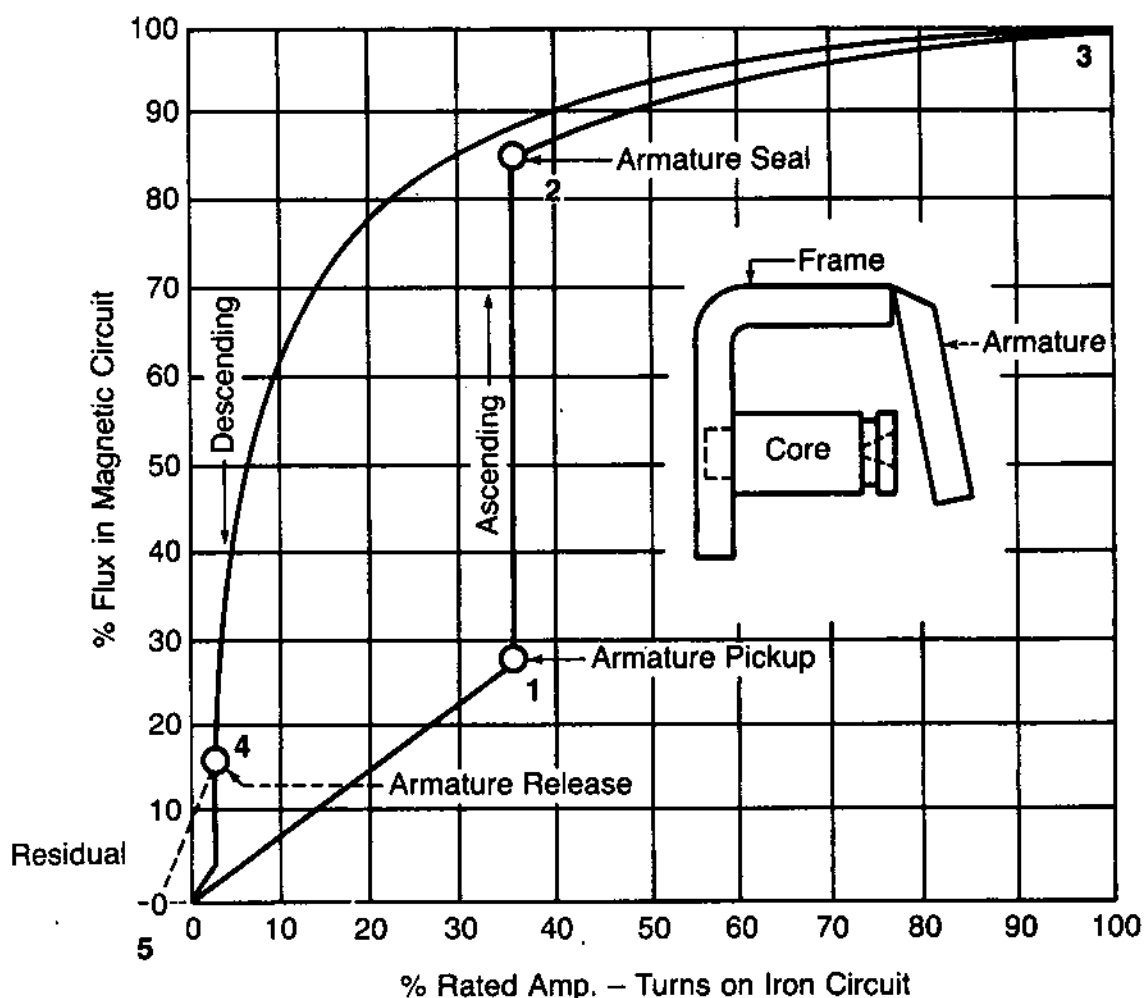


Fig. 17 - Effect of D-C Voltage Applied to a Relay Operating Coil

held in, the descending portion of the curve would go from point 4 to point 5, shown as dotted line. The intersection of line 4-5 and the ordinate is the measure of the residual magnetism. It would be necessary to reverse the polarity of the current and increase its value to a field intensity of 0-5 to de-magnetize the circuit to zero. Decreasing of the residual magnetism can also be accomplished by providing additional air gap in the magnet circuit. The air gap does not affect the coercive force required (0-5) to buck down the residual flux in the iron to zero.

1. Magnetic Hysteresis

The lagging of the change of flux in a magnetic substance behind the change of magnetizing force is known as magnetic hysteresis. The difference between the ascending and descending portion of the curve in Figure 17 is caused by the hysteresis of the iron.

2. 40% Saturation

The iron in the relay circuit reaches near-saturation at about 35 percent of the rated magnetizing ampere-turns, as shown in Figure 17. Iron is assumed to have reached saturation when the rate of flux increase drops with an increase of magnetizing force. At this condition the iron is carrying all the flux it efficiently can and has reached the optimum state of its magnetic characteristic. This phenomenon is fortunate for it enables repetitive accuracy in operation of a relay. When the operating coil is de-energized the flux will decay rapidly to some pre-determined armature release value. This value will be the result of the air gap and kick-out spring combination selected. The time period that the armature would stay in after de-energizing is almost negligible.

If it is desired to provide a time delay from the moment of de-energizing to armature drop-out, the rate of flux decay must be delayed. This can be achieved by surrounding the magnetic circuit by a short-circuit turn of very low resistance. Any change in the magnetic field will induce a voltage in the short circuited turn causing a large current to flow in it. This induced current will try to maintain the flux at its original value. This energy dissipated in the form of heat causes the flux to decay more slowly toward the armature release point and thereby causes a time delay.

B. Plugging Relays-Double Winding Coil Time Delay Relays

Plugging relays and double winding coil time delay relays have the solid core construction shown in Figure 18. In these relays the armature must remain closed after energizing and de-energizing of the coil, and drop out only when a neutralizing voltage is applied to the coil. This requires a high residual magnetism, consequently the reluctance of the magnetic circuit is kept as low as possible. A small air gap is required to provide

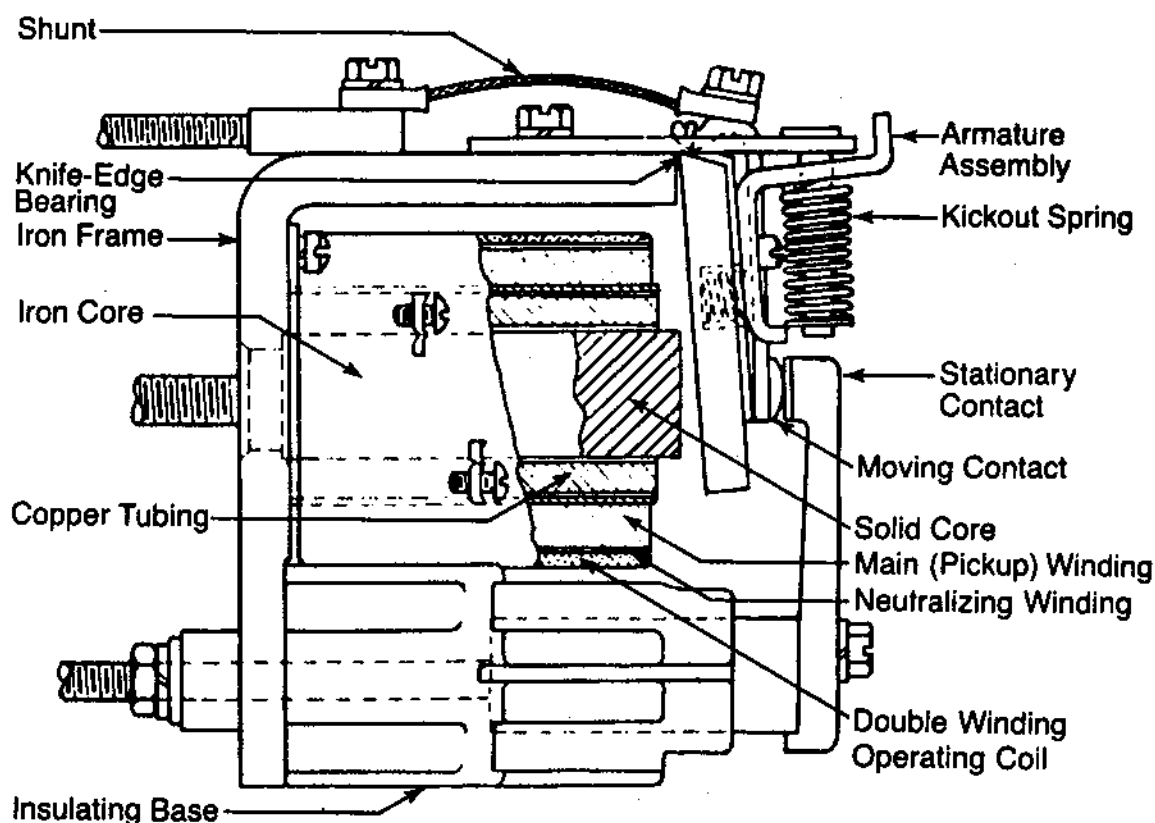


Fig. 18 - A Solid Core Relay

consistent repetitive operation. Shim material the thickness of this small air gap would be mechanically too weak to be practical so a thin film of chrome plating is applied to both the frame assembly and the armature. The magnetic force resulting from the high residual flux overcomes the kick-out spring force. It requires the use of a neutralizing winding to buck the residual flux to an armature release value.

The armature drop-out time for a plugging relay depends on the time it takes the neutralizing winding magnetic force to reach the armature release value. The armature pick-up voltage or current characteristics can be varied by adjusting the kick-out spring or the contact gap, or both. Drop-out voltages or current characteristics are adjustable only by adjusting the contact gap.

Time delay is provided by a copper tube encircling the core and nesting in the coil. A wide variety of time delays after de-energizing of the coil is available by varying the neutralizing coil current.

The low reluctance resulting from the extremely small air gap between the armature and the solid core must be constant. Frequent inspections are necessary to make sure they are free of rust, scratches, or dust that would tend to increase the air gap and thus affect the drop-out characteristics. A .001 inch particle on the contact surface of core or armature could increase the air gap six times its original length. See Figure 19.

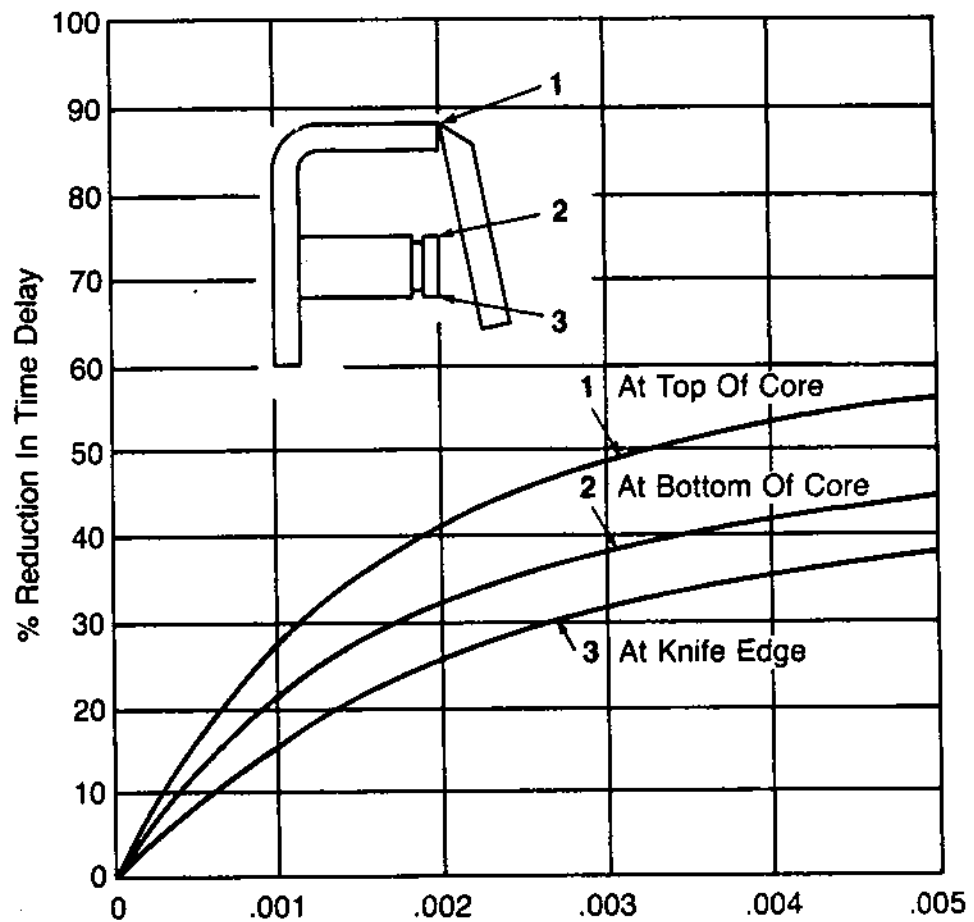


Fig. 19 – Effect of a Foreign Particle in the Air Gap

C. Single Winding Time Delay and Synchronous Relays

Relays in this group are constructed as shown in Figure 20. A non-magnetic shim is permanently assembled onto the core near the pole face. The thickness of the shim is sufficient to provide the required magnetic circuit reluctance. The built-in shim is analogous to a gap in the magnetic circuit to control the amount of residual flux. The iron cross-section at this point is small so the residual flux is at a minimum. This type of core construction will have approximately $\frac{1}{8}$ of the residual magnetism available in solid core construction of the same size subjected to the same saturation.

Figure 21 illustrates another type of construction used in these relays in which a non-magnetic shim is assembled between the core and the pole face using non-magnetic hardware.

D. Anti-Plugging, Control, Instantaneous Overload, and Jam Sensing Relays

The anti-plugging relay uses a non-magnetic shim 0.032 inch thick. It is operated by a conventional single winding coil. Pick-up voltage can be

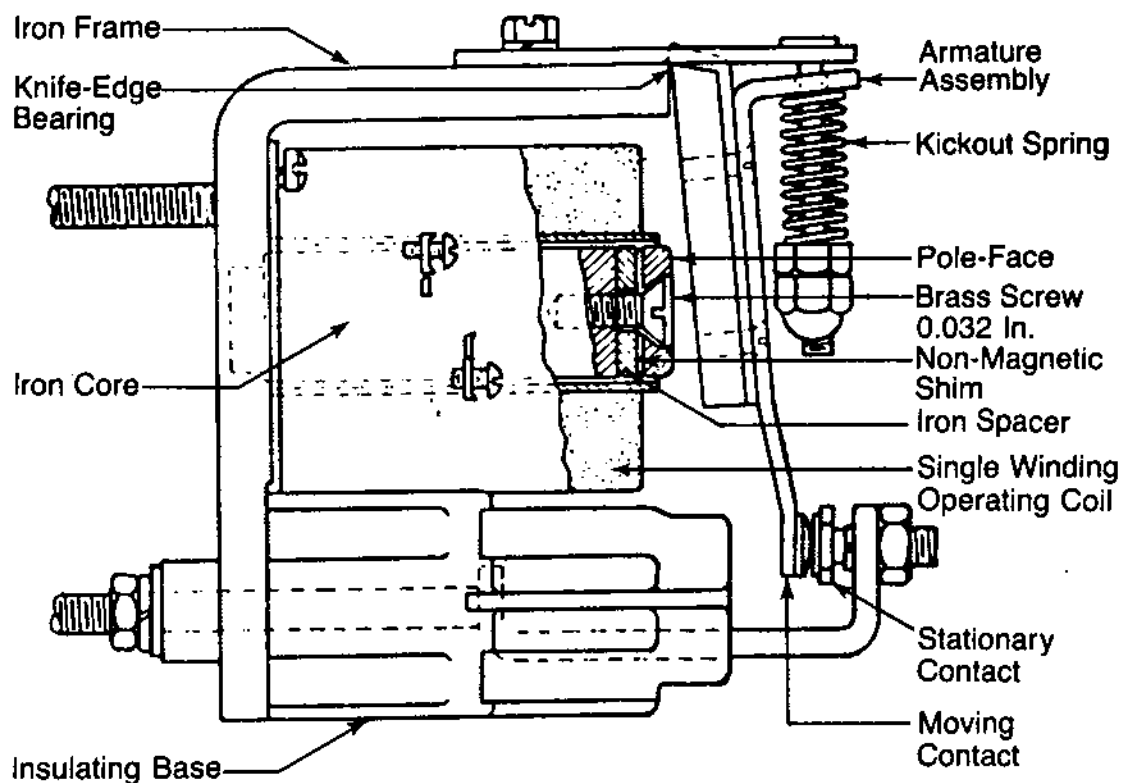


Fig. 20 – Relay with a Permanent Non-Magnetic Shim

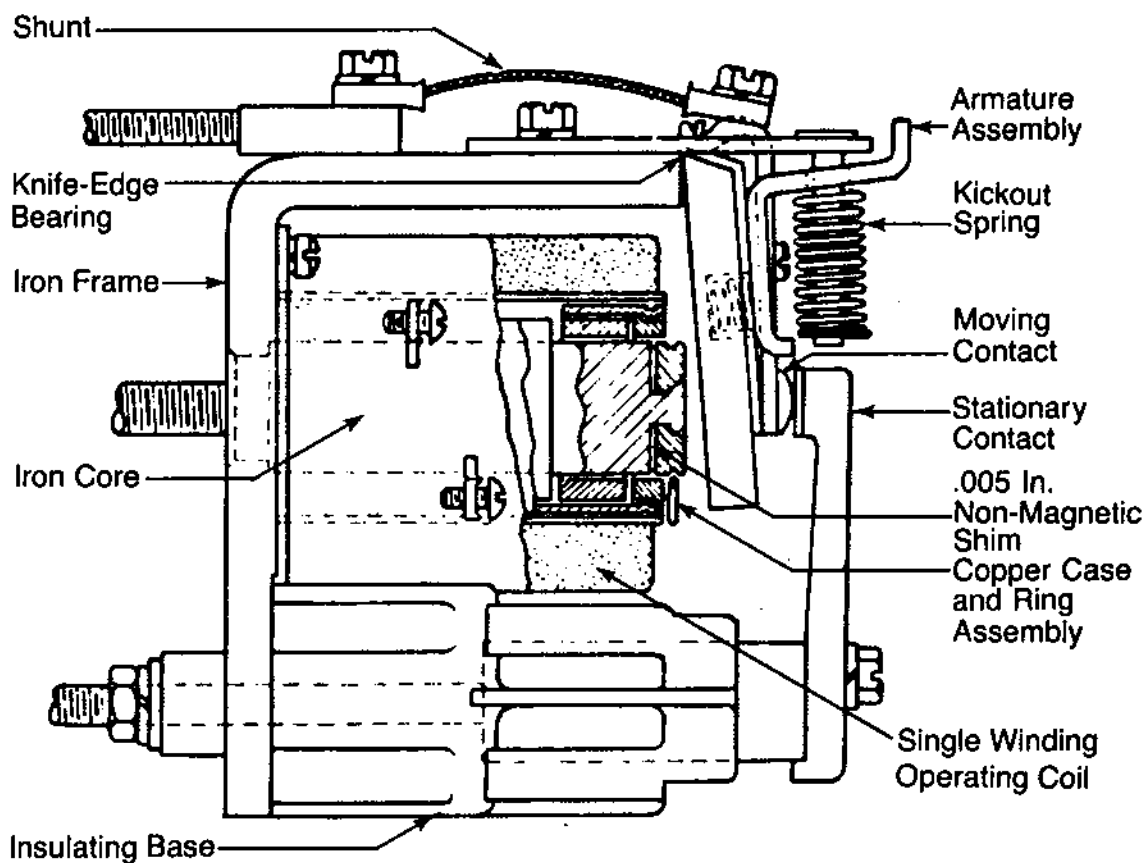


Fig. 21 – Relay with a Non-Magnetic Shim Fastened with Brass Screws

varied by adjusting the kick-out spring and the contact gap. The drop-out voltage can be varied only by kick-out spring adjustment and is not affected by main contact gap adjustment. The low drop-out voltage characteristic of this relay provides the required time delay for anti-plugging applications.

Control relays have a non-magnetic shim between the pole face and the core that is 0.062 inch thick, which produces a fast drop-out time due to higher drop-out voltage. It is operated by a conventional single winding coil. Pick-up voltage is adjustable by adjustment of the kick-out spring and contact gap. The drop-out voltage is independent of the contact gap and adjustment is possible only through adjustment of the kick-out spring tension.

Instantaneous overload or jam sensing relay operating characteristics require use of a non-magnetic shim between the pole face and core that is 0.187 inch thick. Operation is by a series strap-wound coil. An insulated copper tube is nested between coil and core to provide a damping effect for momentary current surges that otherwise could contribute to faulty operation. Pick-up current adjustment is by adjustment of the contact gap and kick-out spring force. The drop-out value is unaffected by the contact gap but adjustable by kick-out spring tension adjustment.

Since adjustable voltage-sensitive relays are constructed so the minimum air gap is 1/32 inch and knife edge bearings are designed for almost infinite wear, the maintenance requirement for these relays is very low. Contacts should be regularly inspected and replaced as necessary.

E. Operating Coils

Proper operation of operating coils is essential to contactors and relays. Coils provide the electro-magnetic force that causes contacts to open and close. If they fail to properly perform this function they must be replaced.

Coils are manufactured with an overvoltage allowance to avoid burnout on occasional overvoltage conditions. The manufacturer's instructions will show what this overvoltage allowance is (usually about 10%).

Common causes of open circuited coils are:

- Excessive moisture or corrosive atmosphere.

- Relocate or use specially treated coils.

- Mechanical damage.

- Replace damaged coil. Handle and store coils with care.

- Excessive vibration or shock.

- Relocate or use cushioned mounting.

Caution: Never replace a coil with one of different rating. A different rating may cause contacts to fail to open. Personal injury or property damage can result.

F. Troubleshooting and Maintenance

If the relay fails to pick up satisfactorily upon being energized, check for:

Damaged Coil.

Improper contact gap.

Excessive friction in moving assembly.

Excessive kick-out spring pressure.

Improper coil voltage.

Improper wiring connection.

If the relay fails to drop out within permissible variation of setting, check:

Contact welding.

Damaged coil.

Incorrect polarity of coil wiring.

Incorrect neutralization current.

Neutralizing current supply connections for excessive voltage drop.

Excessive air gap such as dirt or lint between armature and core.

Excessive kick-out force if drop-out time decreases.

Friction in moving parts.

The main contacts of relays are for circuit closing service only. They should never be applied where they will be required to interrupt a current.

Excessive heating of contacts may be due to insufficient contact pressure. Contact forces should be checked to assure they have not decreased. Refer to the manufacturer or manufacturer's instruction literature for the recommended pressures.

Contact Troubleshooting Chart

Defect	Cause	Remedy
Overheating	Load current too high.	Reduce load. Use larger device. Clean and tighten.
	Loose connections	
	Overtravel and/or low contact pressure.	Adjust overtravel, replace contacts and contact springs.
	Copper oxide or foreign matter on contacts.	Clean with file or sandpaper. Use dust-tight enclosure in dusty atmosphere.
	Load on in excess of 8 hours for copper contacts.	Change operating procedure. Consult manufacturer for more suitable contacts.
	Ambient temperature too high.	Reduce load. Provide better ventilation. Use larger device.
	Line and/or load cables too small.	Apply cable as specified by NEC for 60C conductors.
Welding of Contacts	Magnet stalls or hesitates at contact touch point.	Refer to <i>Magnet Assembly</i> , L-8 this chapter.
	Magnet drops open at contact touch point due to voltage dip.	
	Magnet chatter.	
	Contacts rebound to contact touch when opening.	Correct mechanical defects in stop assembly. Correct mechanical defects in latch.
	Poor contact alignment.	Adjust contacts to touch simultaneously within 1/32", or to manufacturer's spec.
	Excessive inrush current.	Adjust accelerating time or operating sequence. Consult manufacturer for more suitable contact material. Use larger contactor.
	Vibration in mounting.	Move to location of less vibration. Insulate from vibration or shock. Provide more rigid support.
Short Contact Life	Low contact force.	Adjust overtravel. Replace contacts. Replace contact springs.
	Contact bounce.	Correct coil overvoltage. Correct mechanical defects.
	Abrasive dust on contacts.	Use dust-tight enclosure. Do not use emery cloth to dress contacts.
	Load current too high.	Reduce load.
	Jogging cycle too severe.	Reduce jogging cycle. Consult manufacturer for more suitable contact material. Use larger contactor.

Pushbuttons and Operator Controlled Switches

Pushbuttons and other operator controlled switches often require the attention of the maintenance department because of frequency of operation and operating conditions. This attention is usually in the nature of installation and replacement. In instances when the operator's controls must be located remotely from the machine, the purchaser may be responsible for selection and installation of the pilot control devices.

Normal use results eventually in the control station becoming unreliable. The maintenance department is then faced with the need to replace, these low cost devices are seldom repaired. Stocks of standard pushbutton units and selector switches are usually kept on hand. If the device is a special unit a duplicate may have been purchased with the original equipment. If it is not possible to replace a pushbutton or switch with an exact duplicate, rewiring of the control circuit may be required.

In replacing such a pilot control device as a pushbutton or selector switch, the old unit should be carefully examined to determine the cause of failure. If the current it has been interrupting exceeded the rating of the device the overloaded condition will be evidenced by burned contacts and shortened life. Such a condition should be investigated. Care should be taken not to apply pushbuttons or switches above their ratings.

The variety of pushbuttons and other operator control devices is great and the possible combinations almost limitless. There are standard and heavy duty units to meet electrical and physical operating conditions, standard, and oil and dust tight enclosures for a variety of atmospheres and to meet safety requirements of the NEC. There are surface, flush, switchboard, and pendant mountings. There are finger, palm, and foot operated units, and button, lever, and stick operators, and flush and extended operators. There are selector switches, indicating lights, pushbuttons, and limit switches. Figure 1 shows some typical pushbutton stations, Figure 2 is an exploded view of a typical pushbutton, Figure 3 illustrates some contact block designs, and Figure 4 pictures a die-cast pushbutton enclosure.

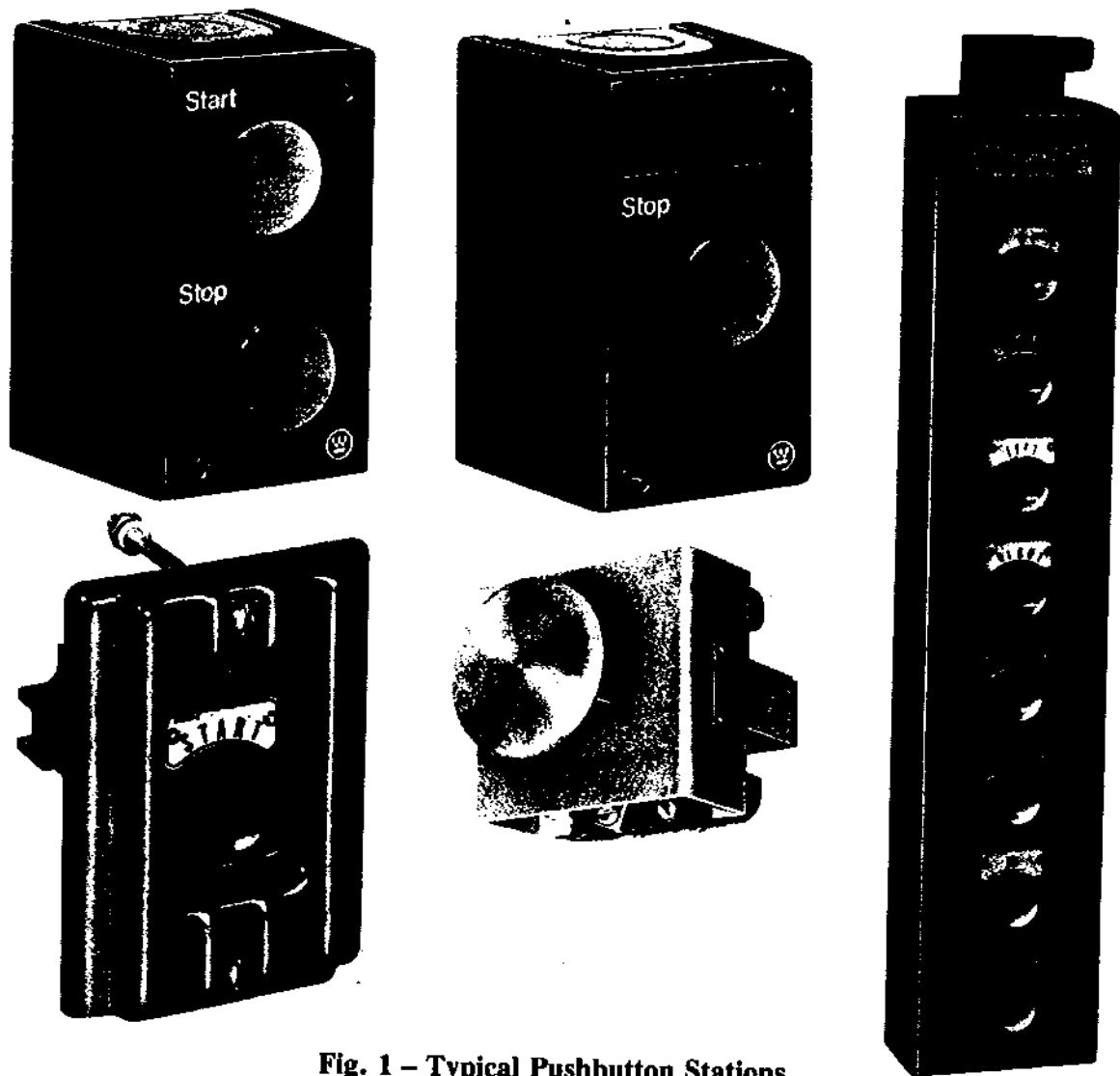


Fig. 1 – Typical Pushbutton Stations

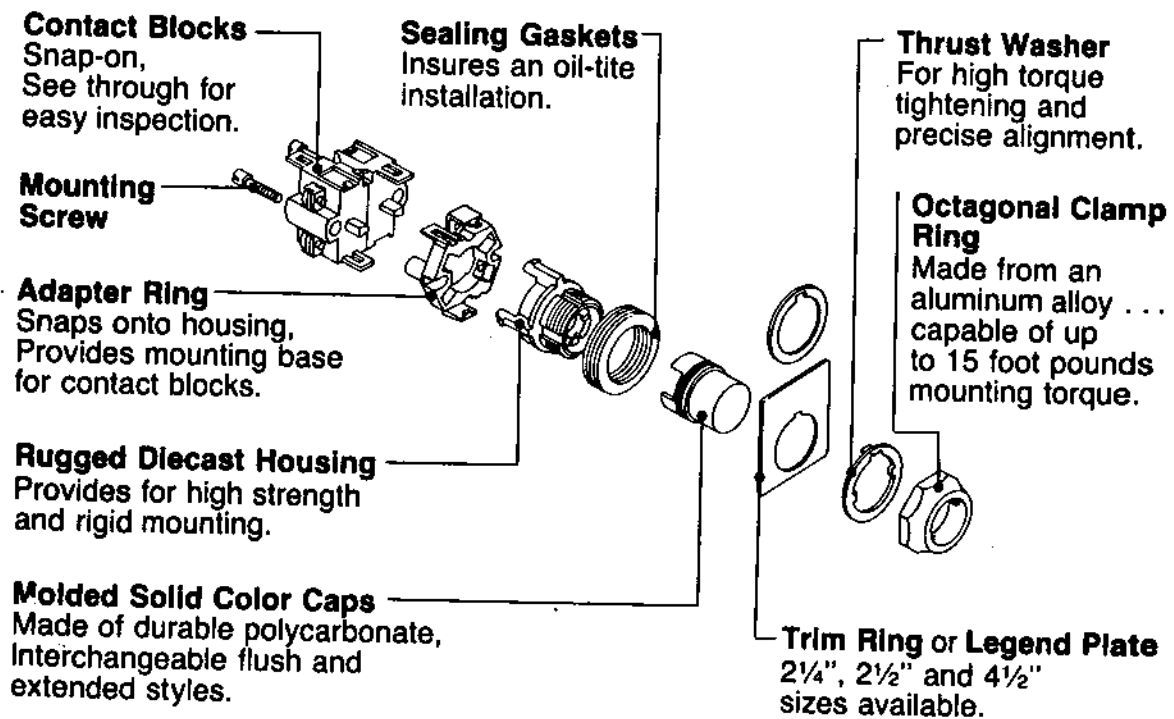


Fig. 2 – Exploded View of a Pushbutton

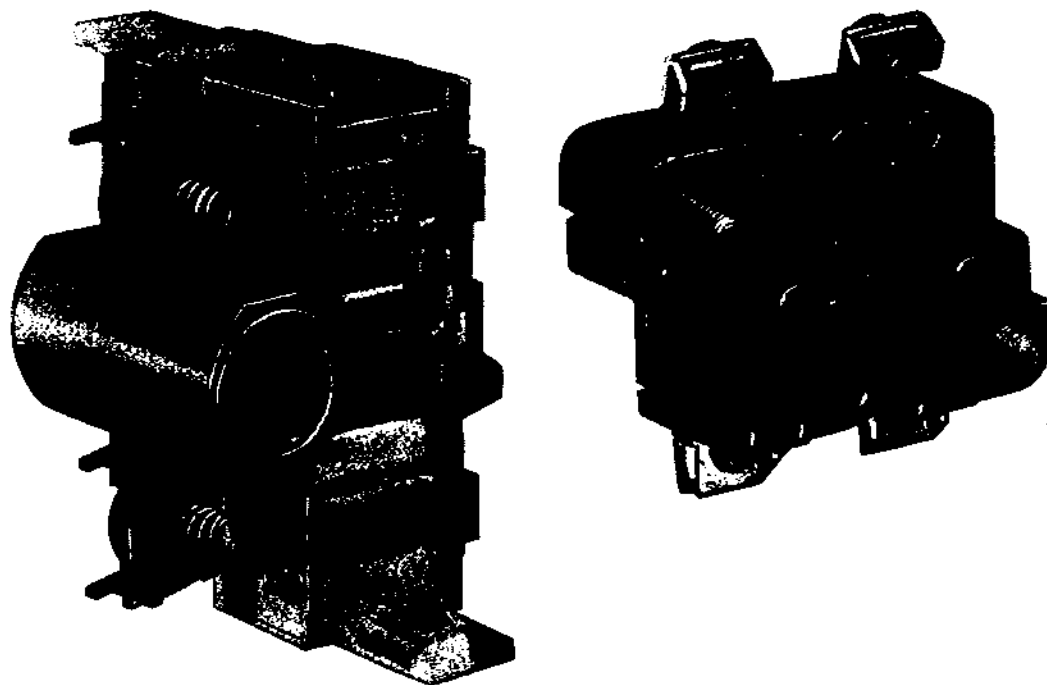


Fig. 3 – Typical Contact Blocks

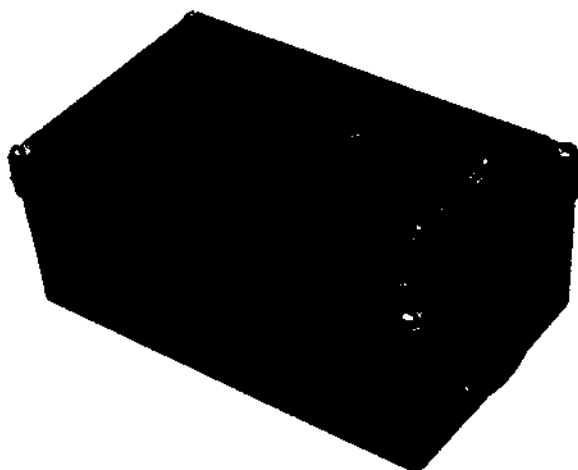


Fig. 4 – Die-cast Enclosure and Cover

3.1 Connection Diagrams for Pushbutton Stations

The great variety of devices and combinations makes any detailed treatment of wiring impractical for this book. In replacing units even in simple circuits, all wires should be carefully identified and marked and a sketch of all connections made before the old unit is disconnected. Electrical wiring should be performed only by experienced personnel who can read and interpret wiring diagrams. While color coding of wires is now the normal practice, wiring will be encountered that is not coded, here the possibility of making a wiring error is great. The replacement device should be double checked to make sure it is not designed to be wired differently from the original.

Two terms used in pushbutton control circuits have a fundamental significance in wiring because they call for different kinds of pushbuttons and produce greatly different results, they are low-voltage protection and low-voltage release.

Low voltage protection is provided by a device in the control circuit which functions to take equipment off the line when the voltage drops below a safe level. This device is usually built into the motor starter. The START pushbutton must be pushed to start the equipment after it has been taken off the line by this device as a result of a power interruption or a voltage drop. If there is line voltage present and it is above the low-voltage limit, the motor starter will pick-up and restore power to the machine. If not the low voltage relay will not remain closed and power will not be restored to the motor until voltage rises above the lower limit and the START button is again pushed. This scheme requires a pushbutton with normally open (NO) contacts.

Low voltage release operates in the same way as low voltage protection except that the power to the motor will be restored automatically when the voltage rises above the low-voltage limit. This scheme requires a pushbutton with two sets of normally closed (NC) contacts.

This automatic restart is a very useful procedure in a plant where there is much motor operated equipment which runs unattended for long periods. Unless automatic restart were possible, a brief interruption would result in considerable down time while each motor was being manually started. Attention must be given to assure that automatic restart is safe.

These two types of control circuits, shown in Figures 5 and 6, are commonly used, but there are many other control schemes in use and the potential for variation is almost limitless. The pushbutton and selector switch symbols shown in Figure 7 will be helpful in interpreting switches on drawings.

A pushbutton or switch does one of two things, it makes or breaks a circuit. The ability to make or break more than one circuit at the same control station is very useful when more than simple start and stop functions are required. Any combination of control sequences can be obtained by applying these two fundamental rules:

Wire all STOP buttons in series with the holding coil of the starter, with each other, and with the electrical interlock.

Wire all START buttons in parallel with each other and with the interlock.

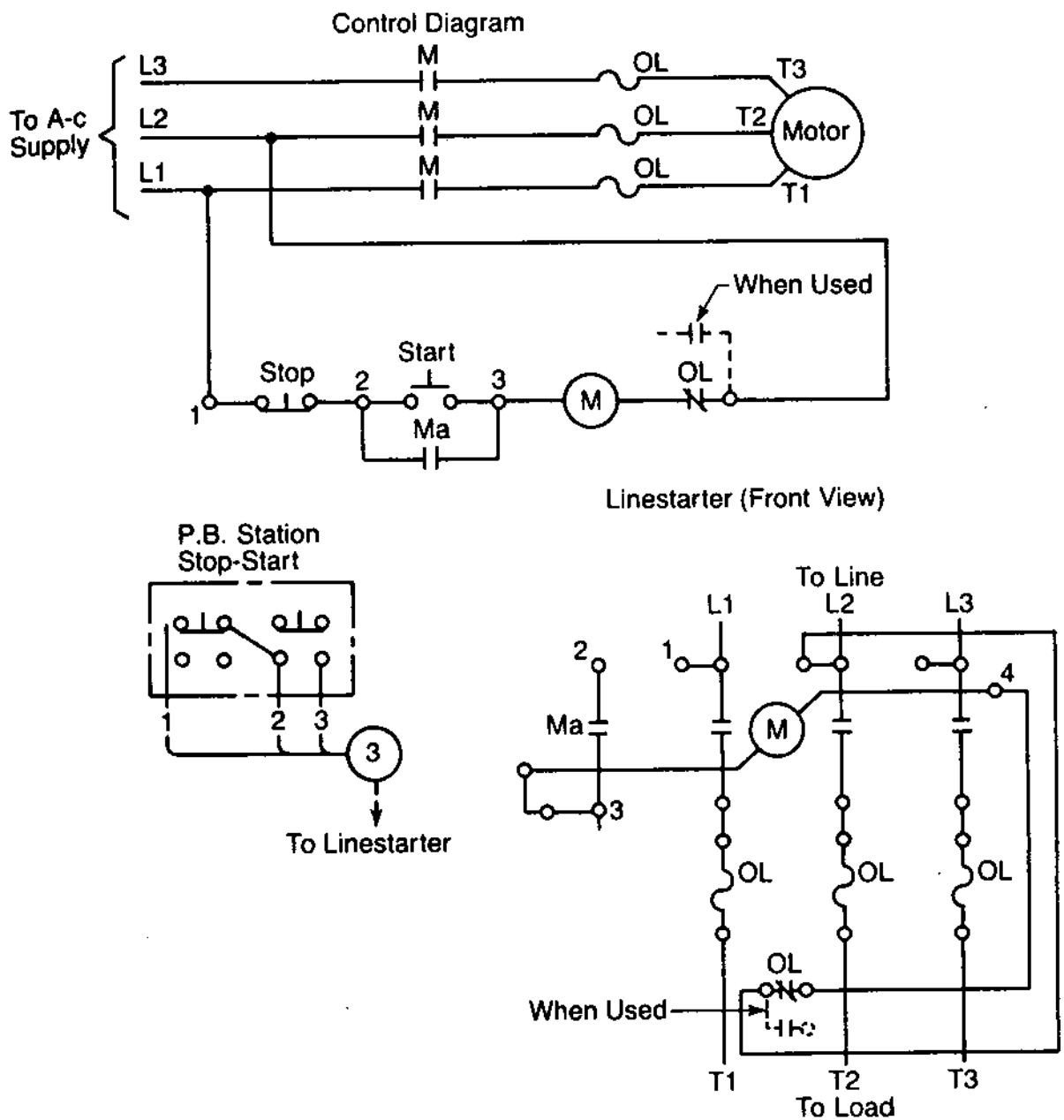


**Fig. 5 – Schematic—Buttons: Two Momentary-Contact
Circuit: Low-Voltage Protection, Single Station
Duty: Start-Stop**

Limit switches are governed by the same wiring rules that apply to pushbuttons. On many applications pushbuttons can be replaced by limit switches. Limit switches with normally closed contacts are similar to stop buttons, those with normally open contacts operate as start buttons.

Momentary contact limit switches, which are spring returned, can be used to provide low-voltage protection. Limit switches applied to low-voltage release circuits are snap action, maintained contact switches.

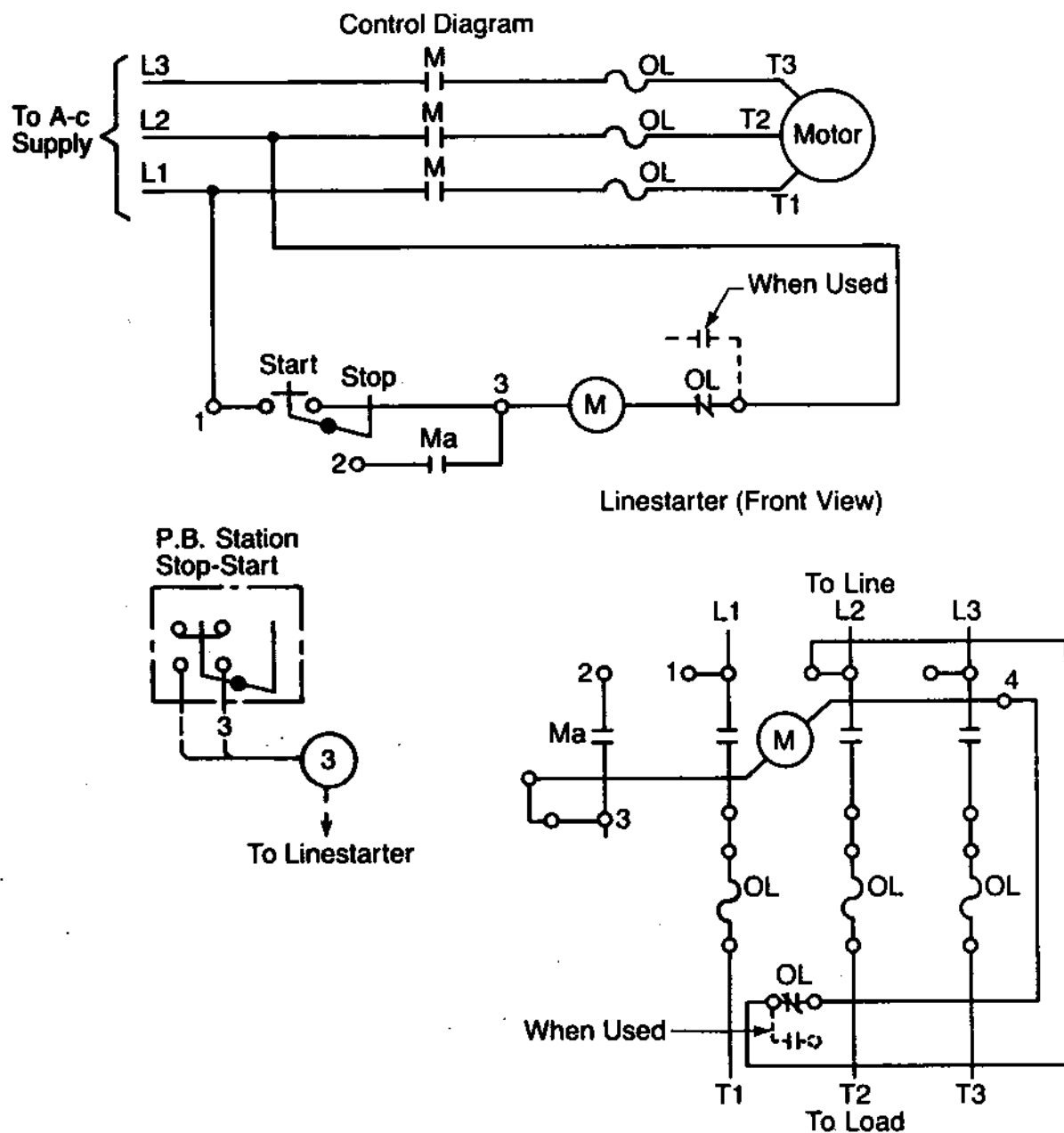


**Fig. 6 - Schematic—Buttons: Two Maintained-Contact
Circuit: Low-Voltage Release, Single Station
Duty: Start-Stop**

Description		Contact Symbol
Selector Switches	2 Pos. SPDT	
	2 Pos. DPST	
	3 Pos. SPDT	
	3 Pos. 2 SPST	
	3 Pos., 2M, 1M, 2B	
	3 Pos., 1M, 2B, 2M	
Pushbutton Units	1 NO, 1 NC, Black	
	3 Pt., Black	
	2 NO, 2 NC	
	Maintained Contact SPDT	

Fig. 7 – Pushbutton and Selector Switch Symbols

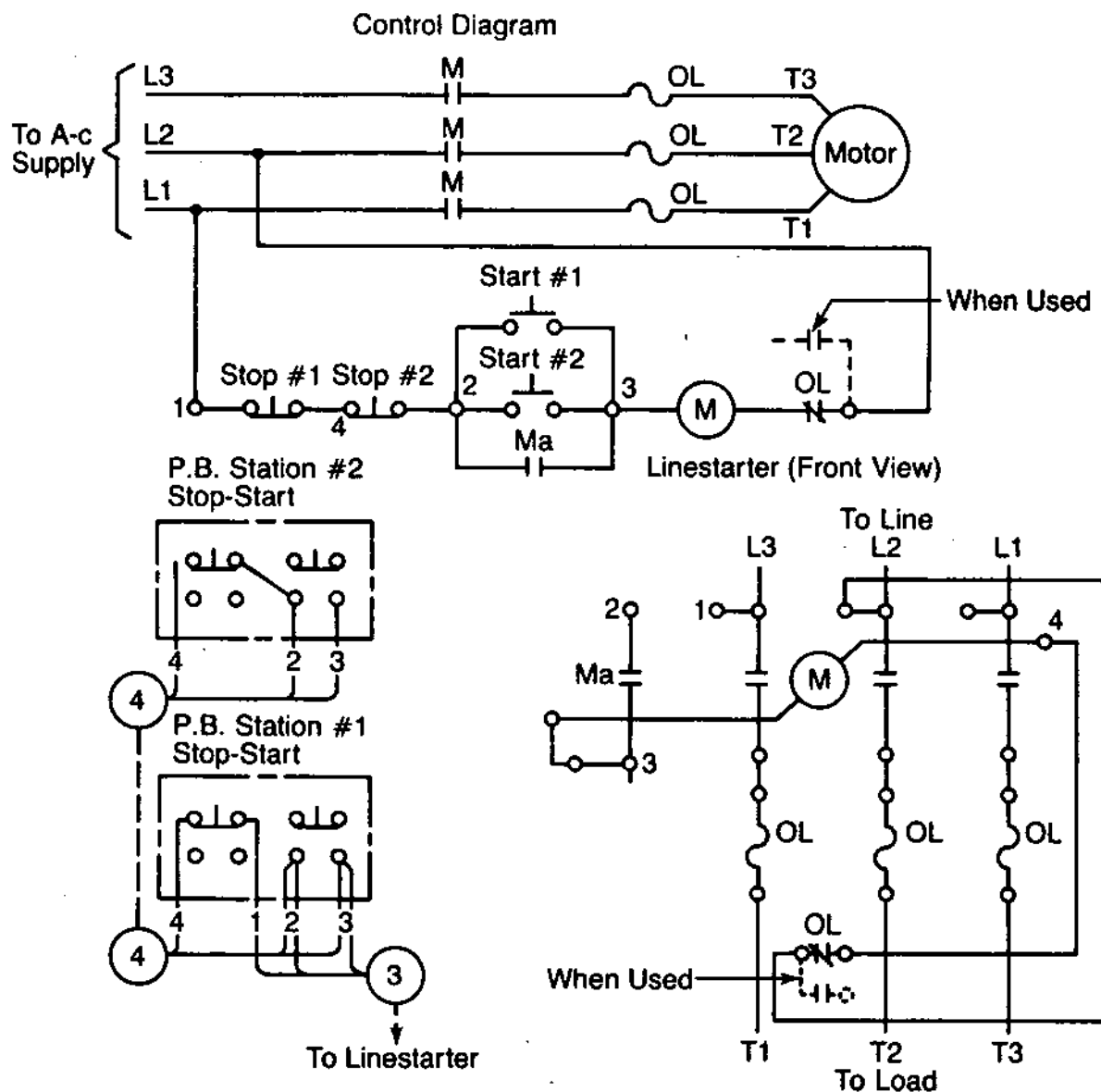


**Fig. 8 – Schematic—Buttons: Four Momentary Contact
Circuit: Low-Voltage Protection, Two Stations
Duty: Start-Stop**

Figures 8, 9, 10 are schematic diagrams of some control circuits which illustrate the variety of circuit designs that may be encountered. In these diagrams the number 1 designates the control lead which is wired to the stop button, number 2 is the common connection point for both the start and stop buttons, and number 3 is the terminal which completes the starting circuit. This scheme of number assignments may not hold true for all manufacturers but the holding interlock parallels the start button so regardless of numbers used for identification of switch connection points, the electrical interlock will be connected in parallel at points 2 and 3 for low voltage control of motors using a magnetic linestarter.

Figure 8 shows a motor which is controlled from two operators. The circuit uses two START-STOP pushbuttons wired as shown. The control scheme requires four momentary contact switches to provide low-voltage protection for the motor and provide start-stop operation from two

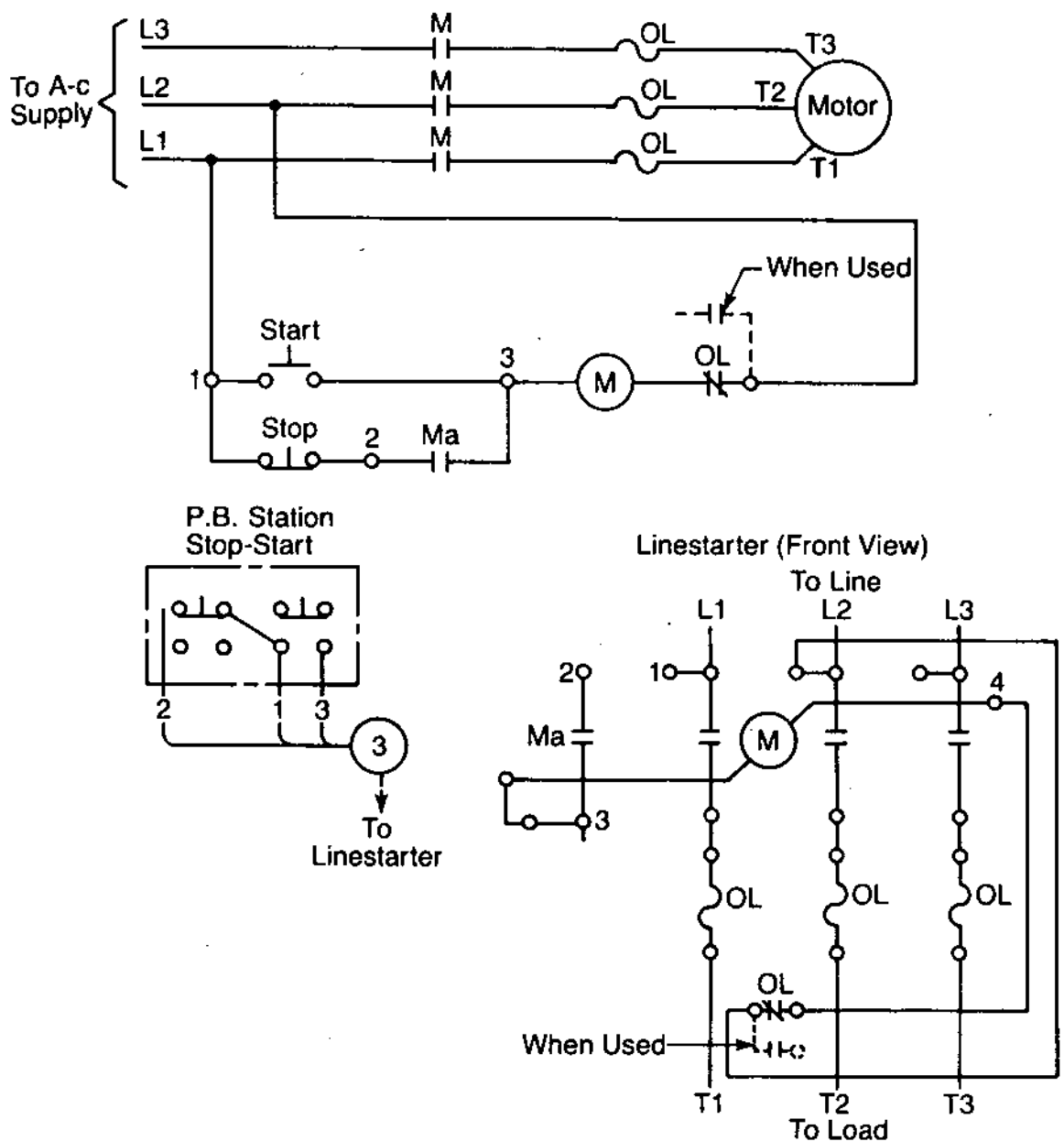


Fig. 9 – Schematic—Buttons: Two Momentary-Contact, One Open, One Closed and Latched

Circuit: Low-Voltage Protection

Duty: Start-Stop-or Inch (to Inch, Latch Stop Button and Operate Start)

locations. This is the kind of control circuit that would be used for a long conveyor or a dual control hoist.

Figure 9 shows a typical start, stop, inch control circuit with low-voltage protection. To perform this function from a single station requires a START-STOP pushbutton wired into the circuit as shown. The switch must have two sets of momentary contacts, one open, one closed with a latch. This circuit is widely used in applications where an operator must be able start then stop and cautiously advance (inch) some motor driven equipment. Application could be a hoist, conveyor, an annealing furnace door, or even an automatic machine tool.

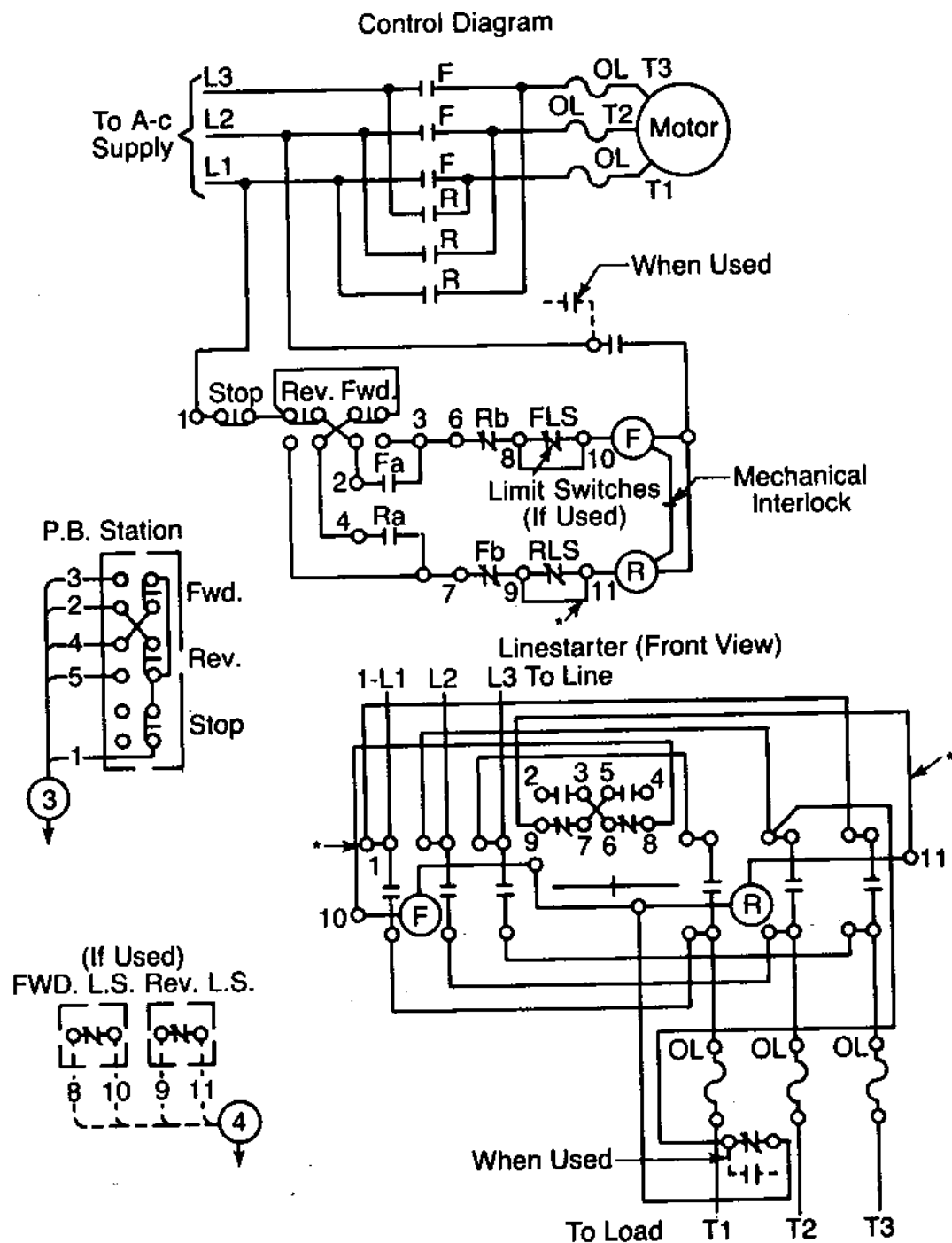


**Fig. 10 - Schematic—Buttons: Three Momentary-Contact
Circuit: Low-Voltage Protection with Electrical and Mechanical
Interlocks Plus Interlocking Pushbuttons
Duty: Forward-Reverse-Stop**

Figure 10 illustrates the growth in complexity of circuitry and numbers of devices as control functions are increased. This diagram shows how an operator control station is wired to obtain forward, reverse, and stop operation by grouping three pushbuttons.

The requirements in this instance are three sets of momentary contacts. They are wired to provide low-voltage protection in the usual manner by means of electrical interlocks plus interlocking through the contact arrangement specified for the pushbutton station. Note that certain jumpers must be removed when a combination forward-reverse line-starter is used with limit switches.

Caution: Re-check wiring after replacement of a control device or a new installation. Make continuity tests, inspect all connections before applying voltage.

Caution: Do not make changes in circuits or in wiring without making certain the changes will not harm the equipment. If there is any doubt, contact the manufacturer. This practice will not only protect the equipment, it will also not invalidate the warranty.

Molded Case Circuit Breakers

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Accessories, Modifications, Mounting 2:4.14

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Part 4 Verification of Manufacturer's Published Data 2:4.45

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Molded Case Circuit Breakers

A circuit breaker is defined in the National Electrical Code as “a device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a pre-determined overcurrent, without damage to itself when properly applied within its rating”. A molded case circuit breaker is one that is assembled as an integral unit in a supporting and enclosing housing of insulating materials.

Molded case circuit breakers are designed to provide circuit protection for low voltage distribution systems. They protect connected apparatus against overloads and short circuits.

Molded case circuit breakers are designed, built, and tested in accordance with NEMA, Underwriter's Laboratories, Inc., and other standards. They are designed to be applied in accordance with the National Electrical Code which under the Federal Occupational Safety and Health Act is mandatory.

Other standards with which compliance is required in various world markets include: British Standards Institute (BSI); German Standards (VDE); Canadian Standards Association (CSA); European Standards (IEC); and others.

4.1 Circuit Breaker Components

Establishment of these standards of design and application has lead to a uniformity of requirements in local building codes for safety and construction. There are many manufacturers of circuit breakers producing many different types, but they are all made from the same basic components; a molded case (frame), the operating mechanism, arc extinguishers and contacts, trip elements, and terminal connectors. Refer to Figures 1 and 2.

A. The Molded Case

The function of the molded case is to provide an insulating housing to mount and enclose the other circuit breaker components. These cases are made of reinforced phenolic or glass polyester to combine mechanical strength and high dielectric strength with compact design.

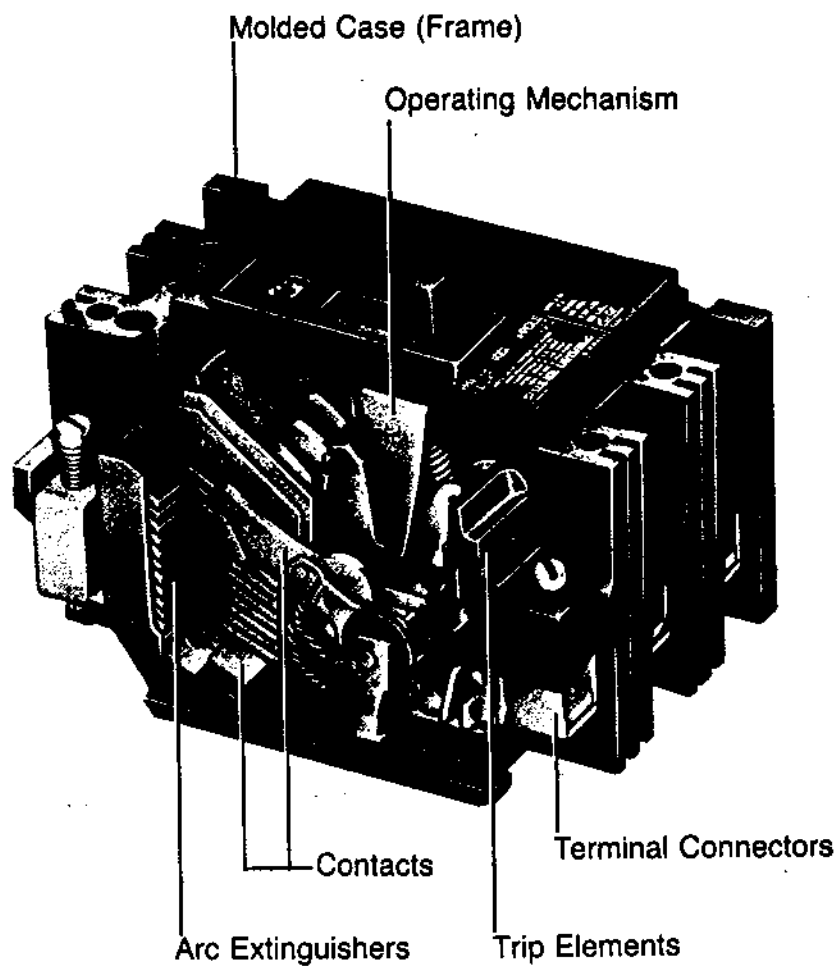


Fig. 1 – Cut-Away of a Typical Molded Case Circuit Breaker

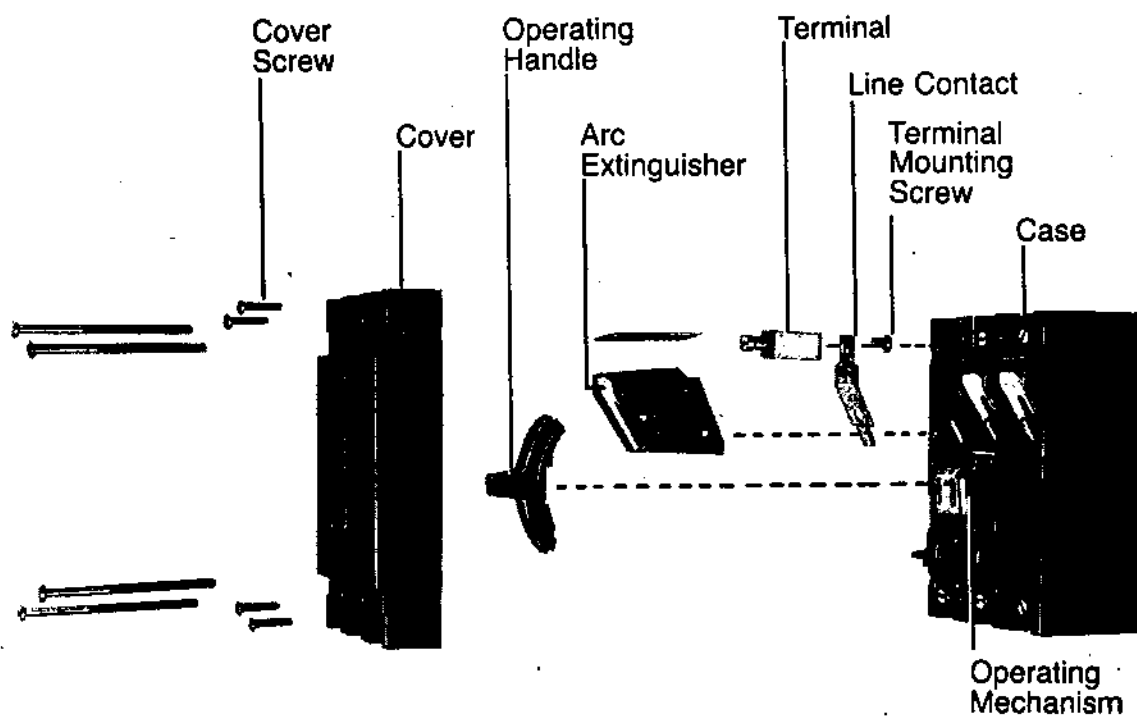


Fig. 2 – Basic Components of a Molded Case Circuit Breaker

Different types and sizes of molded cases are assigned identifying symbols which indicate characteristics such as maximum allowable voltage and current, interrupting capacity, and dimensions. There is no uniformity in these identifications between manufacturers because of the different characteristics of the breakers. For example, 400 ampere, 600 volt breakers supplied from two manufacturers might have different dimensions and different interrupting capacities.

B. Operating Mechanism

The operating mechanism opens and closes the breaker. This is a toggle mechanism of the quick-make, quick-break type in which the speed with which the contacts snap open or closed is independent of the speed with which the handle is moved.

This mechanism also provides a trip-free function which prevents the breaker from being held closed by holding the handle in the ON position.

The operating mechanism will hold the handle in a position midway between the off and on positions to indicate when the breaker has tripped.

C. Arc Extinguishers

The function of the arc extinguisher is to confine, divide, and extinguish the arc drawn between the breaker contacts when the breaker interrupts a current. The extinguisher consists of specially shaped steel grids isolated from each other and supported by insulating housing. When contacts are opened the arc drawn induces a magnetic field in the grids which draws the arc from the contacts into the grids. The arc thus split into small arcs is extinguished very rapidly. Refer to Figure 3.

D. Trip Elements

The function of the trip element is to trip the operating mechanism in the event of a prolonged overload or short circuit current. The trip element may be either electro-mechanical or solid state.

Bimetals and electromagnets are used in conventional breakers to provide overload and short circuit protection. Bimetals, heated by the sustained overload current will deflect due to the difference in the rate of thermal expansion of the two metals, thus tripping the breaker. Refer to Figure 4.



Fig. 3 – Arc Quenching Grid

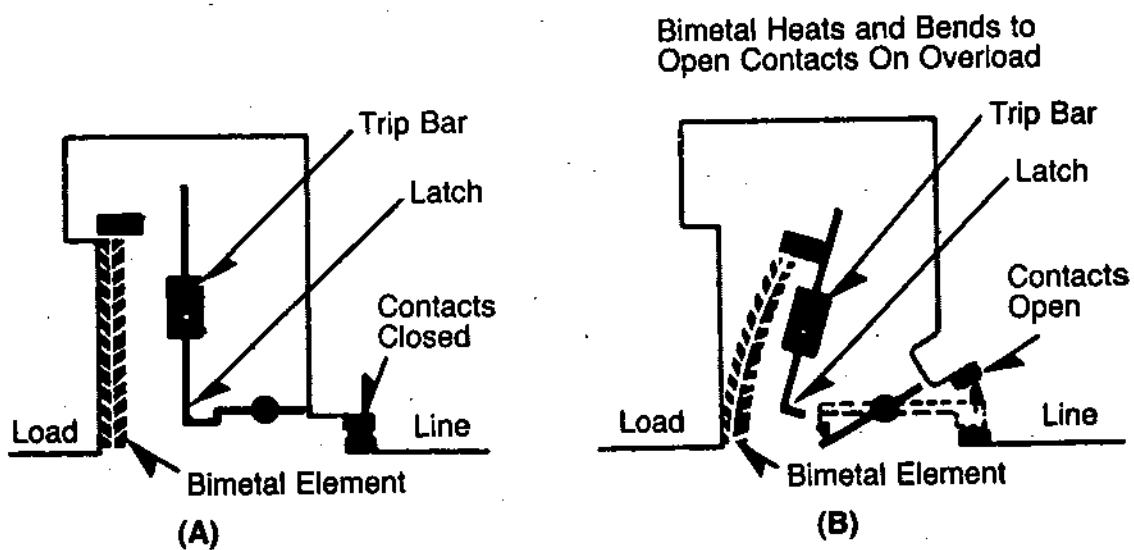


Fig. 4 – Thermal Action to Trip Breakers

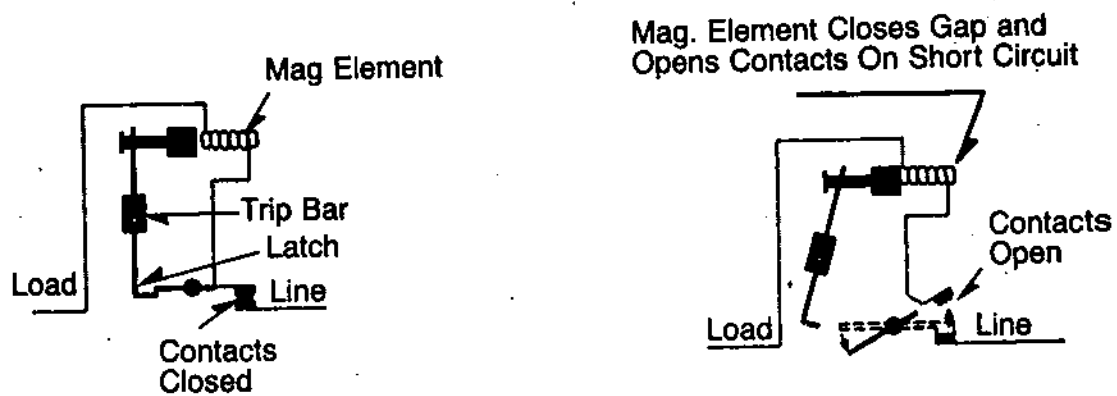


Fig. 5 – Magnetic Trip Action

Magnetic trip action is achieved when a short circuit passing through the electromagnet in series with the load current attracts the armature producing an unlatching action causing the circuit to open. Refer to Figure 5.

Thermal elements, bimetals, are calibrated at the factory and are not adjustable. The magnetic trip element is adjustable on some breakers.

Solid state trips are used in some breakers. They use current transformers and solid state circuitry which provides reliability and repeatability. Once the tripping point is established it remains constant. The breaker will trip at precisely that point time after time.

E. Terminal Connectors

The function of the terminal connector is to connect the circuit breaker to it's power source and load. There are various methods of connecting the line and load sides of circuit breakers, bus bars, panelboard straps, rear connected studs, plug-in adapters, etc. When conductors (cables) are used, terminals are used to make the connection. There are many sizes and types of terminals available to accommodate single or multiple conductors. Refer to Figure 6. Terminals are usually made of copper if they are to be used on copper conductors, or aluminum for use with either aluminum or copper. When aluminum conductors are used, joint compound is recommended to breakdown oxidation and assure better metal-to-metal contact which reduces heating.

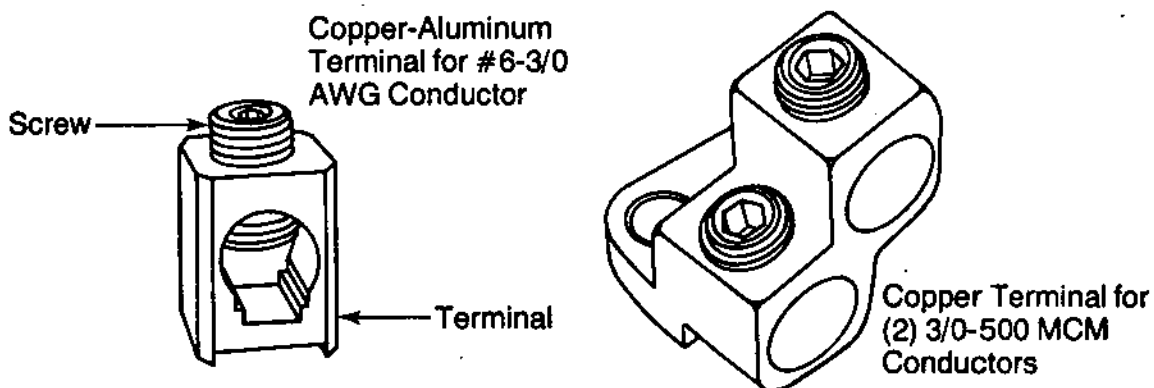


Fig. 6 – Terminal Connectors

Effective January 1, 1974 all UL listed multiple conductor terminals must be so constructed that each conductor can be tightened without removing another conductor. Figure 7 illustrates typical old and new terminal designs. Note that with the obsolete design conductors C and D cannot be tightened without removing conductors A and B, whereas in the new design any conductor can be tightened without disturbing any other. Both types of terminal design will be encountered in maintenance work.

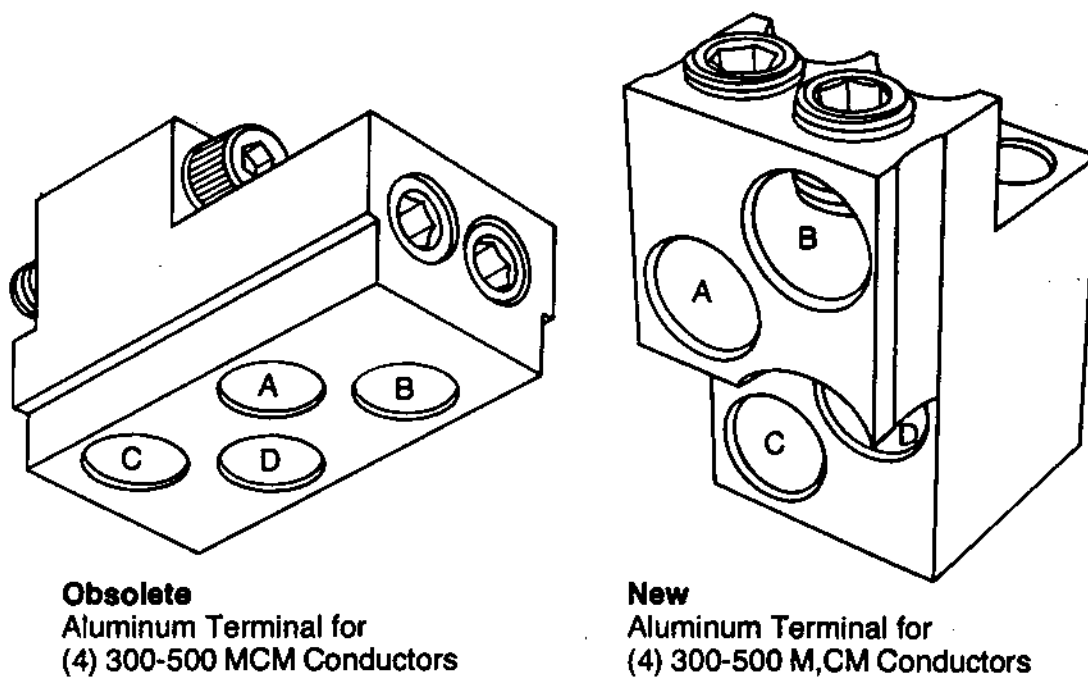


Fig. 7 – Old and New Terminal Designs

Warning: Check terminals frequently for tight connections. On a low voltage circuit the equipment may not operate properly or consistently if a voltage lead is loose. Leads carrying any appreciable current will overheat if there are loose connections, this heating produces further looseness. If two or more leads (particularly stranded wire) occupy the same terminal recess in a solderless connector, the effect of cyclic heating, and cooling could eventually cause them to loosen sufficiently to drop out or begin an arcing process in their socket.

4.2 Special Breakers

A. Systems Power Breakers

Systems power breakers are power rated molded case circuit breakers capable of interrupting 50 to 150 kA depending upon breaker size. They have high mechanical strength and require minimum maintenance. Contacts are replaceable in the field. Refer to Figure 8.

B. Magnetic-Only Breakers

Magnetic-only breakers, identified in the National Electrical Code as instantaneous type, are similar to standard thermal magnetic breakers except they do not have thermal trip elements. They provide short-circuit protection only. Refer to Figure 9.

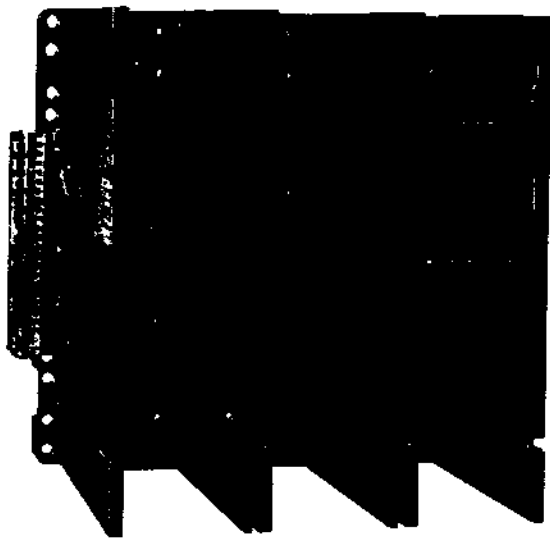


Fig. 8 - Systems Power Breaker

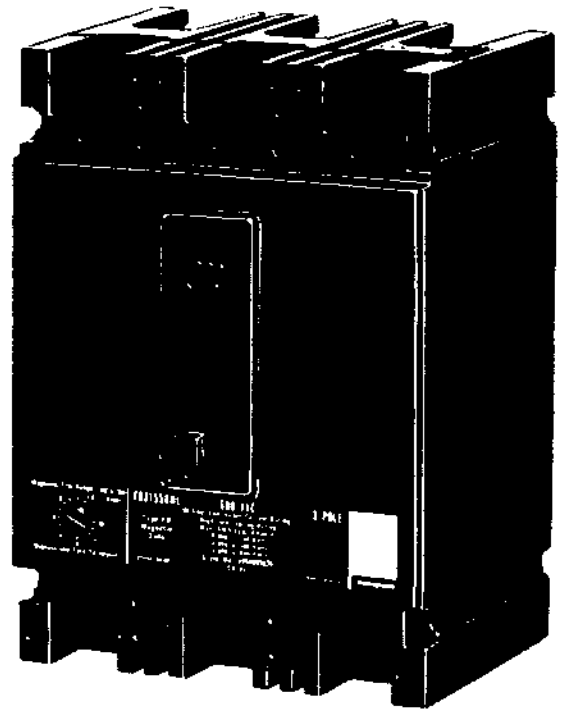


Fig. 9 - Magnetic-Only Breaker

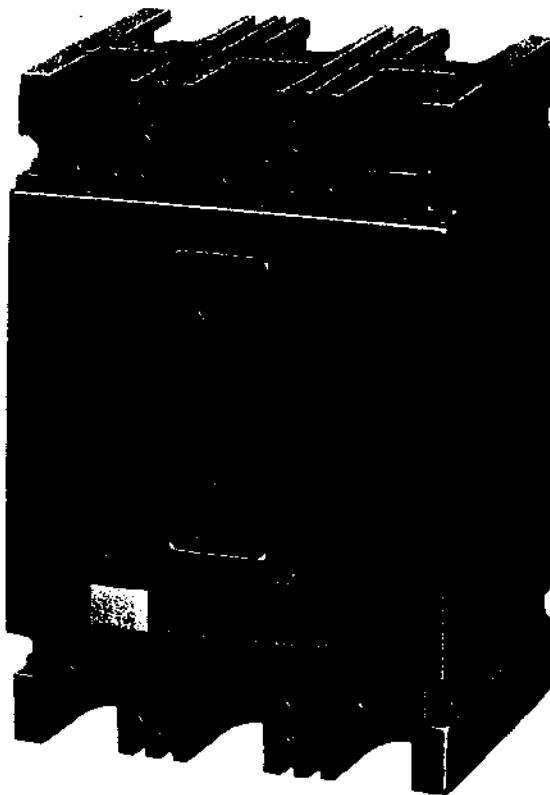


Fig. 10 - High Interrupting Capacity Breaker

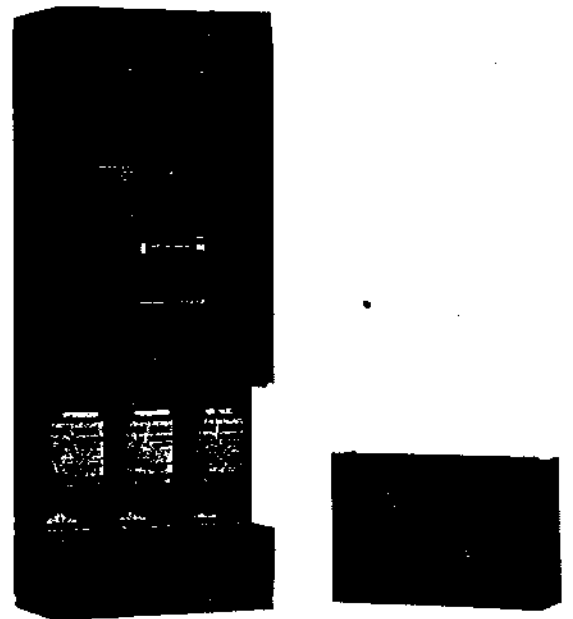


Fig. 11 - Integral Current Limiting Breaker

C. High Interrupting Capacity Breakers

High interrupting capacity breakers are similar to and the same size as standard thermal magnetic breakers but are especially designed to provide higher interrupting capacity. Refer to Figure 10.

D. Integral Current Limiting Breakers

Integral current limiting breakers are similar to standard thermal magnetic breakers except a current limiting device is incorporated. It can be used in distribution systems where fault currents as high as 200,000 symmetrical RMS amperes are possible. Refer to Figure 11.

E. Non-Automatic Breakers

Non-automatic breakers, molded case switches, contain neither thermal nor magnetic trip elements and will not trip on overloads or faults. They function as compact, high capacity disconnects.

F. Dual Voltage Breakers

Dual voltage breakers are a method of using one circuit breaker with one trip rating to protect dual voltage equipment with different current ratings for each voltage rating. These breakers have two sets of load terminals with the second set referred to as center tap studs. Circuit breakers cannot be modified for dual voltage operation in the field. Refer to Figure 12.

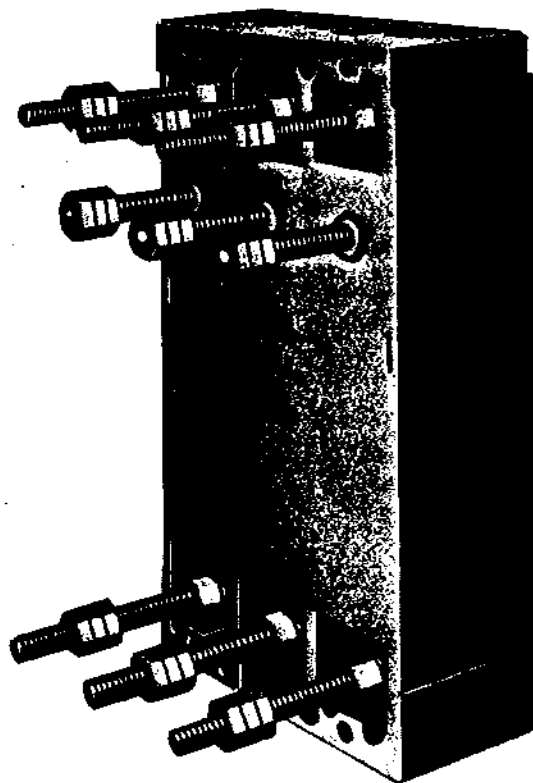


Fig. 12 – Dual Voltage Breaker

G. Mining Service Breakers

Mining service breakers are strengthened internally and externally, they are tested in accordance with the Federal Register and for more than 10,000 tripping operations. Refer to Figure 13.

H. Breakers with Paralleled Poles

Breakers with paralleled poles are made by the addition of external straps at the line and load ends. There is also an internal strap ahead of the trip elements to assure an equal division of current. Refer to Figure 14.

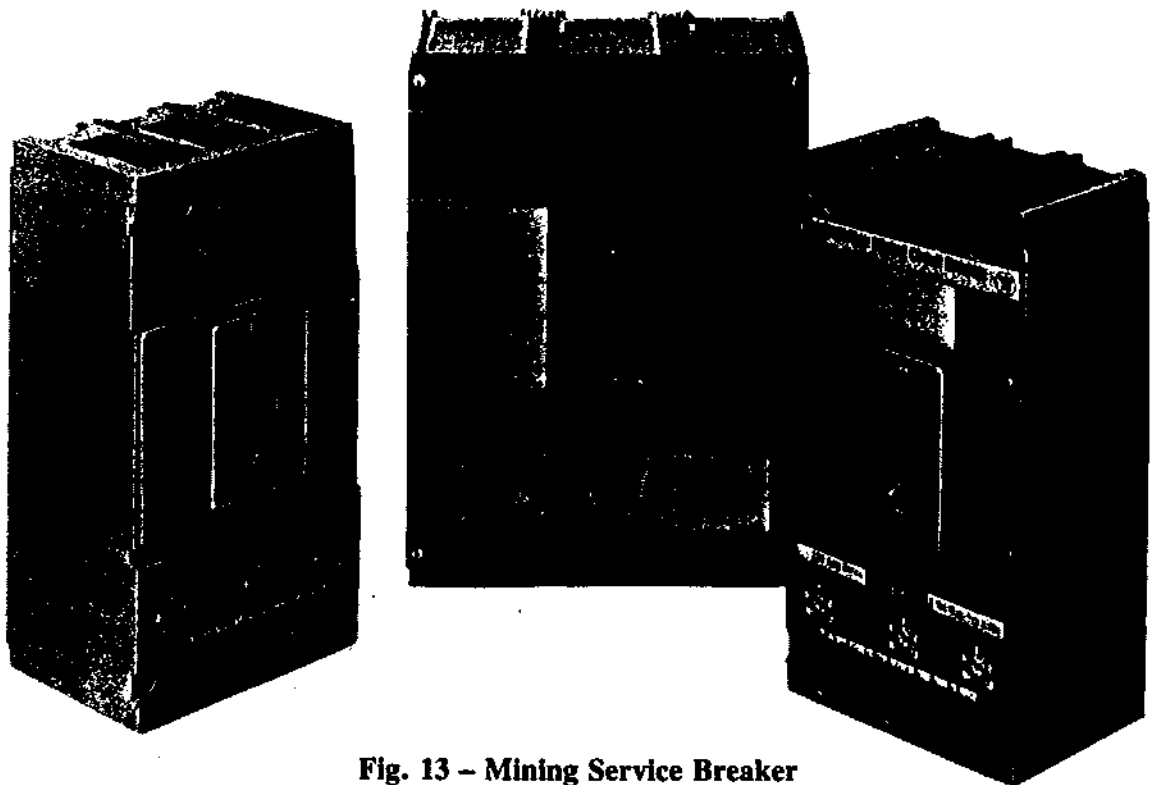


Fig. 13 – Mining Service Breaker

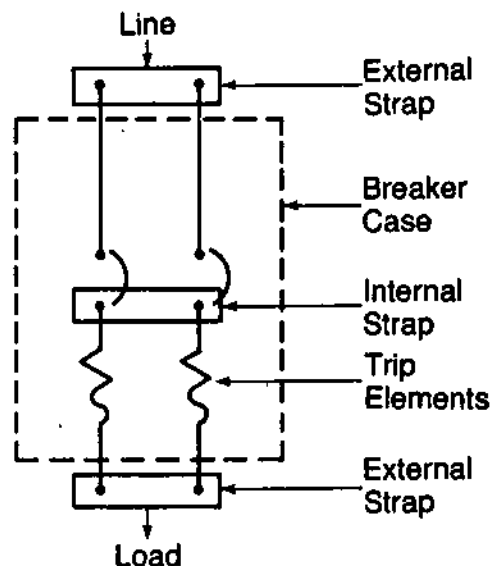


Fig. 14 – Breakers with Parallel Poles

I. Field Discharge Breakers

A field discharge breaker is a three-pole non-automatic breaker with contacts arranged so when the two outside poles are opened the center pole is closed. This breaker is used exclusively to discharge the field of a direct-current motor or generator, usually through a resistor. Refer to Figure 15.

J. Special Breakers for SCR Power Supplies

These drawout mounting breakers are designed with a 2 or 4 times magnetic trip adjustment and special time delay trip characteristics to specifically provide maximum protection and coordination with SCR power supplies on offshore drilling rigs. Suitable for application at 100% of rating.

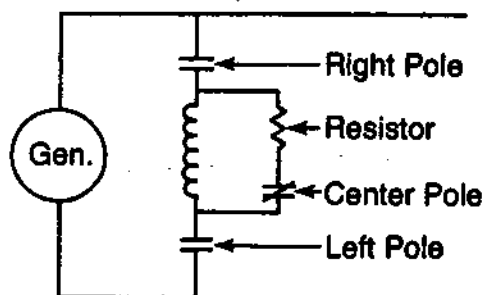


Fig. 15 - Field Discharge Breaker - Typical Circuit Application

K. Switching Neutral Breakers

As with the case of the delta breaker, the switching neutral breaker is a standard breaker with a special pigtail terminal. NEC Article 514-5, which covers gasoline service-station pumps, states that "each circuit leading to or through a dispensing pump or island shall be provided with a switch or other acceptable means to disconnect simultaneously including the grounded neutral if any." Figure 16 shows a standard connection for a single phase, three-wire system using a switching neutral breaker.

L. 1000 Volt Breakers

These breakers are identical in size with the standard 600 volt breakers but are modified to suit 1000 volt applications. The largest application of 1000 volt molded case circuit breakers is in the underground coal mining industry. They are available up to 2000 amperes with 10,000 amperes symmetrical interrupting capacity. They can be supplied with thermal magnetic trip units, or magnetic only trip units.

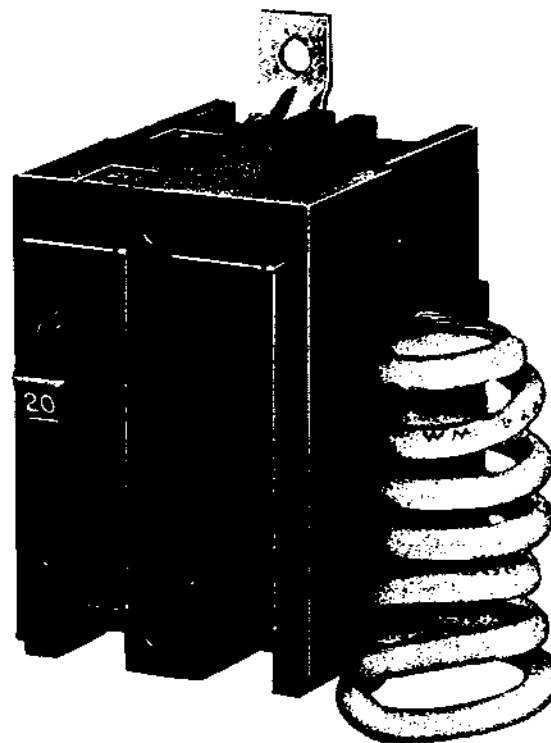
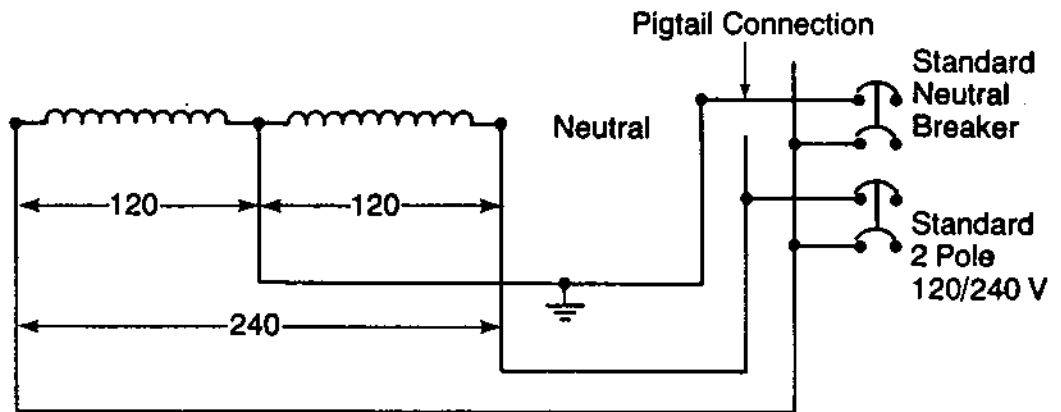


Fig. 16 – Switching Neutral Breaker and Connection of a Switching Neutral Breaker

M. Visible Contact Breakers

Visible contact breakers are similar to molded case breakers except that they are equipped with a window of transparent, heat-resistant thermo-plastic over the breaker contacts. This permits instant, visual verification of whether the contacts are open or closed. This fulfills the needs of industrial plants where safety codes require visible contacts as an additional safety precaution for maintenance personnel. The steel industry is the largest user of these breakers. These breakers can be supplied with thermal magnetic, magnetic only, or ambient compensating trip elements to cover a wide variety of applications. Refer to Figure 17.



Fig. 17 – Visible Contact Breaker

N. Motor Circuit Protectors

Motor circuit protectors function to clear low level faults in motor circuits before they can cascade to high level faults. These devices operate on a magnetic principle with a specially designed current sensing coil in each of its three poles to provide sensitive low level protection of motor circuits. These devices are rated to correspond to NEMA starter sizes and comply with NEC requirements. Clearing time is much shorter than conventional dual element fuses. Refer to Figures 18 and 19.

O. Current Limiter Attachments

Current limiter attachments can be used to increase the interrupting capacity of some circuit breakers to as high as 200,000 amperes symmetrical at up to 600 volts. When the limiter interrupts a fault an indicator on each pole identifies the faulted phases. See Figure 20.

Warning: Correct the circuit fault indicated by a blown current limiter before restoring service. Failure to do so can result in severe personal injury and property damage.

P. Ground Fault Circuit Breakers

Ground fault circuit breakers are single pole thermal magnetic breakers which incorporate solid state ground fault sensing circuits to detect

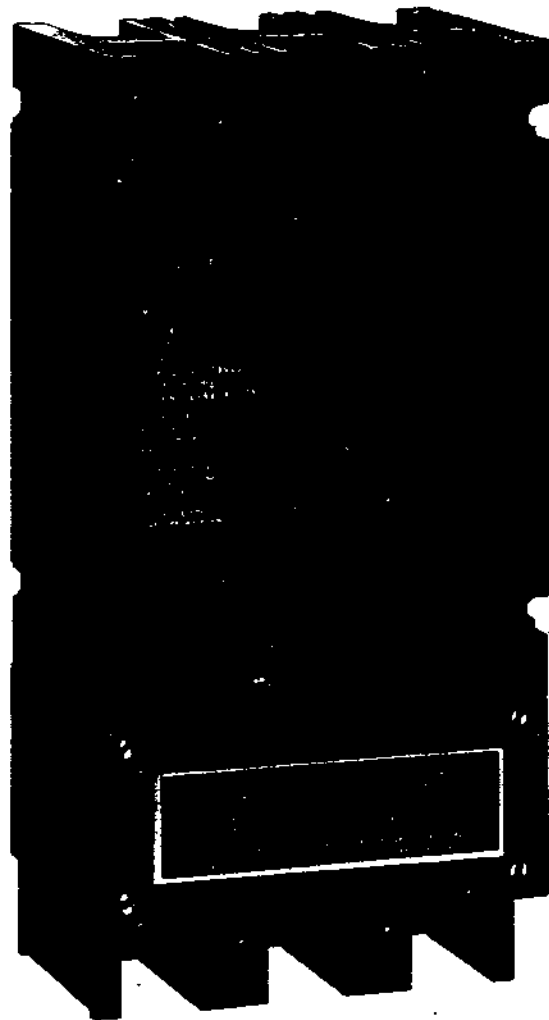


Fig. 18 – Motor Circuit Protector with Current Limiter Attachment

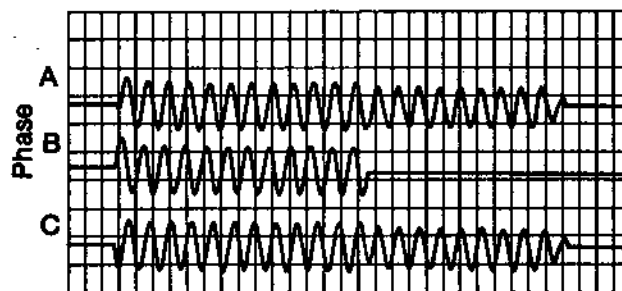


Fig. 19 – Locked Rotor Test Oscillogram

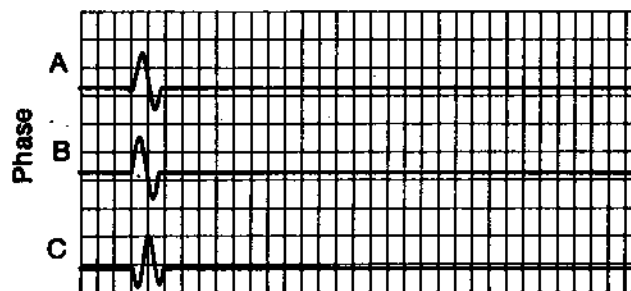


Fig. 20 – Clearing Time for Typical MCP (Less Than One Second)

ground currents. The function is to protect personnel from ground faults of five milliamperes or more as well as to provide overload and short circuit protection. Refer to Figures 21 and 22.

4.3 Accessories, Modifications, Mounting

There are many accessories, modifications, and mountings available for circuit breakers, some of the more frequently encountered are shown here.

A. Shunt Trip

This device is used to trip a circuit breaker from a remote location electrically. It consists of a momentary rated solenoid tripping device mounted in the breaker. The solenoid must be energized by some control power source with voltage up to 250 volts direct current or up to 600 volts alternating current. When the solenoid coil is energized from a remote location using some electrical pilot device (such as a pushbutton) the plunger moves to activate the trip bar of the breaker. At the same time a cut off switch opens the circuit to the solenoid coil. Refer to Figure 23.

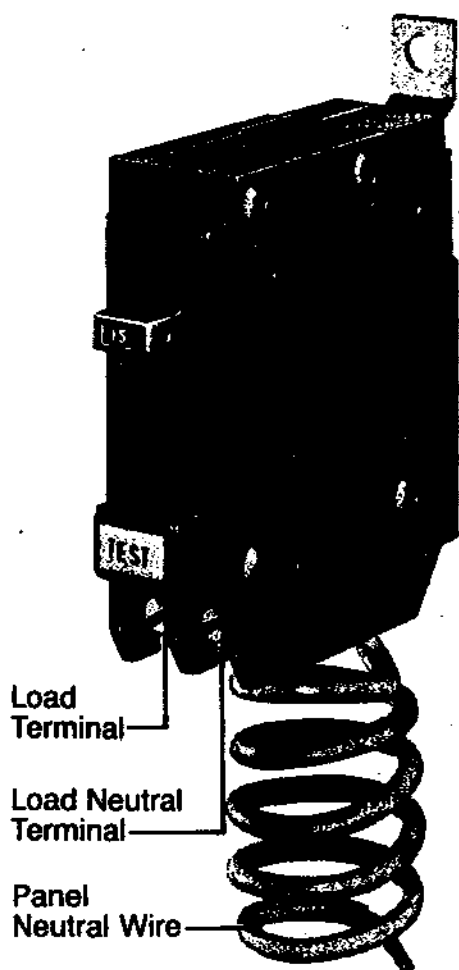


Fig. 21 - Ground Fault Circuit Breaker

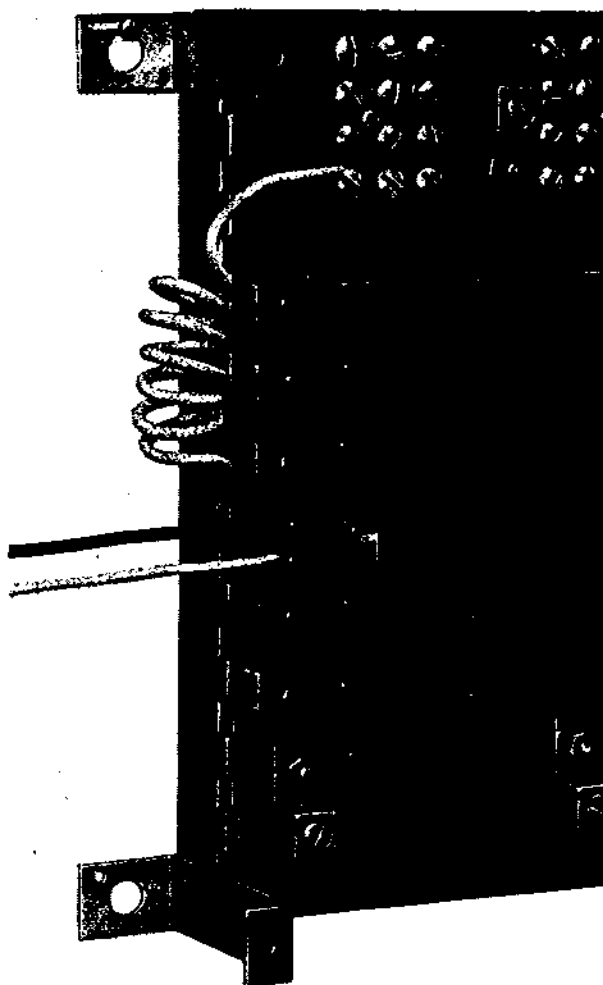


Fig. 22 - Ground Fault Circuit Breaker Installed

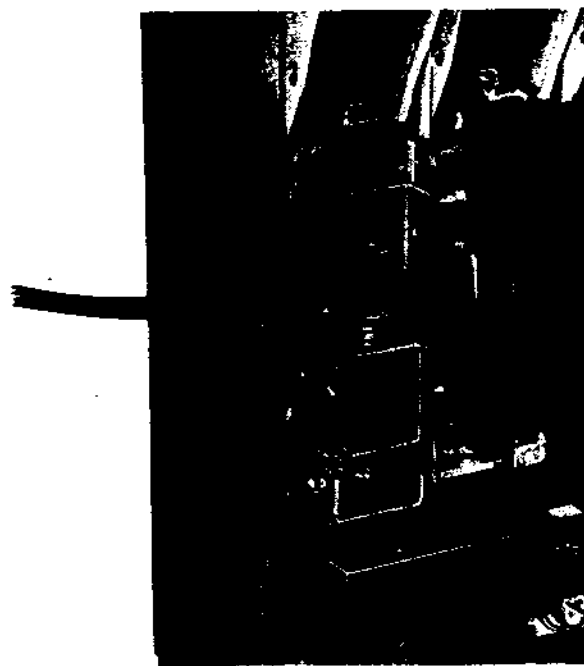


Fig. 23 – Typical Shunt Trip Installation

Caution: The shunt trip cannot be used to operate the breaker, it is a means of remotely tripping only. To re-close, the breaker handle must first be moved to the RESET position, then to the ON position.

Some examples of application of shunt trips are:

Example 1

When ground fault protection equipment is used, it is necessary to trip the breaker when a dangerous level of phase to ground current is sensed. The most practical method of doing this is by means of a shunt trip. Figure 24 shows a ground fault protection system. When a ground fault occurs, the ground fault current is reflected in the output of the current monitor and is applied to the static sensor unit which will activate the shunt trip and cause the breaker to trip (open) and clear the ground fault.

Example 2

The high, frequent cycling of welding machines makes normal thermal overload protection by a circuit breaker impractical. As a result, some welding machines are equipped with a temperature-sensitive element called a thermistor which is imbedded in the windings of the machine to provide overload protection. The thermistor is supplied as a normally open contact which will close when the welding machine reaches a pre-set temperature. To disconnect the power on an overload the thermistor is electrically connected to a shunt trip in a magnetic-only circuit breaker. The welding machine is protected from short circuit faults by the breaker, and from overloads by the thermistor. Refer to Figure 25.

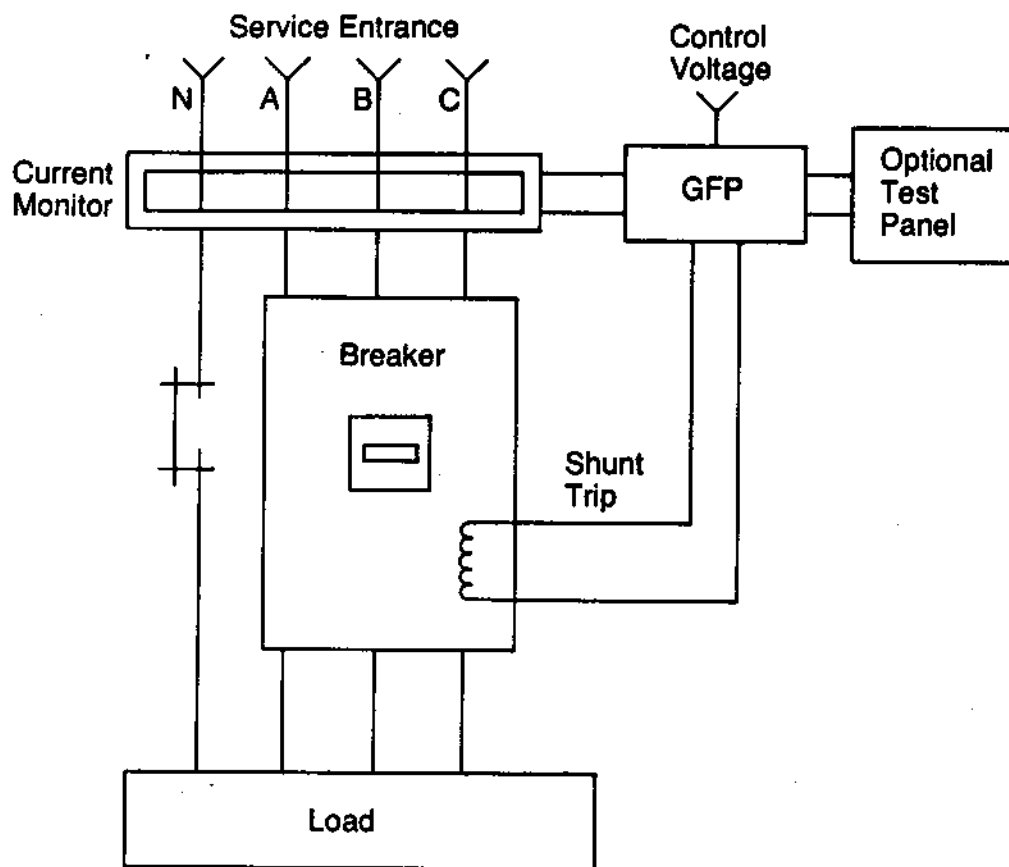


Fig. 24 – Ground Fault Protection System with Shunt Trip

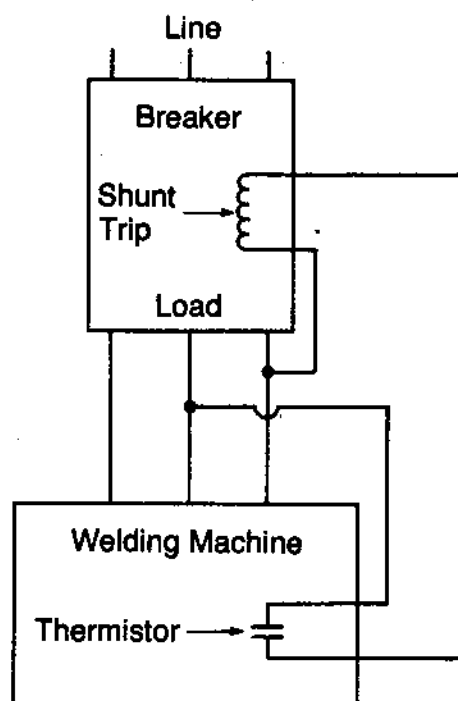


Fig. 25 – Welding Machine Protected by Magnetic Only Circuit Breaker and Thermistor

B. Undervoltage Release Devices

Undervoltage release devices trip the breaker when the voltage falls below a predetermined level. There are two types of standard undervoltage releases available: automatic reset and handle reset.

The electro-mechanical automatic reset undervoltage release consists of a spring and solenoid mounted inside the circuit breaker. The spring is cocked or precharged through the contact mechanism when the breaker trips or opens and is held cocked by the solenoid coil. When the voltage falls below 40 to 60 percent of the solenoid coil rating, the solenoid will initiate tripping of the breaker by releasing the spring. The breaker cannot be turned on until the voltage returns to 80% of normal. They are normally available for voltages up to and including 250 volts d-c and 600 volts a-c. Refer to Figure 26.

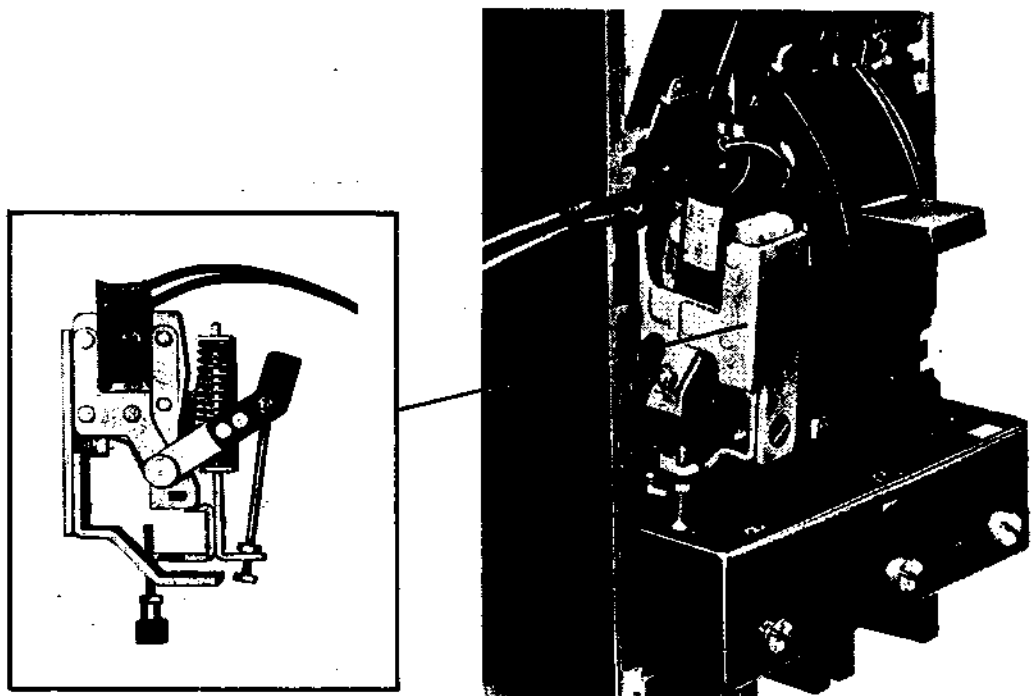


Fig. 26 – Electromechanical Undervoltage Release Device

The handle reset undervoltage release spring is cocked or pre-charged through the breaker handle mechanism. The major advantage of this type is that the breaker mechanism cannot even be latched when there is no power on the UVR coil. This eliminates breaker mechanism damage. This UVR is used in all standard and 1000 volt mining service breakers. Refer to Figure 27.

One of the big advantages of the undervoltage release is that it is fail-safe, i.e. power is not required to trip the breaker, just a loss of power. (The shunt trip must have power to trip the breaker.) The electro-mechanical automatic reset type UVR is field mountable in most industrial breakers. Standard leads extend 18 inches out the side of the breaker on both types.

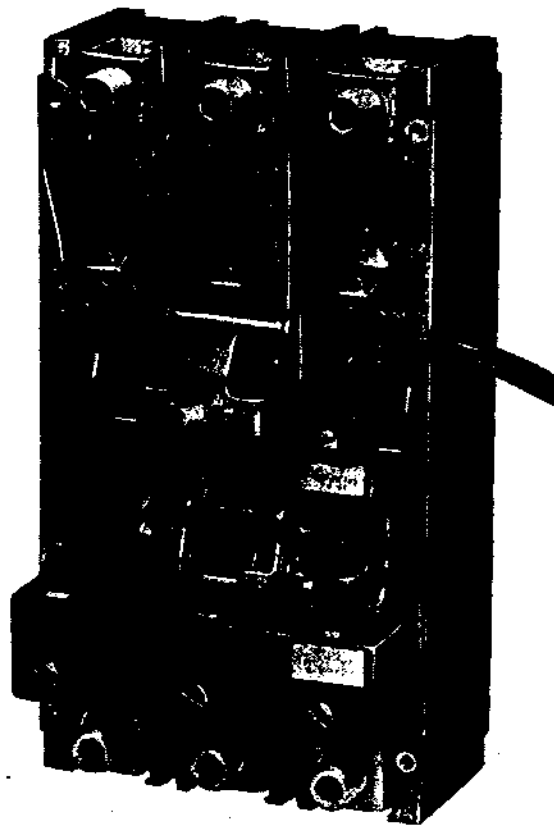


Fig. 27 – Handle Reset Undervoltage Release Device

One of the most common applications of undervoltage releases on circuit breakers is in underground coal mines. Due to the long trailing cables from the power supplies to the mining equipment, low voltage conditions are common. To protect personnel and equipment when this condition occurs, the circuit breaker trips and cannot be energized until power has been restored (75-80 percent of coil rating). Protection of this nature is specified by the U.S. Bureau of Mines.

C. Auxiliary Switches

Auxiliary switches (extra contacts) consist of normally open and/or normally closed contacts, mounted in the breaker, that can open or close when the breaker is opened or closed. To provide positive, identification the contacts are defined as A contacts which are open when the breaker is open or tripped; and B contacts which are closed when the breaker is opened or tripped.

These contacts are rated for pilot duty at 120 volts. They typically are in the form of small single-pole double-throw snap switches providing Normally Open and Normally Closed contacts within the same housing. Auxiliary contacts are field mountable on most industrial breakers.

Auxiliary switches are connected in control circuits whenever it is desirable to indicate whether the breaker is opened or closed. Here are three examples:

- (1) Indicating lights are occasionally mounted on switchboards to furnish a visual indication that the circuit is energized. If an indicating light is to be lit whenever a breaker is closed, this would require one A contact.
- (2) There are some applications where it is desirable to have an indicating light (red) lit when the breaker is closed and another indicating light lit (green) when the breaker is open. This would require an A and B contact. Figure 28 illustrates a typical auxiliary switch.
- (3) The National Electric Code (Article 430-74A) requires that motor control circuits be disconnected from all sources of supply when the disconnecting means is in the open position. The disconnecting means may be either common disconnecting of power and control circuits or disconnecting by means of adjacent switches. If a separate control source is used, a standard breaker will only disconnect the power source and not the control source. Therefore, one method of meeting this requirement would be to mount a separate disconnect switch adjacent to each breaker. Another, perhaps easier method, would be to connect the control circuit to an A contact in the breaker. Refer to Figure 29.

D. Alarm Switches

Alarm switches differ from auxiliary switches in that they function only when the breaker trips automatically – not with the manual operation of the breaker handle. An alarm switch consists of “normally open” contacts that close when the breaker trips due to an overload condition, short circuit, or operation of a shunt trip. The “normally open” contacts can be placed in a circuit with an indicating light, a buzzer, or a bell to provide an audio/visual warning by closing and completing the circuit when the breaker trips. Standard leads extend 18 inches outside the breaker. The alarm switch is not field mountable. Refer to Figure 30.

E. Motor Operators

Motor operators provide for complete remote control by means of a pushbutton or other pilot device. Positive switching action is accomplished by use of an operating arm engaging the breaker handle. When the motor operator is energized from a remote location, the operating arm moves the breaker handle to either the ON or OFF position. At the same time, an internal cutoff switch opens the circuit to the motor pre-



Fig. 28 – Typical Installation of an Auxiliary Switch

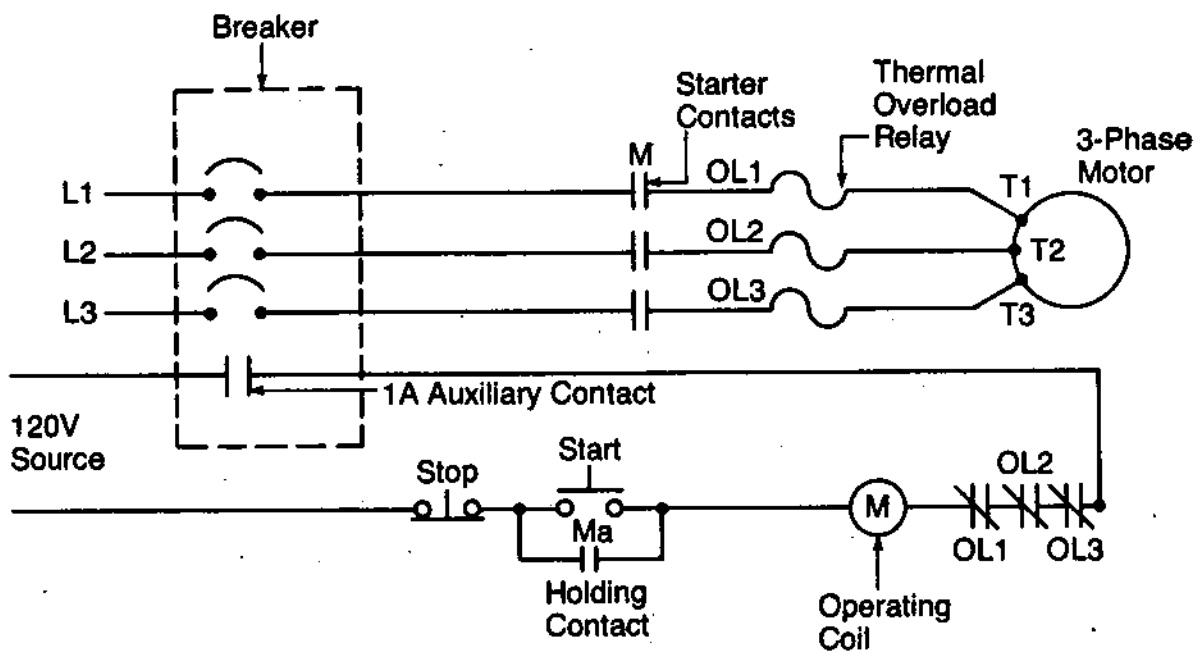


Fig. 29 – Combination Motor Starter with Auxiliary Contacts to Disconnect Separate Power Source

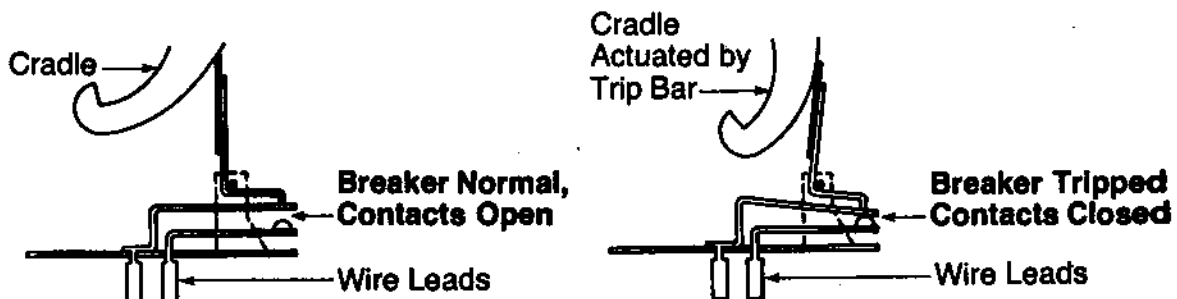


Fig. 30 – Alarm Switch

venting damage. In case of a power failure or some other emergency, means are provided for manual operation. Refer to Figure 31.

The motor operator is not intended to increase the number of operations of the breaker. It is intended only for infrequent operation in line with UL endurance standards for molded case breakers.

F. Mechanical Interlocks

Mechanical interlocks There are several methods of mechanically interlocking circuit breakers. Each method, although somewhat different, achieves the same result: it interlocks two breakers so that only one may be closed (ON) at a time, yet both may be open (OFF) simultaneously. The three most common types of mechanical interlocks are the walking beam, sliding bar, and key interlock.

The walking beam type interlock (see Figure 32) operates on a walking beam or teeter-totter principle. An insulated plunger extends inside at the rear of the breaker and blocks the closing mechanism of one breaker when the other breaker is in the closed position. The closed breaker must be open before the open breaker may be closed. Circuit breakers for use with walking beam interlocks require special machining and are always ordered directly from the factory.

The sliding bar type interlock (see Figure 33) mounts on the panel in front of two breakers. When the bar is extended toward one breaker blocking the handle in the open position, the opposite breaker can be closed. The closed breaker must be opened and its handle blocked with the sliding bar before the opposite breaker can be closed. Most breakers do not require alteration for use with this attachment.

The key interlock (see Figure 34) mounts directly to the breaker cover. Its plunger is extended by turning the key in the cylinder, thereby blocking the breaker in the open position. Various keying arrangements can be supplied: key removable only when plunger extended; or key removable when plunger either extended or retracted. This enables an electrician doing maintenance work to lock a breaker in the off position, remove the key and not worry about someone accidentally energizing the breaker.

A pair of breakers, remote from each other, can be interlocked so that only one can be closed at a time by using key interlocks operable by the same key, and key removable only when plunger is extended. These interlocks cannot be field mounted.

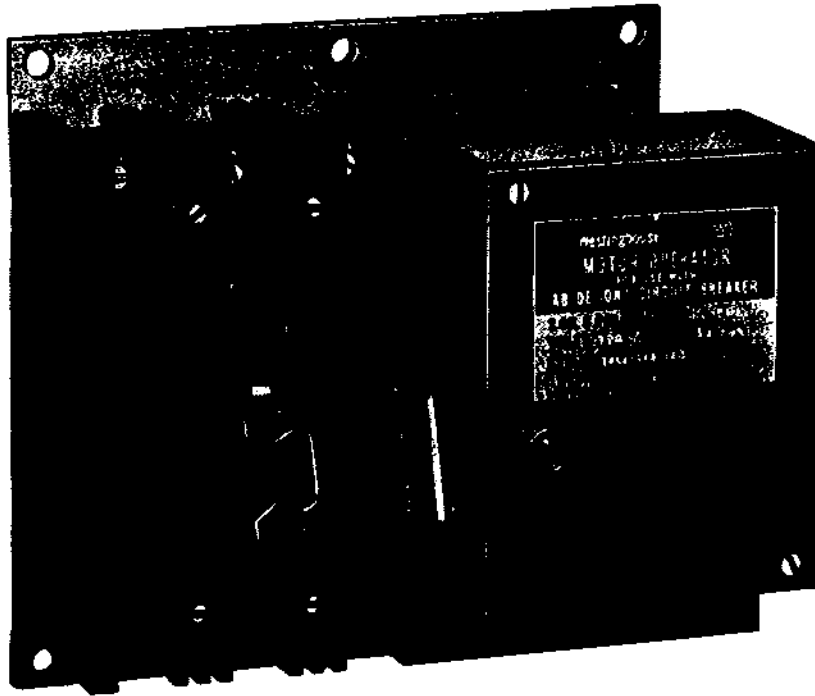


Fig. 31 - Side Mounted Motor Operator

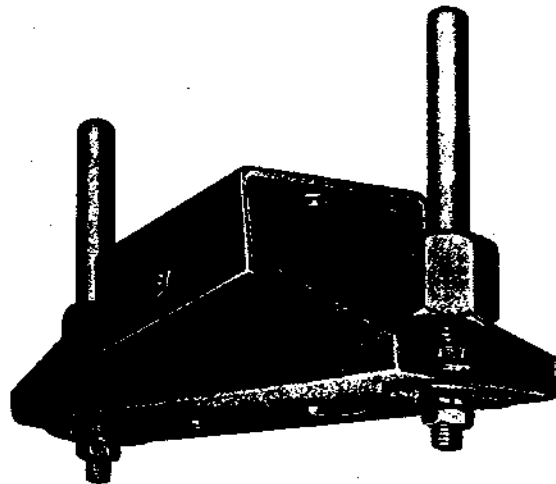


Fig. 32 - Typical-Walking Beam Interlock

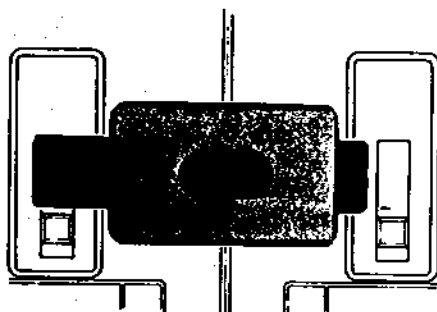


Fig. 33 - Sliding-Bar Type Handle Interlock

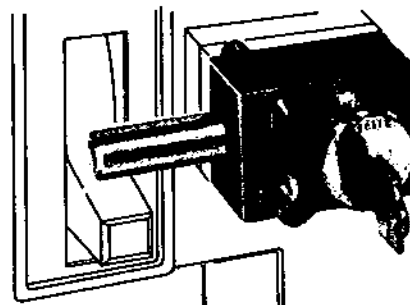


Fig. 34 - Key Interlock

G. Mounting Devices

Mounting devices are available in a variety of forms to mount breakers on panels. Figure 35 illustrates face plate, clamp, and base mounting for standard one inch breakers. The face plate mounting method is used for front panel mounting. The face plate snaps over the front of a single, two, or three-pole breaker. The clamp is used for base mounting of the breaker on a panel. Two are required per breaker. The base mounting plate can accommodate six single pole or three double pole breakers. The breaker snaps into position on the plate. Mounting plates can be cut for specific needs.

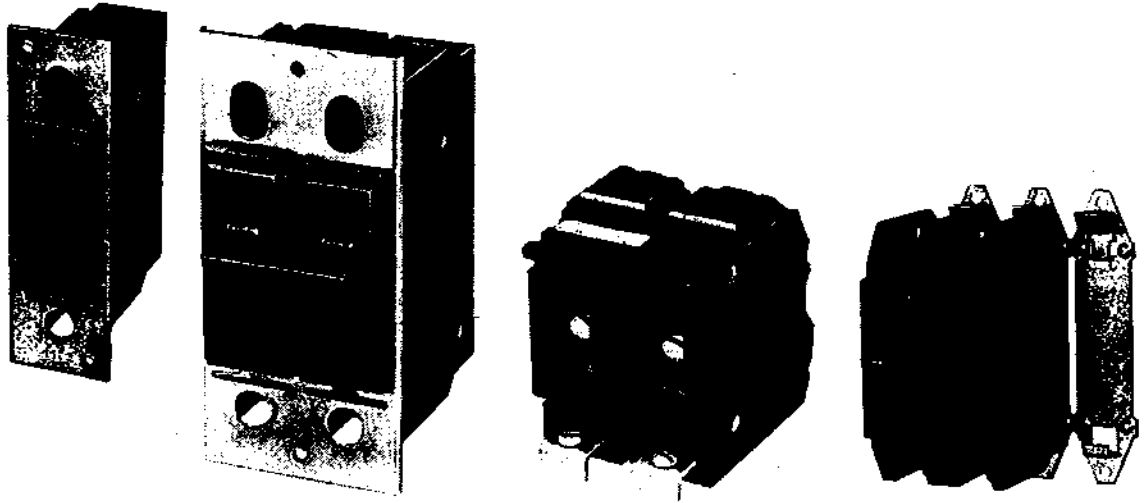


Fig. 35 – Face Plate, Clamp, and Base Mounting

H. Panelboard Connecting Straps

Panelboard connecting straps connect the line side of breakers to the panelboard bus. Panelboard depths and bus spacing vary depending upon the type of panels and the manufacturer. Therefore, the panelboard builder should be consulted to determine the correct strap when ordering for an existing panelboard. Refer to Figure 36.

I. Terminal Shields

Terminal shields protect personnel from accidental contact with current-carrying parts by shielding the line side terminal connections. These are commonly used where safety codes are stressed. Refer to Figure 37.

J. Handle Locks

Handle locks are available to prevent accidental or deliberate operation of circuit breakers. The “trip free” handle of the breaker enables it to trip on overload or short circuit conditions, even though handle locks are in place. However, handle locks must be removed before the breaker can be reset. Handle locks for small breakers are shown in Figure 38.



Fig. 36 – Panelboard Connecting Strap

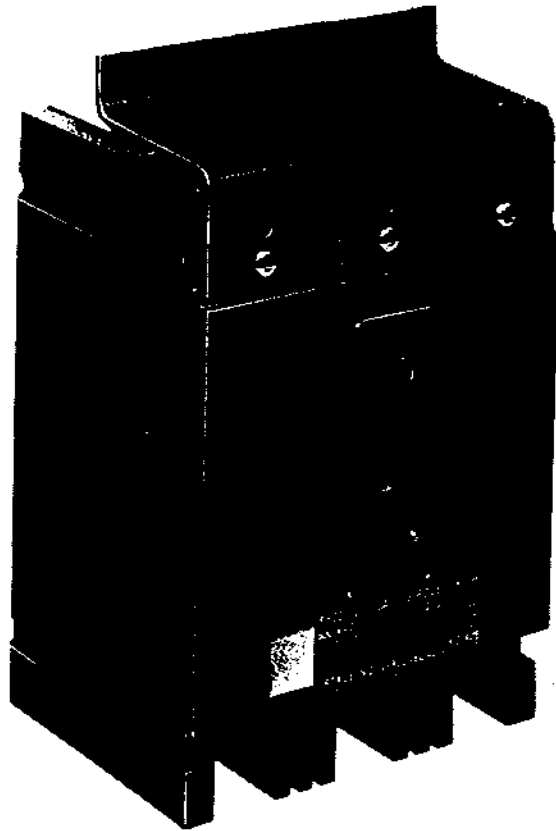


Fig. 37 – Extended Line Terminal Shields

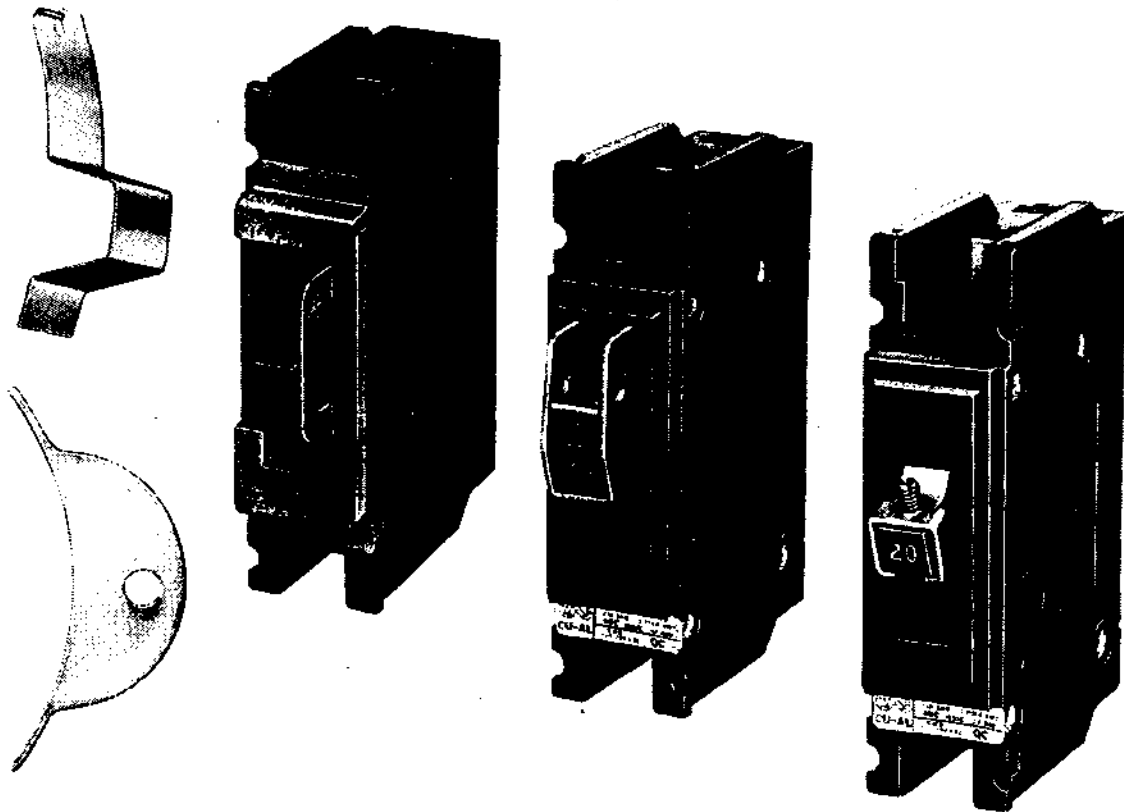


Fig. 38 – Locking Devices for Small Breakers

K. Rear Terminal Studs

Rear terminal studs are used for adapting breakers for switchboard and other rear connected applications (see Figure 39). The studs actually bolt onto standard breakers without any modifications. A short stud must be assembled adjacent to a long stud to maintain clearances required by Underwriters' Laboratories, Inc. Breakers mounted in switchboards and other equipment are front removable by unscrewing the nuts that hold the studs to the breaker.

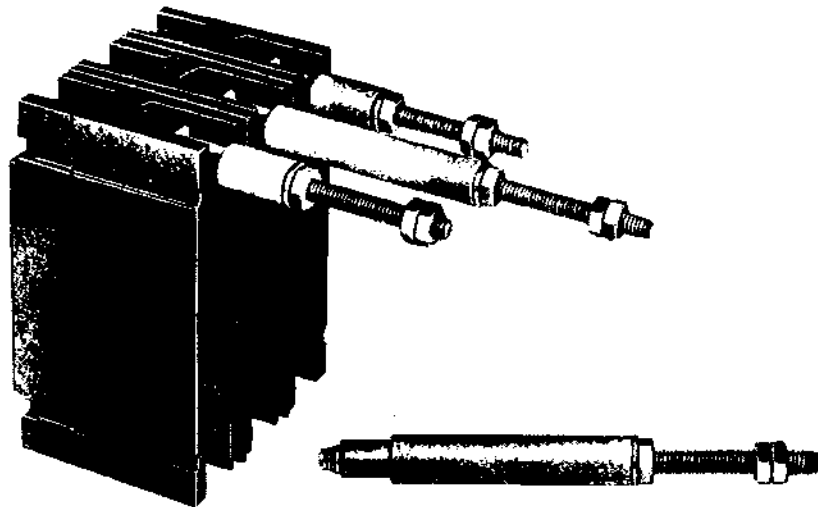


Fig. 39 – Rear Terminal Studs

L. Plug-in Adapter Kits

Plug-in adapter kits for rear connection applications, such as switchboards, a plug-in adapter kit (see Figure 40) makes installation easy and permits front removal of breaker. Tulip-type connectors and threaded studs or flat bus-bars are built into the molded support block which connects to the bus.

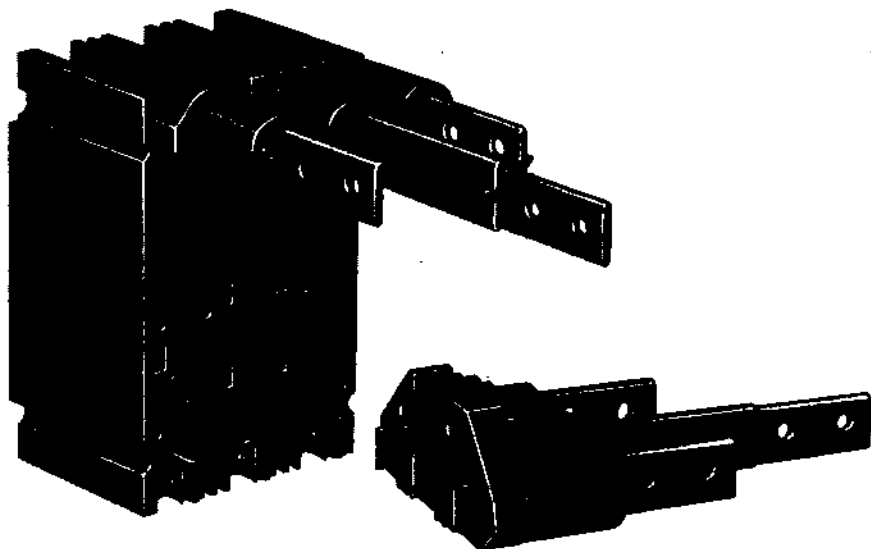


Fig. 40 – Plug-In Adapters

M. Ground Current Limiter

The ground current limiter is used only on direct-current systems to trip a circuit breaker when the ground current becomes excessive. It consists of a continuously rated solenoid tripping device mounted in the breaker. The solenoids are similar to those used in shunt trips except that they are current devices instead of voltage devices. The solenoid coil is specially designed and calibrated to carry a predetermined amount of current continuously. Any current beyond the predetermined current will activate the solenoid coil, causing the plunger to move and hit the trip bar, opening the breaker.

Ground current limiters are usually used in the mining industry for early detection of insulation deterioration of d-c motors. Figure 41 illustrates a typical schematic of a three-pole breaker protecting a d-c motor with the ground current limiter. Note that the ground current limiter is placed in series with the third pole of the breaker to provide isolation of the motor when the breaker is open. As the insulation of the d-c motor starts to break down, the leakage current to ground becomes larger. When the insulation deteriorates enough to activate the ground current limiter, the customer knows that the motor needs to be repaired. Without the ground current limiter, the insulation could deteriorate to the point that the motor would have a line to ground fault and be damaged beyond repair.

N. Fuse Mounting Base

Fuse mounting bases are occasionally used with non-automatic breakers (molded case switches) to provide a compact fused disconnect. The typical fuse mounting base mounts underneath the non-automatic breaker. The line side of the fuse bolts directly to the breaker and the load side to the mounting base. See Figure 42.

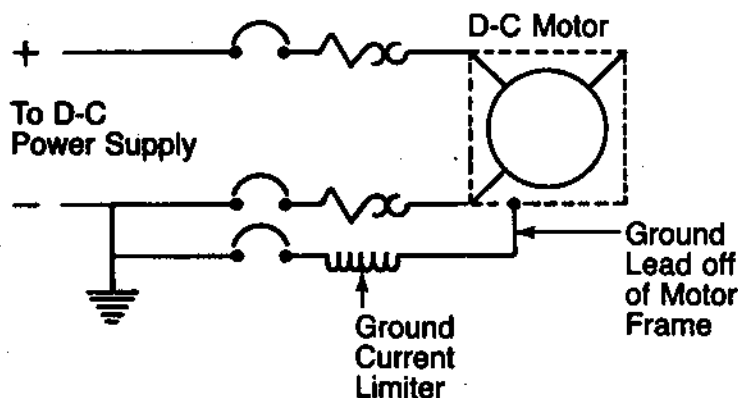


Fig. 41 – Schematic of a Ground Current Limiter in a 3-Pole Breaker

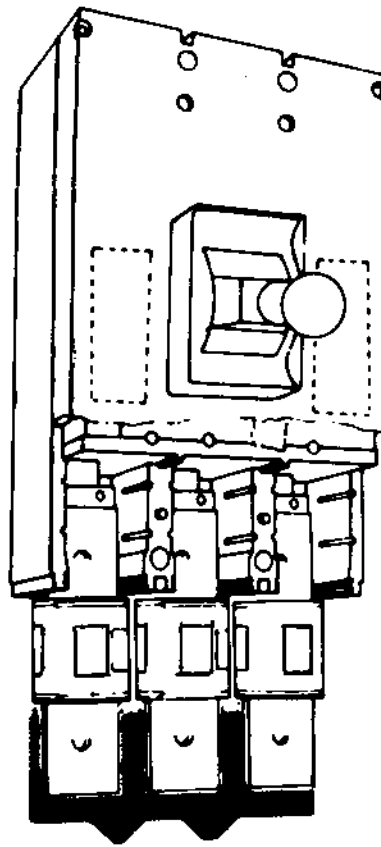


Fig. 42 – Fuse Mounting Base

4.4 Essential Field Maintenance

Molded case circuit breakers have an excellent record of reliability which, to a great extent, is due to the enclosed design which minimizes tampering and exposure to dirt, dust, and other contaminants. Maintaining reliability depends upon the proper application and installation of the breaker.

A. Field Service

To insure that proper breaker life is attained, it is essential that all terminal connections and trip units be tightened to the proper torque value as recommended by the manufacturer (see Figure 43). Poorly cleaned conductors, improper conductors for the terminal used, and loose terminations are all faulty conditions which may cause undue heating and deterioration of the breaker. Any routine maintenance inspection should involve a check for tightness of all terminal connections and trip units.

Circuit breakers which are normally operated manually require no further operations to insure that their contacts are clean and that the mechanical linkages operate freely. For breakers which are normally not operated on a regular basis, an occasional manual operation will provide the necessary exercise.

IMPORTANT Trip unit screws and terminal bolts or rear connecting studs MUST BE TIGHTENED SECURELY to prevent heating at connections.		
Breaker	Torque Trip To Base	Torque Terminal To Base
JA-KA-LB	6-8 Ft. Lbs.	6-8 Ft. Lbs. 1/4" Scr. 15 Ft. Lbs. 7/16" Scr.
MA	15 - Ft. Lbs.	30-35 Ft. Lbs.
NB	15 - Ft. Lbs.	30-35 Ft. Lbs.
LA	15 - Ft. Lbs.	8-10 Ft. Lbs. 1/4" Scr. 15 Ft. Lbs. 7/16" Scr. CU Term 10 Ft. Lbs. 7/16" Scr. AL Term
PA-PB	10 - Ft. Lbs.	15 Ft. Lbs. On Rear Conn.

JA-KA-LB-LA Only

1 Screw
2 Terminal
3 Flat Head Screw
4 Plug
5 Terminal Projections

6-8 Ft. Lbs.
6-8 Ft. Lbs.

Fig. 43 – Manufacturer's Connection Torque Values – Usually Accompany the Breaker

B. Field Testing

Data obtained from field tests of molded case breakers often differs from published information, resulting in confusion on the part of the user as to which is correct. This is caused by the test conditions existing during factory tests as opposed to test conditions existing in the field. Manufacturers conduct all tests in controlled ambient conditions, using test equipment designed specially for the product tested and so can obtain consistent results.

Unless the breaker is equipped for electrical field testing where sufficient test instructions are provided, all testing should be done through a reliable service organization.

4.5 Troubleshooting Guide for Molded Case Breakers

Breaker Condition

1) Frequent Thermal Tripping

Causes

Corrective Action

A) Excessive current.

The breaker may be operating properly and clearing an overload. Check to see if the current is in excess of the thermal trip rating.

B) Terminals not torqued properly to base of breaker.

Visually inspect terminal area for any discoloring which would indicate loose connections. Proper torque values are furnished on a tag with breakers.

C) Cable improperly torqued in terminal.

Visually inspect for discoloration. Cables can become loose during service due to such reasons, as vibrations in machine tool applications and cold flow when aluminum cables are used.

D) Improper wire size.

Since the cable acts as a heat sink and carries heat away from the breaker, the proper size is important. For example, if a cable rated 90 amperes is carrying 150 amps, this would cause excessive heating in the breaker.

E) Ambient temperature too high.

This can become a problem on hot summer days. If the temperature fluctuates and frequently exceeds 40C (140F), an ambient compensating breaker should be installed. If the temperature is consistently above 40C, a specially calibrated 50C (122F) should be installed.

Breaker Condition

- F) Trip unit improperly torqued to base.

If all the above items check out, then the trip unit should be removed from the breaker and inspected for discoloring. Torque values are given on tags supplied with all breakers with removable trip units.

2) Breaker trips magnetically

Causes

- A) High inrush current from motor.
- B) Check type of field testing – slow rise versus 6 cycle pulse.
- C) High peak current on Wye-Delta starter transfer (open transition).

Corrective Action

Adjust magnetic trip rating to the next higher setting or until breaker does not trip on starting.

A slow or gradual increase in current until the trip range is reached will result in the breaker tripping at a lower value than indicated on the trip unit. This does not mean that the breaker is defective. A six-cycle impulse test should be used. This is how the breaker is calibrated at the factory.

If an open circuit is experienced during transfer, either by design or by error, the peak current during transfer could exceed 20 times full load amperes. The open circuit should be closed or an extremely high magnetic trip setting must be supplied on the breaker but, the desired close motor protection is lost.

Breaker Condition

3) Mechanical and electrical malfunctions

Causes

Corrective Action

A) High humidity.

Breakers should be removed from high humidity locations since this can cause dielectric and other problems associated with moisture. The best solution is inclusion of space heaters in the enclosure.

B) Corrosive environment.

Breakers should be removed from corrosive environment if possible. Specially treated breakers are available to resist corrosive environments.

C) If attachments are included on breaker, make sure the attachments are functioning properly.

Remove the cover from the breaker and determine what type of attachment is installed. Then, check for proper functioning. Make sure proper voltage is applied to an undervoltage release or the breaker will not operate. Make certain that the shunt trip is not energized while trying to close the breaker.

4.6 Verifying Performance of Molded Case Circuit Breakers

The remainder of this chapter is a reproduction of NEMA Standards Publication No. AB2-1980, *Procedures for Verifying the Performance of Molded Case Circuit Breakers*, copyright 1980 by NEMA and reproduced here with permission.

PROCEDURES FOR VERIFYING THE PERFORMANCE OF MOLDED CASE CIRCUIT BREAKERS

*(Approved by NEMA as Authorized Engineering Information
9-6-79.)*

User needs were considered in the development of this standards publication.

These procedures have been prepared by the Molded Case Breaker Section of NEMA. They will be reviewed periodically by the Section and will be updated, as necessary, to reflect advances in technology. Comments and suggestions will be welcomed; they should be addressed to:

Manager, Engineering Department
National Electrical Manufacturers Association
2101 L Street, N.W.
Washington, DC 20037

* * *

NEMA Standards Publication No. AB 2-1980 revises and supersedes AB 2-1976.

Part 1

General

Throughout this publication, the term "circuit breaker" refers to a "molded case circuit breaker."

The *National Electrical Code** defines a circuit breaker as: "A device designed to open and close a circuit by nonautomatic means, and to open the circuit automatically on a predetermined overcurrent without injury to itself when properly applied within its rating."

A molded case circuit breaker is one that is assembled as an integral unit in a supporting and enclosing housing of molded insulating material.

* Refer to Appendix A for a list of the Codes and Standards referenced in this publication.

The *Code* also states that the purpose of a circuit breaker is to open "the circuit if the current reaches a value which will cause an excessive or dangerous temperature in conductors or conductor insulation."

Molded case circuit breakers undergo extensive production testing and calibration at the manufacturer's plant. These tests are based on Underwriters Laboratories Inc. *Standard for Safety for Molded Case Circuit Breakers and Circuit-Breaker Enclosures*, UL 489. Circuit breakers carrying the UL label have factory-sealed calibrated elements. An unbroken seal assures that the mechanism has not been subjected to alteration or tampering, and that the breaker may be expected to perform according to the UL requirements. A broken seal voids the UL label and jeopardizes the manufacturer's warranty.

Molded case circuit breakers have an excellent record of reliability that, to a great extent, is due to the enclosed design which minimizes tampering and exposure to dirt, dust, and other contaminants. This reliability also depends on proper installation and careful application, particularly with reference to the maximum available short-circuit current of the circuit to which the circuit breaker is applied.

Reliability after installation also depends upon environment and maintenance. All devices with moving parts require periodic check-ups. A circuit breaker is no exception. It is not unusual for a circuit breaker to be in service for extended periods and never be called upon to carry out its overload or short-circuit functions. Therefore, the breaker should be exercised periodically to assure that it is functioning. Also, current faults may have occurred without causing the breaker to respond, and it is well to be alert to the possibilities of such occurrences, although experience indicates that both types of overcurrent would very likely have produced some recognizable symptoms, such as deteriorated conductor insulation or operation of a source-side overcurrent device.

Where concerns such as the foregoing are justified, a program of field testing and preventive maintenance as outlined in the following parts of this publication may be desirable:

Part 2, Circuit Breaker Tripping Characteristics

Part 3, Verification Test Procedures

Part 4, Verification of Manufacturer's Published Data

The procedures in Part 3 are intended for checking the condition and basic electrical operation of circuit breakers, but they cannot be considered as calibration tests or comparisons to published application curves. Part 4 outlines factors to be considered if laboratory accuracy is to be approached. If checking indicates maloperation, the circuit breaker should be removed and sent to the manufacturer for investigation and test. *It is not advisable to attempt repairs in the field.*

Manufacturers of circuit breakers with electronic trip units also make testers for checking the operation of each function provided by the trip unit. The tester is a separate device and can be used only with the trip unit or units for which it is designed. Manufacturer's instructions must be carefully followed to assure accurate results.

If a tester is not available, electronic trip units can be tested by using a low-voltage high-current source such as those used to perform the tests described in this publication. The procedures given for other types of circuit breakers of equivalent ratings should be followed.

Manufacturers stand ready to furnish this service and some are equipped to perform field tests on any make of unit. Such a service will be found more practicable where accurate tests are required and for all tests on circuit breakers rated 600 amperes and above. This is in part due to the need for special heavy loading equipment and very greatly due to the difficulty of making suitable testing connections.

It should be mentioned here that proper packing and packaging is essential to avoid damage when shipping circuit breakers.

There is adequate experience to indicate that where electrical testing is not practical, or cannot be justified, the manual mechanical exercising of a circuit breaker is usually effective in assuring its probable proper electrical operation. A few operations of the handle, performed periodically, together with a careful visual inspection of terminal connections for tightness, physical damage or evidence of overheating are considered good practice. This will keep mechanical linkages free, and the wiping action by contacts will tend to avoid resistance buildup and thereby minimize heating. Circuit breakers used for frequent switching need no further exercising.

Circuit breakers can trip unexpectedly from exposure to continuous currents beyond their ratings, from unduly high ambient temperatures, from poor or improper connections, from damaged plug-in members, and from other conditions which transfer undue heat to the breaker mechanism. Some of these conditions violate application specifications; for example, a molded case circuit breaker applied in a panelboard should

not be loaded in excess of 80 percent of its continuous current rating if, in normal operation, the load will continue for 3 hours or more.

There has been an increase in the number of incidents involving serious damage to switchgear, raceways, and panelboards and occurring totally independently of overcurrent interrupting devices such as fuses and circuit breakers. These faults develop mainly on systems above 250 volts where ground faults or transients initiate arcing short circuits, drawing currents below the response ratings of overcurrent devices. Such arcs develop high power, and the energy precipitates a chain reaction, electrical conflagration, and burning of the equipment, frequently without the fuses or breakers ever experiencing currents approaching their ratings. Protection against such occurrences should be seriously considered for installations involving voltages above 250 volts and may be accomplished by the application of ground fault sensing and interrupting equipment.

Part 2

Circuit Breaker Tripping Characteristics

The typical molded case circuit breaker is equipped with both time-delay and instantaneous tripping devices.

1. ***Time-delay tripping*** has inverse time characteristics, i.e., the larger the overload, the less time required to trip. This has the following advantages:

- a. Under moderate overloads of short duration, the circuit breaker allows sufficient time for such applications as motor starting.
- b. Under severe overloads the circuit breaker will trip quickly, providing adequate protection for circuit conductors and insulation.

2. ***The instantaneous or magnetic tripping device*** responds to short-circuit currents and opens the circuit breaker instantaneously. This characteristic has the following advantages:

- a. It limits the duration of the short-circuit current to a minimum amount of time, thus giving maximum protection to the circuit conductors and to the circuit breaker itself.
- b. It reduces damage at the point of fault to a minimum.

Time-delay circuit breakers having a frame size of 100 amperes or smaller may be of the nonadjustable magnetic-trip type with no provision for adjusting the magnetic setting to higher or lower values. Circuit breakers with larger frame sizes may have adjustable magnetic trip devices whereby the current value at which the instantaneous trip will operate can be set by the user to intermediate current values.

Some circuit breakers have time-delay features to provide for heavy inrush currents such as those which occur when large blocks of incandescent lamps are cut in. Thus it is imperative to have the manufacturer's overload (time/current) curves whenever an appraisal is made of the circuit breaker's performance.

The characteristics of a circuit breaker may be affected by improper terminal connections at the time of installation. Distorted plug-in stabs or sockets, poorly cleaned conductors, improper conductors for lugs in use, and loose terminations are all faulty conditions which may cause undue heating and deterioration of the circuit breaker and its response characteristics.

Operating linkages are such that it is unlikely that friction would change parameters, and it would take extreme corrosion to cause "freezing" of the operating mechanism.

Frequent operations due to heavy short-circuit currents may cause erosion of contacts and/or tracking of insulation.

A. Cable Connection Inspection

The connections to the circuit breaker terminals should be inspected to determine the proper conductor ampacity and the existence of proper electrical joints. If overheating of connections is evident by discoloration or arcing, the surfaces must be cleaned before testing and reinstallation. As stated previously, it is essential that electrical connections be made properly to prevent overheating. Aluminum lug connectors are usually plated and should not be cleaned with abrasives.

B. Testing Considerations

When testing circuit breaker tripping characteristics, it is recommended that the overcurrent tests be performed on individual poles at 300 percent of rated current. The reaction of the circuit breaker to this overload will be indicative of its reaction throughout its entire overcurrent tripping range. This load has been chosen as the test point because it is relatively easy to generate the required current in the field and the wattage per pole from line to load is large enough so that the dissipation of heat in the nonactive pole spaces is minor and does not affect the test results appreciably.

The minimum/maximum range of values given in Table 2-1 was developed to encompass most circuit breakers; for more specific values the manufacturer's data for the circuit breaker being tested should be used.

C. Evaluation of Results

1. **Minimum Tripping Times (Col. 3 and 4)** — The minimum values shown in Columns 3 and 4 of Table 2-1 should not be considered significant in field testing unless nuisance tripping has been experienced. These values are provided as a guideline only. If minimum tripping times are lower than those shown in Table 2-1, the breaker should be retested after being de-energized and cooled for the required time.

2. **Maximum Tripping Times (Col. 5)** — Under normal test conditions, the circuit breaker will trip in less time than the maximum values shown in Column 5 of Table 2-1. Under improper test conditions the maximum values may exceed those given in Table 2-1.

3. **Maximum Tripping Times for Cable Protection (Col. 6)** — If the test value exceeds the maximum tripping time shown in Column 5 of Table 2-1 but falls below the maximum tripping time for cable damage shown in Column 6, the circuit breaker is providing an acceptable level of protection. Coordination with other protective devices should be considered before replacing a circuit breaker which trips beyond the time-current curve.

Table 2-1
Values for Overcurrent Trip Test
(at 300 Percent of Rated Continuous Current of Circuit Breaker)

Voltage, Volts	Range of Rated Continuous Current, Amperes	Tripping Time, Seconds			
		Minimum		Maximum	
		Thermal Breakers	Magnetic Breakers	For Circuit Breaker	For Cable Protection ^①
(1)	(2)	(3)	(4)	(5)	(6)
240	15-45	3	...	50	100
240	50-100	5	...	70	200
600	15-45	5	5	80	100
600	50-100	5	5	150	200
240	110-225	10	5	200	300
600	110-225	10	...	200	300
600	250-450	25	...	250	300
600	500-600	25	10	250	350
600	700-1200	25	10	450	600
600	1400-2500	25	10	600	750

① These values are based on heat tests conducted by circuit breaker manufacturers on conductors in conduit.

Part 3

Verification Test Procedures

Testing of circuit breakers is intended to enable personnel such as plant maintenance men to assure, without using a laboratory, that a particular circuit breaker is able to perform its basic circuit protection functions.

The following constitutes a guide and recommendations for the types of tests which might be performed during routine maintenance by QUALIFIED and TRAINED personnel. The tests are:

- A. Insulation Resistance Test
- B. Individual Pole Resistance Test (Millivolt Drop Test)
- C. Time-delay Overcurrent Trip Test
- D. Instantaneous Magnetic Overcurrent Trip Test
 - 1. Runup Method
 - 2. Pulse Method
- E. Rated Current Hold-in Test

These tests are based on proven maintenance practices and are aimed at assuring that the circuit breaker is functionally operable. This is in contrast to those tests which are designed to specifically check the accuracy of the manufacturer's published calibration performance curves and which must be done under precisely controlled ambient temperature and electrical conditions.

Caution: It should be understood that all tests must be made only on circuit breakers and equipment which are de-energized, disconnected, and isolated, so that no accidental contacts are made with live lugs or other connections.

A. Insulation Resistance Test

An insulation resistance test is used to determine the quality of the insulation between adjacent poles of a circuit breaker and from its poles to ground.

The resistance test is made with a direct-current voltage which is higher than the rated voltage, to determine the actual resistance of the insulation. The most common method employs a "Megger"® type instrument. Most such devices in use have outputs of 500 volts or less; however, much more reliability will be derived if 1000-volt instruments are used because they are more likely to pick up tracked insulation surfaces. Resistance values below 1 megohm are considered unsafe and should be investigated.

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An insulation resistance test should be made:

1. Between line and load terminals of individual poles with the circuit breaker contacts open.
2. Between adjacent poles and from poles to the metallic supporting structure with the circuit breaker contacts closed. The latter test may be done with the circuit breaker in place after the line and load conductors are removed, or with the circuit breaker bolted to a metallic base which simulates the in-service mounting.

B. Individual Pole Resistance Test (Millivolt Drop)

Certain abnormalities in the current-carrying circuits of the circuit breaker can be detected by making a millivolt drop test across the line and load terminals of each pole of the unit with the circuit breaker contacts closed.

The manufacturer should be consulted in order to determine the allowable voltage drop for the circuit breaker under test. It is recommended that this test be made with a direct current which is approximately 50 percent of the continuous current rating of the circuit breaker; however, currents for the larger circuit breakers may be as low as 50 amperes if the millivoltmeter is of sufficient sensitivity. The millivolt drop across each pole is measured and recorded for comparison against the manufacturer's submitted data. If such data is not available, it may be practical to compare the test values with those for poles of other circuit breakers of a similar size and style.

C. Time-Delay Overcurrent Trip Test

Prior to the electrical operation tests, the mechanical operation of the circuit breaker should be checked by turning it on and off several times.

Repeated tests on any pole must be spaced by at least 20 minutes; tests on adjacent poles must be spaced by at least 5 minutes. If these times are too short, subsequent tests will indicate tripping sooner than the characteristic curve values. If precise results are required, the between-test intervals should be sufficient to permit the temperature of the circuit breaker to return to that of the surrounding ambient air.

The simplified test setup shown in Figure 3-1 is suggested as basic and minimum for checking the mechanical operation of the circuit breaker. It can be assembled with readily available equipment and devices ordinarily on hand. The values shown are for testing units with ratings up to 100 amperes. Test equipment for higher current ratings will be propor-

tionately larger. Tests at greater currents, or higher accuracy, will require more sophisticated loading equipment, instrumentation, and timers.

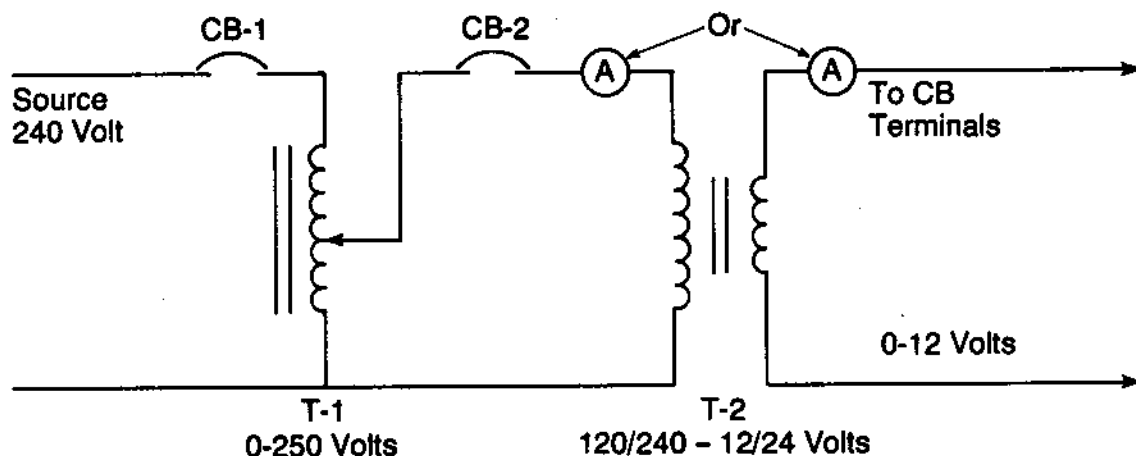
The stepdown transformer should have isolated 12-volt secondary coils. The current adjustment device may be either a variable-voltage transformer or a manually-operated induction regulator. From the standpoint of portability, it may be well to anticipate that the combined weight of these two units will be between 250 and 400 pounds. Voltage requirements for loading may be more or less than 12 volts depending on circuit breaker sizes and test cable impedances.

For testing larger circuit breakers, two stepdown transformers may be used in parallel.

If 6-volt transformers are used, larger circuit breakers may be tested.

For circuit breakers rated above 250 amperes, the use of custom-built test equipment is advisable; or the services of the manufacturers or other qualified service organizations should be considered.

The input control circuit breaker must be rated to match the ratings of the two transformers and to carry the current for the highest time-delay overcurrent run. With these coordinated, pulses up to 400 percent of the



The following or similar equipment may be employed:

- A — Ammeter
- T-1 — Powerstat, 45 amperes
- T-2 — Buck-boost transformer (dual primary and secondary coils not shown)
- CB-1 — Main circuit breaker, 50 amperes, general purpose
- CB-2 — Control circuit breaker, 30 amperes, general purpose

Fig. 3-1 — Typical Schematic Arrangement For Testing Molded Case Circuit Breakers Rated 100 Amperes or Less

transformer ratings and of not more than 10 seconds, with a 3-minute rest period between pulses, should not thermally overburden the transformers.

On a practical basis, the current may be measured on the primary of the loading transformer if the coil ratio is known, or on the secondary for the smaller rated circuit breakers. Panel, portable, or clamp-on ammeters may be used.

The test cables should be approximately 4 feet in length and should be of a size commensurate with the breaker rating. They should be bound together, where practicable, to minimize inductive reactance. Bus bars should be as short as possible for large circuit breakers which are tested with specialized equipment. Plug-in circuit breakers should be tested only when mounted in the proper base.

The circuit breaker should be loaded and tested in accordance with the details previously discussed under Testing Considerations (see par. B of Part 2).

D. Instantaneous Magnetic Overcurrent Trip Test

These tests are intended to simulate short-circuit conditions, but it must be remembered that in the field it is practically impossible to impose the 5000-ampere (or more) pulse that is imposed in the laboratory.

In routine tests it is more important to determine that the magnetic trip feature is operating and will trip the circuit breaker, rather than determining the exact current value at which the magnetic trip feature operates. To duplicate the manufacturer's published data, exact determination of trip current values can be obtained, but the necessary precise control of test conditions will probably prove impractical. It must be recognized that on circuit breakers in the larger frame sizes the instantaneous magnetic overcurrent trips have adjustable settings, usually from 6 (Lo) to 10 (Hi) times the continuous current rating.

Since the magnetic trip characteristics of the circuit breaker can be influenced by stray magnetic fields, the test set-up must be made in such a way that the fields caused by the test equipment itself, by steel enclosures, or by the conductors to the circuit breaker, do not affect the test results. Results can also be greatly influenced by the wave shape of the current and, therefore, it is desirable to have sinusoidal output from the loading equipment.

The equipment shown in Figure 3-1 will be suitable for these tests if the currents and time intervals are as stated in par. C.

Testing of the instantaneous magnetic trip feature may be by the "runup" method or the "pulse" method:

1. **Runup Method**—In this method one pole of the circuit breaker to be tested is connected to the test equipment, and the current control is set at a point where approximately 70 percent of the expected tripping current will flow when energized. The power is then turned on and the current increased until the circuit breaker trips. The recommended time for increasing the current is between 2 and 5 seconds. If the current is increased too slowly, tripping may be due to the time-delay element, especially if more than one test is run at a high current level. If the current is increased too rapidly, an erroneous current reading may be obtained because the meter indication lags behind the actual current value due to meter damping.

The runup method requires skill on the part of the operator in recognizing the relationship between actual current and the meter indication.

Caution: If the circuit breaker does not open within 10 seconds, the loading circuit must be de-energized to protect it from damage.

2. **Pulse Method**—This method will be more accurate than the runup method if done properly, but it requires that the test equipment be equipped with a pointer-stop ammeter or a calibrated image-retaining oscilloscope. It involves the following steps:
 - a. After the circuit breaker is connected, current is applied in short pulses of 5 to 10 cycles.
 - b. The current is increased on each succeeding pulse until the circuit breaker trips.
 - c. The current is then reduced to just below that point and, by repeated pulses, the pointer stop on the ammeter is adjusted until the pointer movement is barely perceptible when the current is pulsed.
 - d. The current can then be raised slightly and rechecked at the current at which the circuit breaker trips.

Although this method is a more accurate procedure, it is subject to an error introduced by current offset. Figure 3-2 depicts the distortion of the pulse current, commonly called offset or asymmetrical.

An offset current results from closing the circuit at that point of the cycle where the voltage-current relationship results in an asymmetrical current. Experience with field test equipment indicates that the offset may be as high as 20 percent. A circuit breaker can be tripped by the

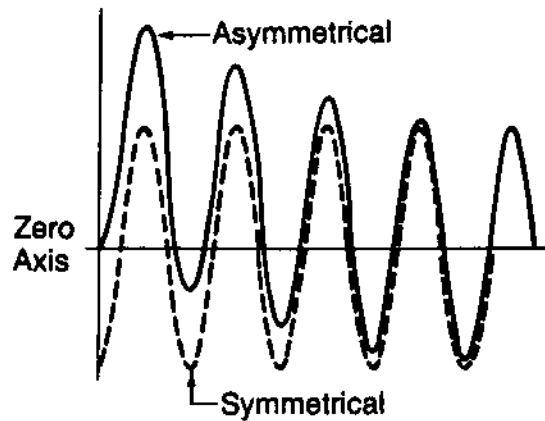


Fig. 3-2 – Current Wave Shapes

offset peak rather than the steady-state current so the effect of the error is such that the indicated trip current may be as much as 20 percent lower than the peak offset current which tripped the circuit breaker. In factory testing, this error is avoided by (1) using synchronous closing of the current control to make contact at a point on the 60-hertz wave so that no offset current occurs, and (2) reading current values on a calibrated image-retaining cathode ray oscilloscope or a graphic recorder.

E. Rated Current Hold-In Test

This is an optional test and is required only if doubt exists regarding a circuit breaker's ability to carry rated load. The circuit breaker shall be mounted in free air with its poles connected in series; all cables, including the series jumpers, shall be of the proper ampacity and shall each be approximately 4 feet long. Rated current is applied and no tripping should occur over a 30-minute period. If the series arrangement imposes too much impedance so that full current cannot be developed, the poles may be tested individually. If tripping does occur, the connections should be checked to ascertain whether undue heat has developed at the terminations. If undue heat appears to have developed within the circuit breaker, further investigation is necessary, preferably by the manufacturer.

F. Testing Limitations

In field testing it will not be practical to meet all of the test conditions specified by UL Standards. In many cases, NONE of the UL standard factory test conditions may be fully met.

One of the most frequently encountered problems is the fact that a circuit breaker may have to be tested in the enclosure in which it is mounted, rather than in open air as specified by UL. Consequently, the

difference in ambient temperature will result in tripping characteristics different from those which would be experienced in open air.

Temporary test connections call for extra care with respect to the tightness of the connections and the size of the conductor in order to reduce heating and voltage drop.

Other frequently encountered problems are the inability to wait the required time for the circuit breakers to cool to room temperature and a room temperature other than 25°C (77°F). If tests are made while thermal-trip circuit breakers are still warm, the trip time will be shorter than if they were allowed to cool completely. When testing individual poles, successive tests can be run on adjacent poles, with no cool-down periods between tests without resulting in more than a 10 percent error.

The recommended method of determining whether a circuit breaker has been calibrated in accordance with the manufacturer's limits is to *meet* all of the UL specified conditions as outlined in Part 4 of this publication.

G. Interpretation of Test Results

The principal purpose of field testing is to permit the user to safely determine whether the circuit breaker is furnishing the protection for which it is intended, or whether it should be replaced. Field testing is *not* intended to determine whether the circuit breaker exactly meets the manufacturer's published curves. A circuit breaker that trips in *less* than the minimum time shown by the manufacturer's trip time curves may furnish more protection than is expected. System coordination of tripping times should be considered before replacing a circuit breaker that trips at a value outside of the time-current curve.

H. Summary

It is again emphasized that common maintenance practices for electrical equipment should be followed in field testing both new and installed molded case circuit breakers. Usually the standard routine operating checks listed in this publication will be sufficient to assure that the circuit breaker is functioning properly. Since molded case circuit breakers have factory-sealed calibrated elements, it is further recommended that **THIS SEAL SHOULD NOT BE BROKEN AND THE CIRCUIT BREAKER ITSELF SHOULD NOT BE TAMPERED WITH.**

The adjustment or repair of molded case circuit breakers in the field is not recommended. If necessary, the circuit breaker should be replaced, or its parts should be replaced or repaired at the factory.

Part 4

Verification to Manufacturer's Published Data

Underwriters' Laboratories Inc. *Standard for Molded Case Circuit Breakers and Circuit-Breaker Enclosures*, UL 489, is the basis for performance standards for all molded case circuit breakers bearing the UL label. Verification of molded case circuit breakers to UL test standards is intended to permit the checking of circuit breakers in accordance with the manufacturer's published data under carefully controlled conditions. The manufacturer's published data are based upon the UL standard and, if verification of these data or application curves is desired from tests, the tests should be performed under carefully controlled conditions as specifically instructed by the manufacturer.

If circuit breaker performance characteristics are to be tested in the field, there are many variables that must be recognized and taken into account. Some simplifications are necessary; however, even simplified testing must recognize variations that can and do exist between one test setup and another. These variations can account for differences in test results, and it must be recognized that a circuit breaker may furnish adequate protection, but appear defective because of the test procedure used.

A. Time Delay Data

Calibration standards and the trip-time values for circuit breakers tested in accordance with UL 489 are based on the following conditions:

1. Circuit breakers are tested in open air at an ambient temperature of 25°C (77°F).
2. UL trip time values are measured from a "cold start." Therefore, before tests are started, circuit breakers must have been in a 25°C $\pm$ 3°C (77°F $\pm$ 5°F) ambient long enough for all parts to have reached the same temperature (at least 2 hours for circuit breakers rated 100 amperes and below, and 4 hours for those rated above 100 amperes).
3. Calibration tests are made with conductors of the size specified in the UL Standard connected to line and load terminals. If, in field testing, the circuit breaker is connected with wire or bus other than that specified, results will vary from published data. The wire should be connected with the lug specifically intended for that breaker, and both the lug mounting screw and cable set screw should be properly secured.

4. Current must be held constant and accurately over the entire test time. The heat generated in the trip unit of a thermal trip circuit breaker is proportional to the square of the current. A small variation of current can cause a large variation in total heat generated.

Example—If a 10-ampere current (I_1) is allowed to change only 10 percent to 11 amperes (I_2), the heat generated will be:

$$\frac{(I_2)^2}{(I_1)^2} = \frac{11^2}{10^2} = \frac{121}{100} = 121\%$$

This shows that an increase of 10 percent in current will cause a 21 percent variation in heat and a corresponding error in trip time.

NOTE—To get field test results comparable to those obtained when circuit breakers are factory tested to UL Standards, ammeters must be carefully checked to a precise standard. *Most panel instruments are accurate to ± 2 percent of full scale reading.* This means that a 500-ampere meter may have an error of ± 10 amperes ($+ 0.02 \times 500 = \pm 10$ amperes). This same 10-ampere error can exist during measurements at all points on the scale. For example, the error at 100 amperes or 1/5 scale may still be 10 amperes, i.e., 10 percent. From the previous example, a 10-percent change in current can cause a 21-percent change in heat in the circuit breaker under test and a corresponding change in trip time. In order to minimize this effect, meter scales should be chosen so that readings are taken in the upper half of the scale.

B. Instantaneous Magnetic Overcurrent Data

Unless very special loading and test equipment is available, it is impossible to duplicate the short-circuit current tests specified in UL 489 which imposes currents not less than the rated maximum interrupting current of 5000 amperes or more. The procedure described in Section D of Part 3 is more in the nature of a check, rather than a test, because current values may not be high enough to differentiate between time-delay and instantaneous characteristics. The following table indicates the

tolerance values to be used during tests of magnetic or instantaneous trip molded case breakers:

Frame Size, Amperes	Tolerances of High and Low Settings	
	Factory	Field ^②
250 and less	$\pm 20\%$	+ 40% - 25%
400 and greater	$\pm 20\%$	$\pm 25\%$

② If single-pole calibration test results fall outside these tolerances, additional testing should be conducted using two poles in series, including A-B, B-C, and C-A phase combinations. All combination test results should fall within the tolerances indicated.

Panelboards and Switchboards

- Types of Panelboards 2:5.2**
- General Construction – Panelboards 2:5.2**
- Installation Procedures 2:5.6**
- Installation of Conduit and Wires 2:5.7**
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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Panelboards and Switchboards

Panelboards

Panelboards are basically standard units utilizing overcurrent protective devices (circuit breakers or fusible switches), 15 amperes through 1200 amperes - 600 volts alternating current maximum. These overcurrent devices are group mounted on a common base and are connected to a common set of conductors (bus bars). The panel base is arranged for installation in a sheet steel cabinet presenting a dead front unit with the cabinet front in place. The devices are accessible for wiring or maintenance, from the front only, by removal of the cabinet front. A lockable hinged door is provided in the cabinet front for access to the operating handles of the overcurrent devices, see Figure 1. Additional flexibility in application and equipment is possible through numerous modifications to the standard designs.

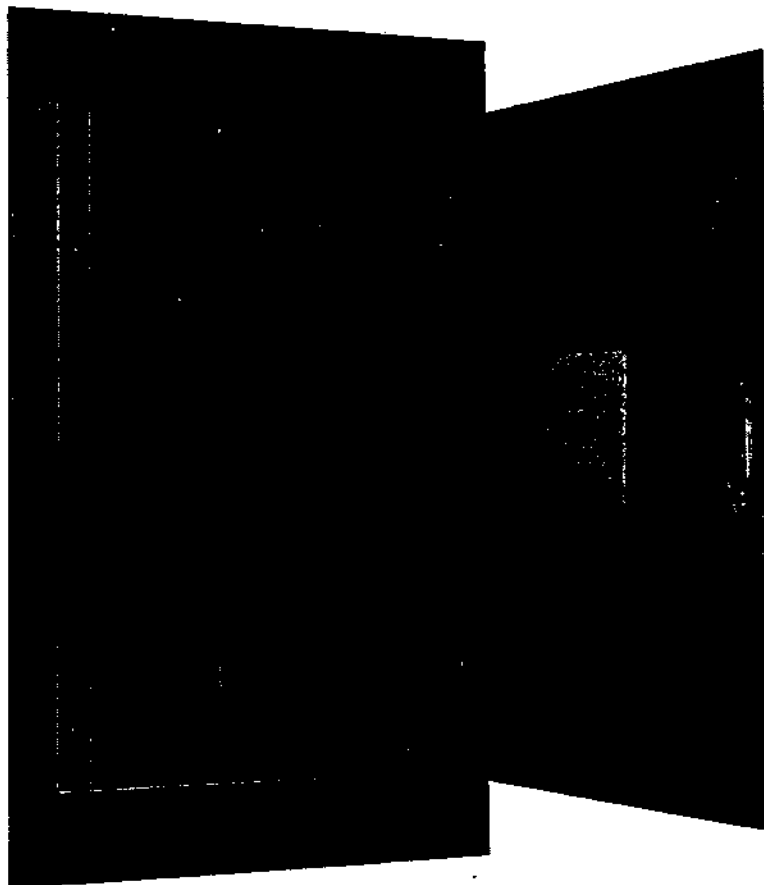


Fig. 1 – Typical Panelboard

5.1 Types of Panelboards

Functionally, a wide variety of panelboards is available to meet specific load and control requirements and installation conditions. These panels fall into five categories:

A. Feeder Distribution Panelboards

Feeder distribution panels generally contain circuit overcurrent devices rated at more than 50 amps. They protect subfeeders that run from this panel to smaller branch-circuit panelboards throughout a specific area.

B. Power Distribution Panelboards

Power distribution panels, similar to the feeder distribution type, have buses normally rated up to 1600 amps at 600 volts or less. They contain control and overcurrent devices sized to match connected motor or other power circuit loads. Generally, the devices are three-phase.

C. Lighting Panelboards

Lighting and appliance branch-circuit panelboards have more than 10% of their overcurrent devices rated 30 amperes or less, for which neutral connections are provided. Generally, these panels have bus ratings up to 225 amperes at 600 volts or less. However, larger bus ampacities must sometimes be selected to meet load requirements.

D. Service Entrance Panelboards

Service entrance panelboards. The term *Service* designates the electric service or supply conductors that extend from the Power Company's line connection or from a power distribution transformer to the service entrance equipment of the building it supplies.

E. Special Panelboards

Special panelboards containing relays and contactors can be obtained and installed when remote control of specific equipment is required. Also falling into this category of special panels are those requiring such modifications as oversized wiring gutters, weatherproof enclosures, and other special requirements.

Standard panelboards are usually U.L. (Underwriter's Laboratories) listed and meet applicable NEMA and OSHA requirements.

5.2 General Construction

A panelboard consists of three major component units: a panel interior, a steel box, and a steel front panel or trim. The box and trim make up the steel cabinet that houses the panel interior.

The panelboard boxes, sometimes referred to as panelboard cans, cabinets, or tubs, are usually made of Code gauge (Underwriter's code thickness) steel. The gauge will vary with the size of the box. Box ends may contain knockouts or may be supplied blank depending on the application. See Figure 2.

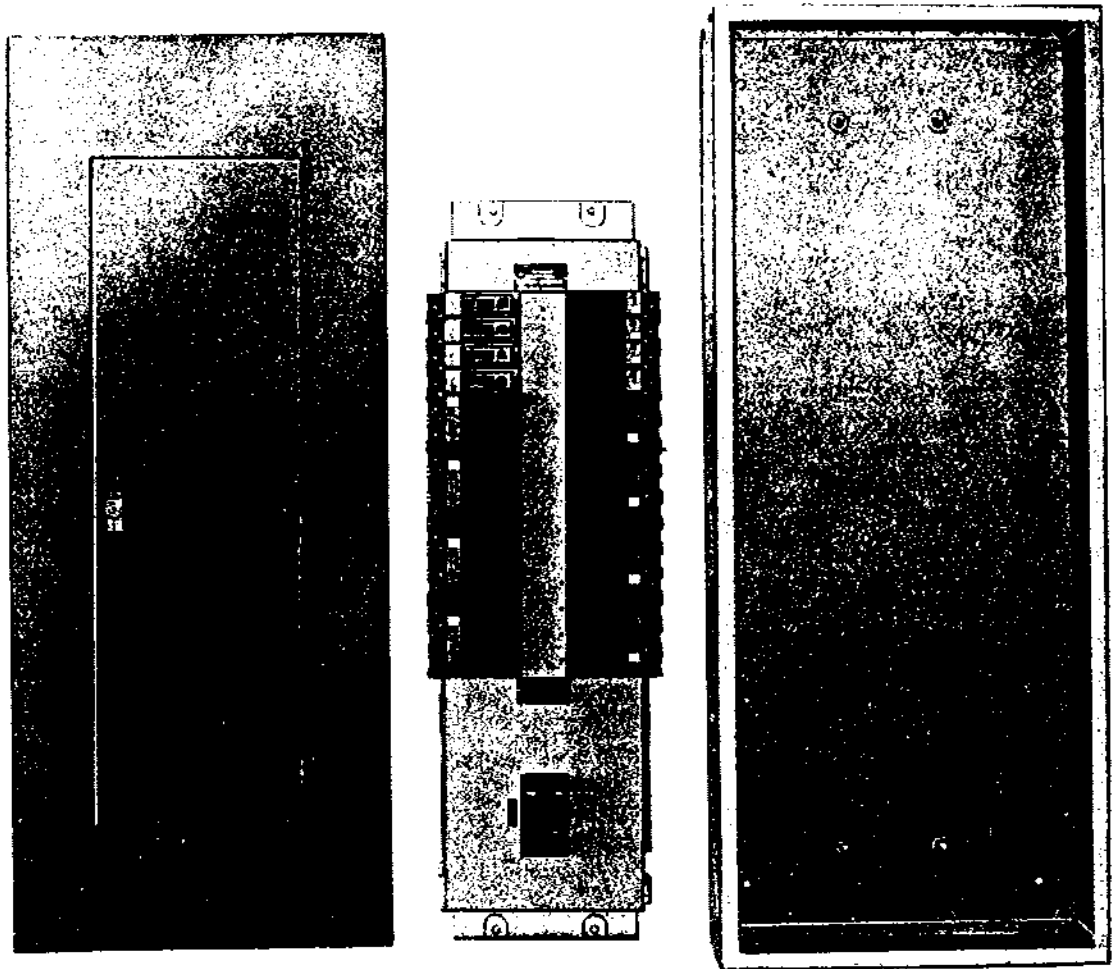


**Fig. 2 – The Three Assembled Units of a Panelboard
Front Panel, Interior, and Box**

The panelboard interior, sometimes called the panel base or chassis, is the electrical part of the panelboard. See Figures 3 and 4.

Panelboard trim is the third element that makes up the completed panelboard. Sometimes this unit is called the panelboard front. It completes the cabinet enclosure and provides the access door to the handles of the protecting breakers and switches. Trims are made of steel and designed to attach to the panelboard box after the panelboard interior has been installed and connected.

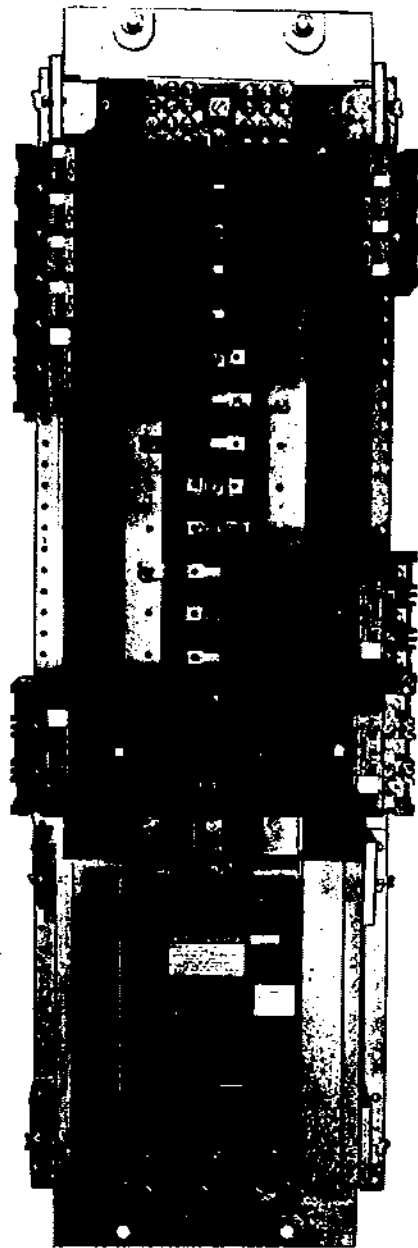


**Fig. 3 - Typical Panelboard Interior
(Panel Base or Chassis)**

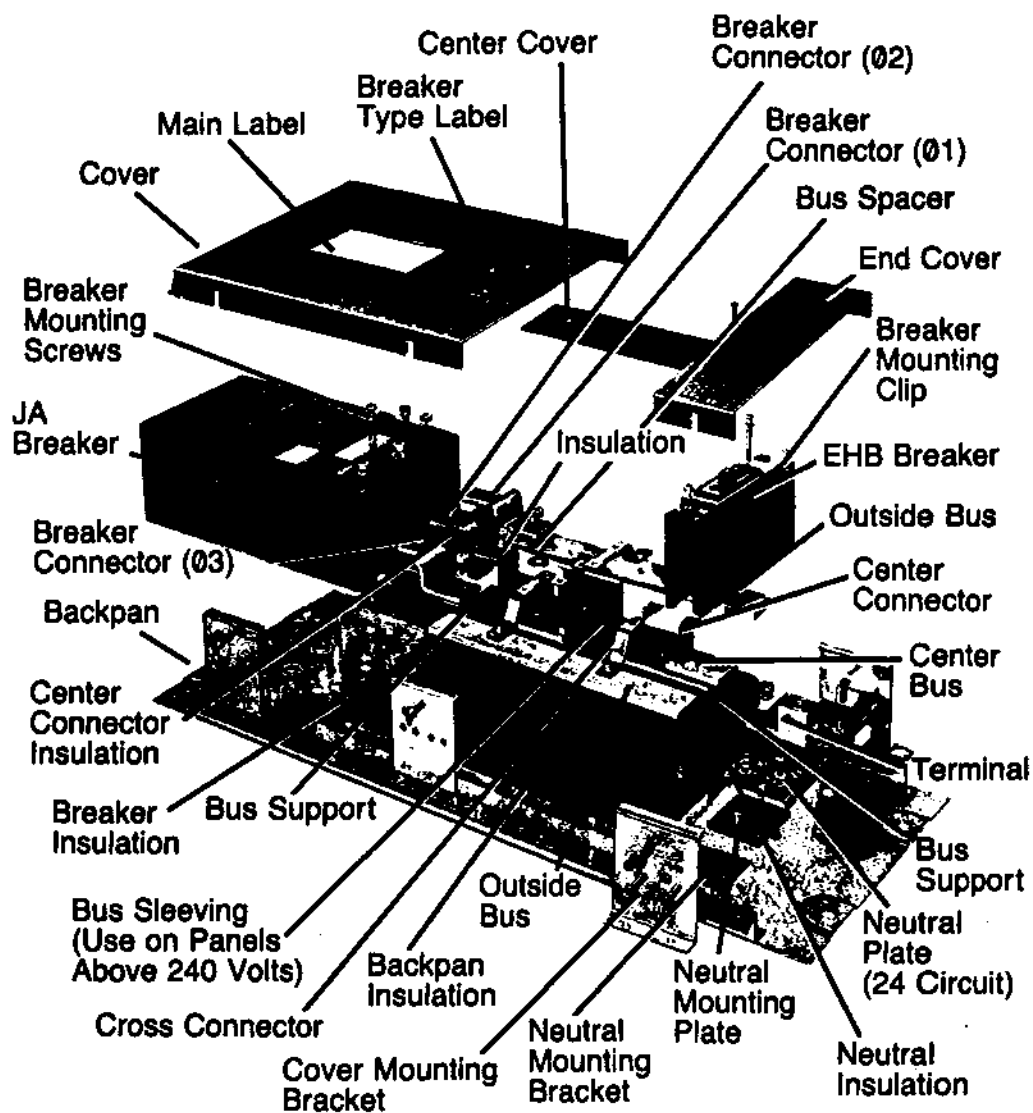


Fig. 4 – Exploded View of a Typical Panelboard Interior

5.3 Installation Procedures

The manufacturers installation instructions should be followed carefully.

Location is an important consideration. The panelboard should be readily accessible and not exposed to risk of physical damage.

Flammable Materials. The cabinet should be located well clear of flammable materials.

Unusual Service Conditions. Panelboards should not be exposed to ambient temperatures above 40C (104F). They should not be subjected to explosive or corrosive fumes, dusts, or vapors, or to high vibration, shock, tilting, or other unusual operating conditions unless designed specifically for the purpose.

Indoor Damp Locations. The panelboard should be located or shielded to prevent moisture or water from entering and accumulating. The box should be mounted with its back at least a quarter of an inch away from the wall or other supporting surface to prevent rusting of the rear of the box due to trapped moisture.

Wet Locations. Boxes for wet locations should be rainproof and sleet resistant if located outdoors, and drip-proof if indoors. A minimum of one fourth-inch clearance should be provided between the box and the supporting surface.

Clearance from Ceiling. The panelboard should not be located against a flammable ceiling. A space of at least three feet should be allowed between the top of the box and the ceiling unless an adequate fireproof shield is provided.

Space Around the Box. When selecting a location sufficient access and work space must be provided around the panelboard. The clear working space in front of the panelboard should be at least thirty inches deep and this space should never be used for storage. Minimum head room should be six and one fourth feet or the height specified in the NEC Article 110.

Mounting of the Box. The panelboard box must be securely fastened to its mounting surface. Wooden plugs driven into holes in masonry, concrete, plaster, etc., cannot be depended upon. See NEC Article 110-13.

Flush Mounting. If the panelboard is installed in a concrete, tile, or other non-combustible wall the front edge should not be recessed more than one fourth inch. If the mounting wall is wood or other combustible

material the cabinet should be flush with the finished wall surface. See NEC Article 373.

Unused Openings in Boxes. Any unused openings in the box should be closed to provide protection equivalent to the metal wall of the box.

Grounding. Panelboard boxes should be grounded as specified in NEC Article 250. When the box contains service equipment it is necessary to bond the box to the grounded (neutral) supply conductor.

5.4 Installation of Conduit and Wires

Conduits should be installed so as to prevent moisture or water from entering and accumulating in the enclosure. Provision should be made to protect conductors from abrasion in accordance with NEC Article 373.

Conductor lengths should be kept to a minimum within the wiring gutter. Excessive cable lengths may produce overheating.

Cable should be long enough to reach the terminal location in a manner that avoids strain on the connecting lug.

The largest practical bending radius should be used with all conductors. Too-short bending may damage insulation and loosen terminal connections.

5.5 Panelboard Interior Installation

Warning: Make sure that all power to all circuits involved is turned off and remains off during installation. Failure to heed this warning can cause severe injury or death by electric shock, and damage to property.

Items that make up the panelboard interior should be carefully unpacked, inspected, and stored until the box has been installed and wiring brought to the panelboard.

The panelboard box should be carefully cleaned prior to installation of the interior. Clean, especially such construction contamination as concrete, plaster, paint, etc., avoid abrasives that may damage the zinc plating and leave the box open to rust.

Follow the panelboard manufacturer's instructions carefully.

Installation Procedure

Alignment devices should be adjusted where provided, see Figures 5 and 6, interior should be installed, and final alignment made. On lighting and appliance panels having one inch wide breakers the interior should be adjusted so the return flange of the dead front pan is no more than $\frac{3}{16}$ inch from the front of the enclosure.

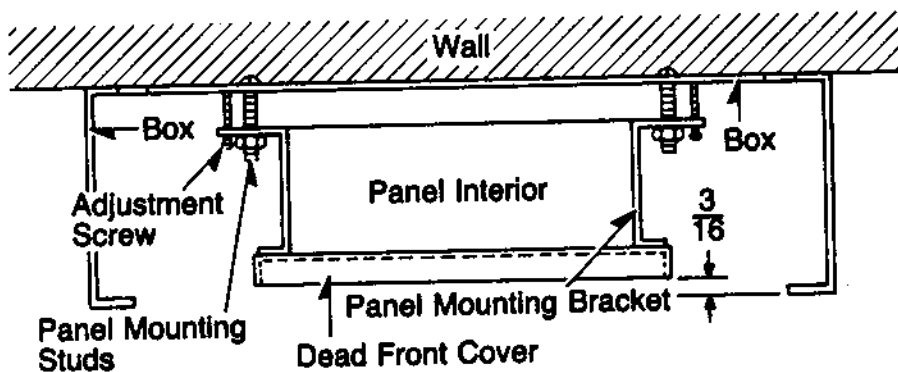


Fig. 5 - Typical Mounting Details for Surface Mounting
(Top Section View)

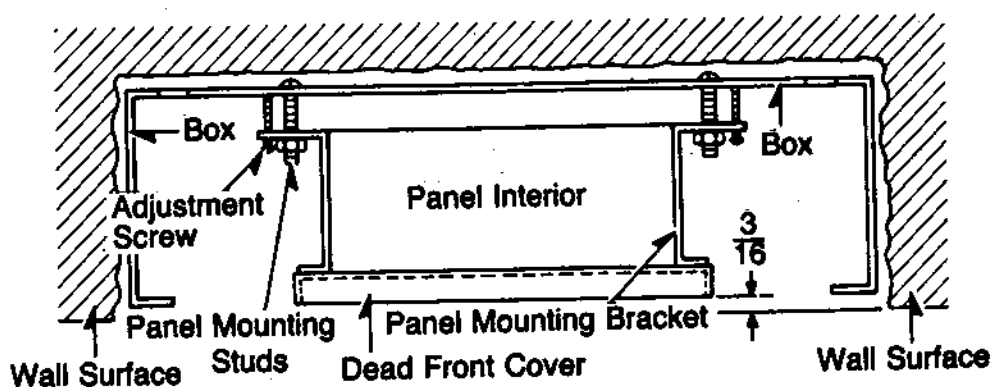


Fig. 6 - Typical Mounting Details for Flush Mounting
(Top Section View)

Connecting Conductors

Care should be taken in stripping insulation from conductors to assure the wire is not ringed or nicked. If aluminum conductors are used all oxide should be cleaned from the stripped portion and joint compound applied.

All lugs should be tightened in accordance with the manufacturer's torque values.

Grounding Panelboards

All panelboards must be grounded as specified in NEC Article 250. A properly sized terminal bar for equipment grounding conductors should be secured inside the panelboard box. The grounding conductors of all

the feeder and branch circuit equipment should be attached to this terminal bar, where the panelboard is used with non-metallic raceway or cable, or where separate grounding cables are provided. The terminal bar should be securely bonded to the box and should not be connected to the neutral bar other than service equipment. See NEC Article 384.

Before Energizing

Fuses of proper class and rating should be installed in fuse holders, current ratings of circuit breakers should be checked.

The panelboard enclosure should be cleaned and clear of all debris and foreign material accumulated during installation, especially metal pieces and extraneous hardware.

(If at this point the job is for any reason stopped, a piece of cardboard or thin plywood should be cut to fit the outline of the box and installed to protect the panel interior until all the wiring and detail work can be completed.)

Tighten all field made connections and all accessible bolted connections to the manufacturer's torque specifications. If torque specifications are not available tighten to the top limit of the values in the table below.

Table 1. Bolted Connections

Bolt Size	Tightening Torque
# 8-32	10-15 in.-lbs.
#10-32	15-20 in.-lbs.
¼"-20	5-7 ft.-lbs.
⅜"-18	10-12 ft.-lbs.
½"-16	18-20 ft.-lbs.
½"-13	40-50 ft.-lbs.

All shipping blocks and bracing should be removed from components and panelboard interior.

All switches and circuit breakers should be manually operated to assure freedom of action.

Warning: If an insulation resistance test of the installed panelboard reveals resistance of less than one megohm on an open branch circuit device the system is unsafe and must be corrected. Failure to heed this warning can cause severe injury or death, and damage to property.

An insulation resistance test must be conducted to assure that the system is free from short circuits and grounds. Check should be phase-to-phase with switch or breaker in both open and closed position. If resistance reads less than one megohm when testing a branch circuit device in the open position the condition is unsafe and must be investigated.

A re-check should be made to determine that all grounding connections are properly made. If the panelboard is to be used as service entrance equipment assure that the neutral is securely bonded to the enclosure.

All interior dead front shields should be properly aligned and tightened.

Panelboard trim installation is the final step prior to energizing. This is the part of the panelboard that is in full view. Care in unpacking and installing, and touch-up painting of scratches and mars will greatly help appearance.

Energizing should be done with a competent electrician present, with all circuit devices closed, and loads disconnected down stream wherever practical.

5.6 Care and Maintenance

A care and maintenance program for panelboards should be conducted on a regularly scheduled basis, at least once a year and after any severe electrical fault.

One check can be made before the panelboard is de-energized. A panelboard that has been carrying its regular load for at least three hours just prior to inspection can be checked for hot spots by placing the hand on the dead-front surfaces of breakers, switches, interior trims, doors, and box sides. If there is any surface so hot the hand cannot be held on it for at least three seconds, there may be trouble and investigation is indicated.

Warning: Before performing any other tests or inspections, all power must be turned off and incoming line terminals checked with a volt-meter to positively assure that the equipment is totally de-energized. Failure to heed this warning can cause severe injury or death, and damage to property.

Check should be made for moisture or signs of previous wetness or condensation inside the panelboard, and in conduits.

Any conduits that have dripped condensate should be sealed, and means provided for the conduit to drain safely.

Any cracks or openings through which moisture can enter the panel-board should be sealed. Sources of any moisture that contaminates or threatens the enclosure should be eliminated.

Any insulating material in the panelboard showing signs of previous or existing moisture, should be replaced or cleaned and dried.

Accumulated dust and dirt should be cleaned out with a brush or vacuum cleaner, not blown out with compressed air.

All visible electrical joints and terminals should be inspected.

Bolts, nuts, and accessible hardware should be re-tightened. Check should be made for any sign of overheating or looseness.

Any parts where contact surfaces are dirty, corroded, pitted, or more than slightly discolored should be replaced or cleaned. Emery cloth should not be used because emery is a conductor.

Fuse clips should be examined. If there is any sign of overheating or looseness, spring pressure and tightness of clamps should be checked. Fuse clips should be replaced where pressure compares unfavorably with other identical fuse clips on the same panel.

Plug fuses should be re-tightened.

Check should be made for signs of deterioration of insulation or melting of sealing wax. Any deteriorated insulating parts or assemblies where sealing has melted should be replaced. Conditions causing over heating should be investigated and corrected.

Operation of all mechanical components should be checked. Switch operating mechanisms and external operators for circuit breakers should be exercised to make sure they quickly and positively switch contacts.

Integrity of all electrical and mechanical interlocks and padlocking mechanisms should be confirmed.

Inspection should be made for missing or broken parts, proper spring tension, free movement, rust or corrosion, dirt, and excessive wear. Adjust, clean, lubricate, repair, and replace as required.

Arc chutes and insulating parts should be examined for cracks or breakage, and for arc spatter, sooty deposits, oil, or tracking, and, where found, cleaned off. If appreciable material has burned away or if the material is burned or deteriorated, parts should be replaced.

Cracked or broken arc chutes and insulating parts should be replaced.

Copper electrical parts, blades, and jaws when inspection indicates need, should be cleaned and dressed. Removing metal from silver contact surfaces is to be avoided.

Sliding contacts should be dressed to remove projecting burrs or arc-transferred material which interferes with free movement.

Contact surfaces should be cleaned to remove any oxides. Fine aluminum oxide paper should be used and as little material as possible removed. Metal and abrasive material should be kept entirely out of the panelboard.

Blades or jaws which are burned away enough to appreciably change their shape or to interfere with the tapered edges and not allow them to act freely should be replaced.

Where contacts show signs of overheating, spring pressures and stiffness of parts should be compared with identical items. Springs, jaws, blades, or contacts if softened or otherwise damaged by heat should be replaced.

Only those parts of the switch mechanism requiring oiling should be lubricated. The manufacturer's instructions contained in applicable service and instruction literature should be carefully followed.

Clean, non-metallic light grease or oil as recommended by the manufacturer should be used.

Molded case circuit breakers should not be oiled or greased.

In the absence of instructions on devices, a general guide is to lubricate with clean light grease sliding copper contacts, operating mechanisms, and interlocks. All excess lubrication should be wiped off to avoid catching dirt.

Insulation resistance should be tested if a severe electrical fault has occurred or if it has been necessary to replace parts.

All insulating surfaces should be cleaned if the panelboard has been exposed to high humidity, condensation, or external moisture.

Warning: Installation of incorrect fuses can cause personal injury or substantial property damage.

Fuses should be checked to make sure they have the proper ampere rating and interrupting rating. Non-current limiting fuses are never used as replacements for current limiting fuses. No attempt to defeat rejection mechanisms that are provided to prevent installation of the wrong fuses should be made.

5.7 Permissible Loading of Panelboards

The ratio of load current to thermal device rating determines the operating temperature. To comply with NEC Article 384, the loads of panelboard circuits should not be greater than 80% of the rating of the thermal device. For complete information on code requirements governing installation and loading of panelboards consult the National Electrical Code, published by the National Fire Protection Association, 470 Atlantic Ave., Boston, MA 02210.

5.8 Low Voltage Distribution Switchboards

Low voltage distribution switchboards are usually free standing units rated from 400 to 4000 amperes, at 600 volts or less. The function of these switchboards is the distribution of power within a commercial or industrial electrical system. These switchboards use molded case breakers and fused switches for control of outgoing branch circuits and either molded case breakers, or power circuit breakers as the main overcurrent device, in contrast to low voltage metal enclosed switchgear which uses power circuit breakers exclusively.

5.9 Switchboard Standards

Article 384 of the National Electrical Code outlines the minimum standards for switchboards. It covers many options involving maintenance, operating convenience, extra safety features, and overload capacities. The National Electrical Manufacturer's Association standards for switchboards are also complete with detailed definitions, test, and performance specifications, application guidelines, and construction and enclosure details.

Switchboards built prior to 1972 were identified by three NEMA classifications, Class I, Class II, Class III.

Both Class I and Class II were designed with group mounted (panelboard construction) branch circuit devices. The Class I was limited to 2000 ampere main bus and was of shallow type construction for installation against a wall; all components including main bus were front accessible only. The Class II was available with a main bus rated

through 4000 amperes and was accessible from both the front and rear of the switchboard. The Class III design had individually mounted branch devices, otherwise, the construction specifications for the Class III were similar to the Class II construction.

Switchboards built after 1971 are not given class numbers. The later standards are somewhat more flexible by allowing the switchboard maximum ampere rating, devices, and physical arrangement to be selected according to function, providing that all facets of the switchboard design comply with good engineering practice and with the respective requirements detailed in the standards. Distribution switchboards, when they comply with Underwriters' standards may have each individual vertical section U.L. labeled, if all the devices in that section are U.L. listed.

5.10 Types of Construction

Although NEMA standards no longer designate the different types of switchboard construction by name, most manufacturer's products fall into the same three categories as when the Class I, II, and III designations were officially used.

Some manufacturers have substituted their own nomenclature to help simplify the specifier's task of designating the type of switchboard best suited to the application.

Two variables in construction or assembly determine the basic types:

Accessibility of internally mounted equipment

and

Method used in mounting and assembling the feeder or branch circuit devices (breakers, switches, etc.).

Figures 7 through 12 show examples of some basic switchboard types in common use which embody combinations of the above variables.

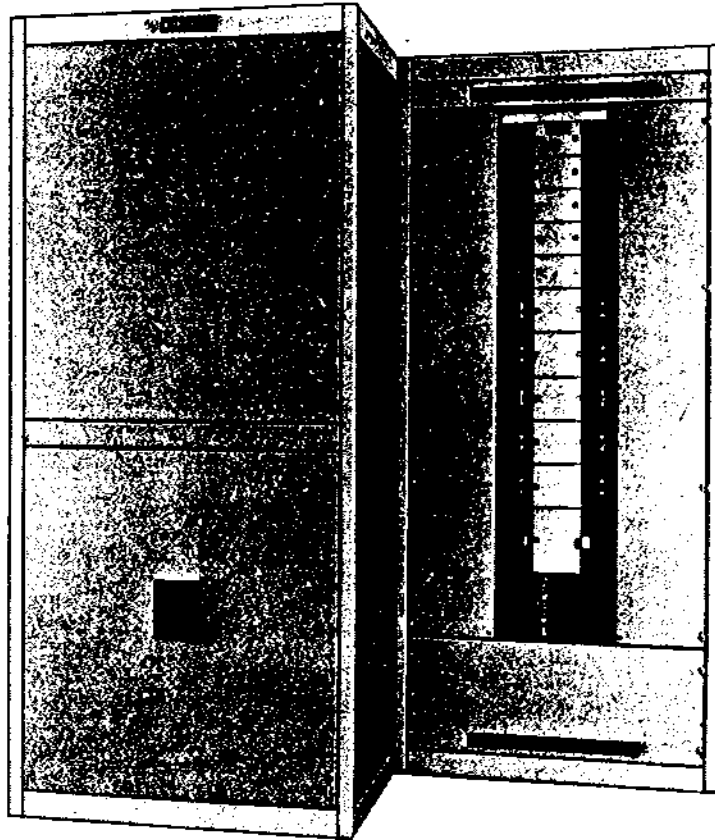


Fig. 7 – Typical All-Front-Accessible Switchboard with Panelboard Type Branch Circuit Devices, Against-the-Wall Mounting

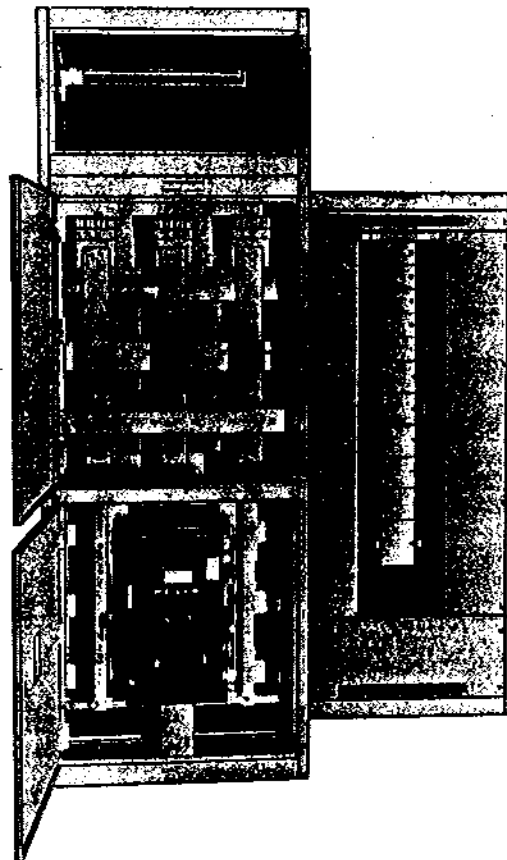


Fig. 8 – Front Accessible Switchboard—Access View

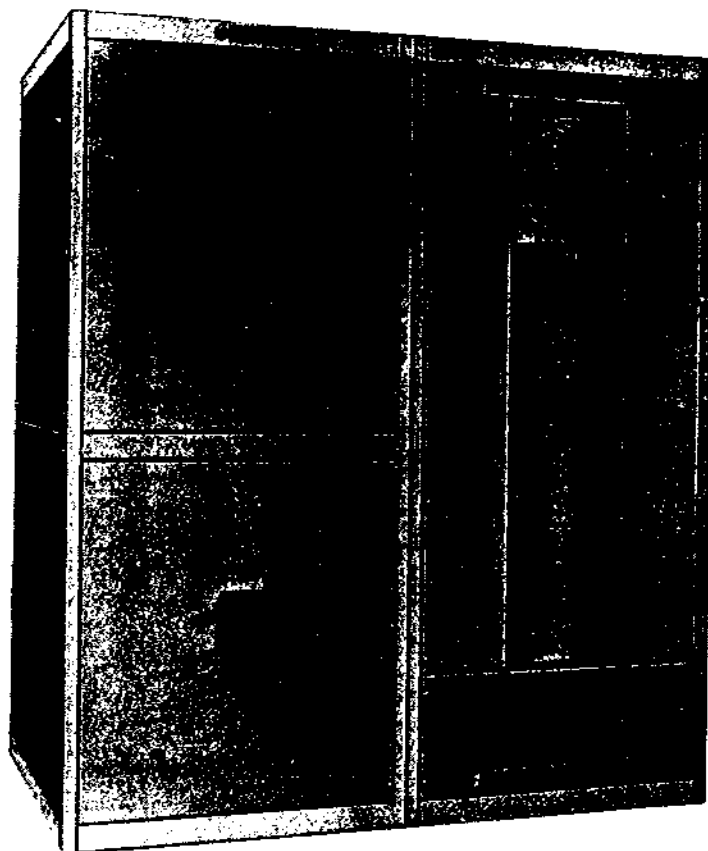


Fig. 9 – Front and Rear Accessible Switchboard with Panelboard Type Branch Circuit Devices



Fig. 10 – Front and Rear Accessible Switchboard with Panelboard Type Branch Circuit Devices, Rear View

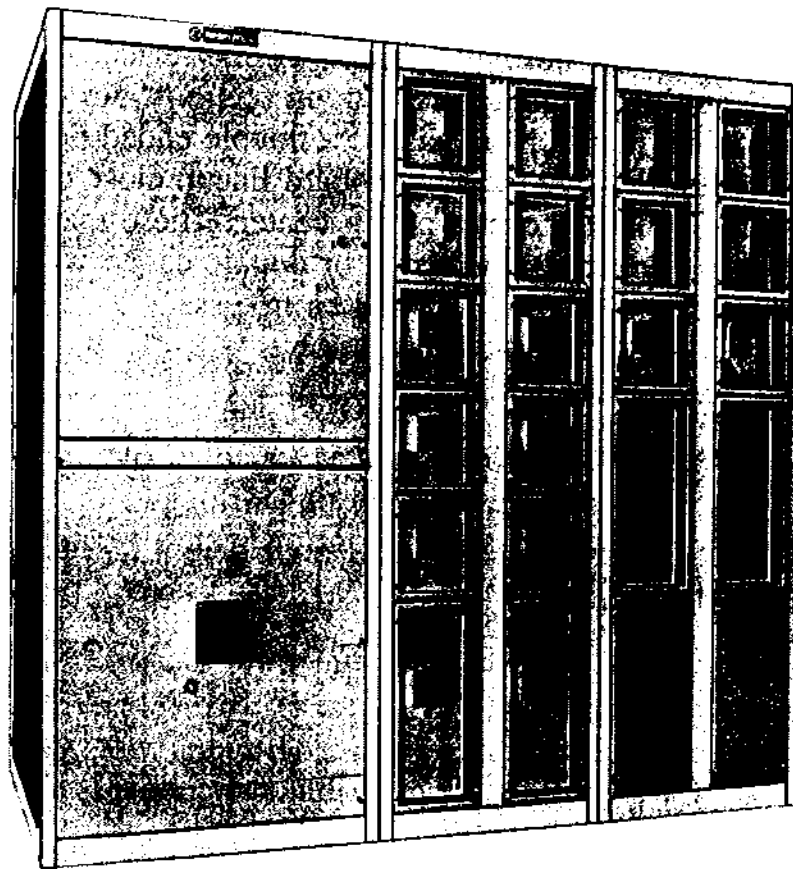


Fig. 11 – Front and Rear Accessible Switchboard with Individually Mounted Branch Circuit Devices

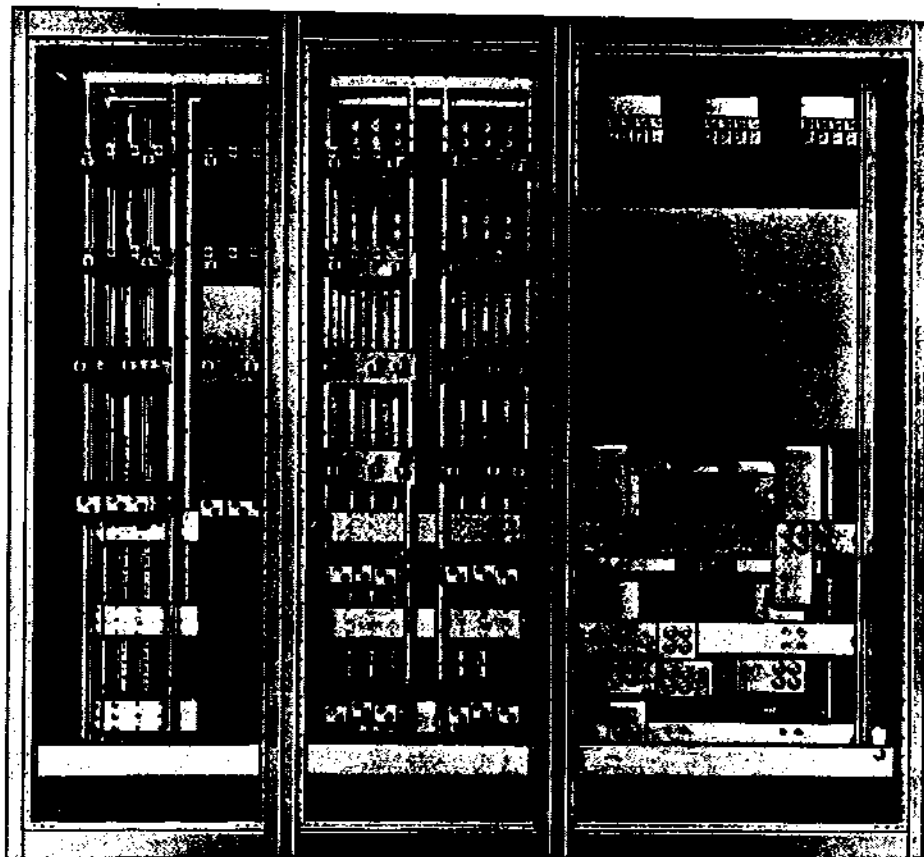


Fig. 12 – Front and Rear Accessible Switchboard with Individually Mounted Branch Circuit Devices, Rear View

5.11 Construction

Distribution switchboards normally consist of one service section (incoming line) and one or more distribution sections. An exception may be where the switchboard is part of a double ended power center. Many installations will have the switchboard lineup close coupled to the main power transformer to form a power center. These may be single ended with only one power transformer or double ended with a power transformer on each end. Usually it will be necessary to have an auxiliary compartment to contain the transition bus between the transformer secondary and the switchboard.

Distribution switchboards can be designed for either indoor or outdoor application. They are most frequently designed for indoor use. Outdoor units usually consist of a standard indoor unit with a weatherproof enclosure assembled around it.

A. Main or Service Sections

A common design concept is followed for all main or service sections whether they are for front or rear accessible switchboards. The service section normally contains or provides for:

- 1 – Main devices through 4000 amperes maximum in all types.**
- 2 – Provision for terminating the incoming power feeders (cable or bus).**

On front accessible only switchboards, where the incoming service is rated 2500 amperes and above and is brought in from the bottom, a bussed pull section is required and is installed adjacent to the service station. Where service cable or bus, 2500 amperes and above, enters from the top a top mounted pull box is used. See Figure 13.

- 3 – Section of main (through) bus.**
- 4 – Ground fault protection as required.**
- 5 – Instrumentation and control devices as required.**
- 6 – Provisions for current and voltage transformers when specified, see Figure 14. Either hot or cold sequence metering provisions are available and are supplied in an isolated compartment with a lockable door.**

Hot Sequence: Current transformers are located on the line side of the main disconnect.

Cold Sequence: Current transformers are located on the loadside of the main disconnect.

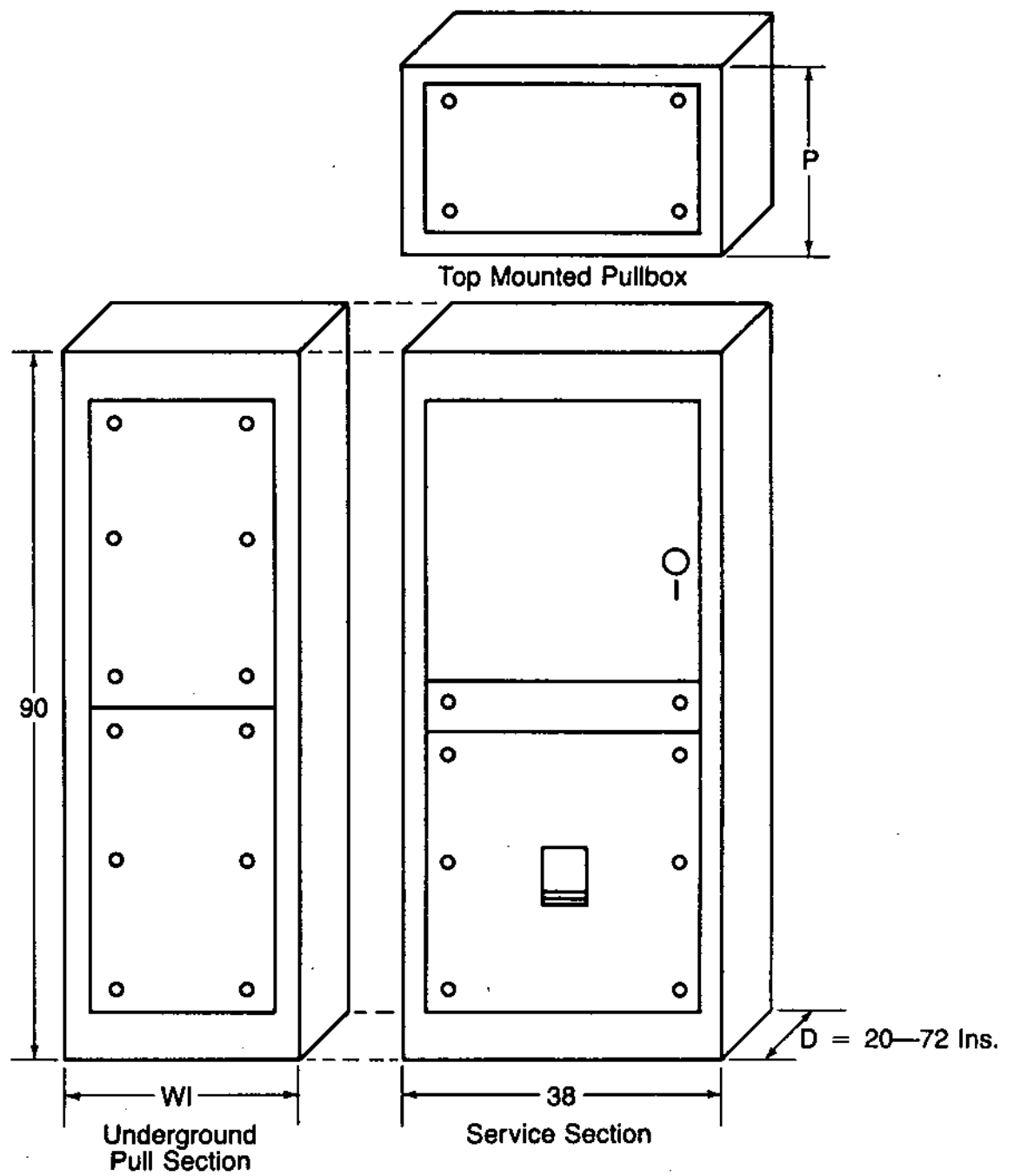


Fig. 13 - Terminating Incoming Power Feeders

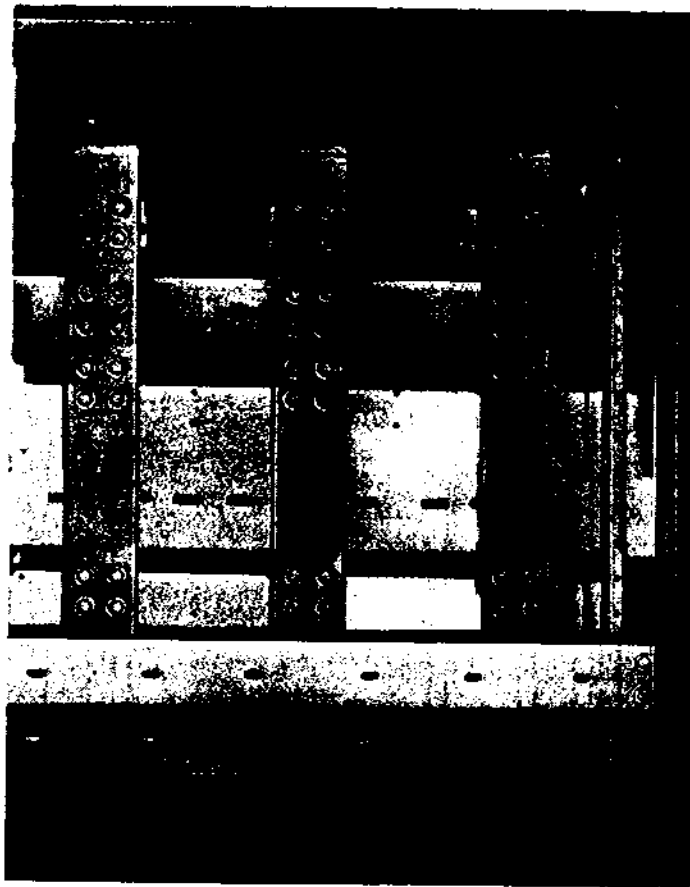


Fig. 14 – Provision for Current and Potential Transformers

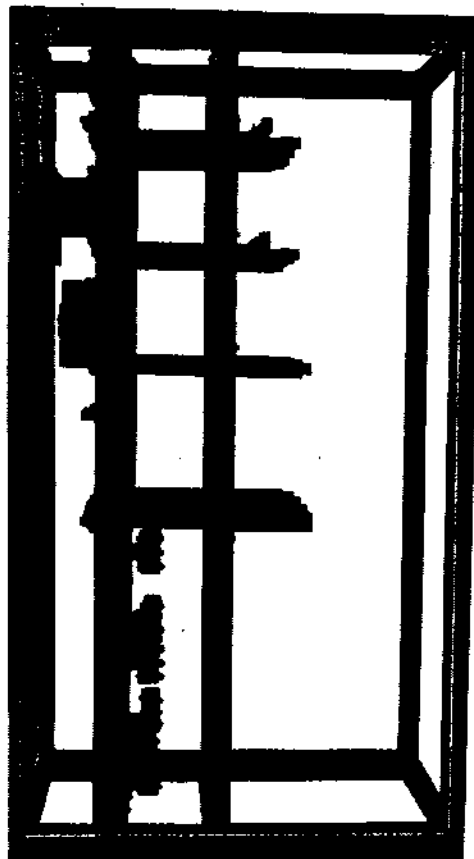


Fig. 15 – Distribution Structures Segregated into Three Compartments, Front to Rear

B. Distribution sections usually contain the following:

- 1 – Branch and feeder overcurrent devices (molded case breakers or fusible switches). These devices are mounted on a panelboard chassis, connected to a vertical section bus located in the panel chassis. Panel mounted devices are applicable for both rear accessible and front only accessible switchboards.
- 2 – Ground fault protection on feeder circuits, when specified.
- 3 – Section of main (through) bus.
- 4 – Section of ground bus.

Panelboard type distribution sections are essentially identical in general construction whether rear or all front accessible, except a shallow type is used for installation against a wall and is accessible only from the front and ends of the switchboard. All sections will align at the rear and any variations in depth due to deep service sections required by large main disconnects, will project from the front.

If mounting against a wall is not required, all sections will be aligned both front and rear and will be the depth required by the largest disconnect. All sections will be both front and rear accessible.

C. Distribution Sections – Individually Mounted Devices

The individual style of mounting offers all the safety features required on modern distribution systems and recommended by industry standards. This style complies with Article 384 of NEC by extending all load connections into a cable compartment at the rear of the structure. Additional bus isolation may be provided by full height insulating barriers between the main bus compartment and the rear cable compartment and between the front device compartment and the main bus compartment.

On some designs the distribution structures are divided into three compartments from front to rear; breaker, main bus, and cable compartment for load connections. See Figure 15. Each of these compartments can be completely isolated from the others.

Where both sets of barriers are installed, the main bus compartment is completely isolated from the electrical work areas. Barriers are removable for inspection and maintenance.

The rear extensions from the load side of the circuit devices are fully insulated, they extend into the cable compartment through barriers that isolate the cable compartment from the bus compartment, see Figure 16.

Distribution sections of this type will normally contain the following:

- 1 – Individually mounted branch circuit devices.
- 2 – Section of main (through) bus.
- 3 – Vertical section bus.
- 4 – Ground fault protection as specified.
- 5 – Instrumentation and control devices if specified.
- 6 – Section of ground bus.

D. Components Common to All Distribution Switchboards Main Bus (Through Bus)

Tin plated aluminum or silver plated copper bus will be found. The tin plated aluminum is usually the standard on low voltage distribution switchboards.

Short circuit rating of 50,000 amperes rms symmetrical is the standard. For 75,000; 100,000; 150,000; and 200,000; amperes rms symmetrical ratings are available and will be encountered.

Bus bar is sized according to Underwriter's Laboratories and NEMA standards. Size is based on a temperature of not more than 65C above an ambient of 25C. A-B-C bus arrangement, left to right, top to bottom, front to rear, as viewed from the front, is standard.

1. Ground Bus

A ground bus is furnished firmly secured to each vertical section: the bus extends the entire length of the switchboard. A grounding lug is attached to the ground bus in one section

2. Ventilation

Switchboard ventilation is provided through louvers located at top and bottom usually in the rear of each structure and at the ends of the switchboard lineup.



Fig. 16 – Rear Extensions Extend into the Cable Compartment for Termination of Feeder Cables

5.12 Installation Practices

A. Receiving

Distribution switchboards are constructed from modular vertical steel structures. Shipping lengths will vary depending on the type of switchboard and the equipment contained therein. Each shipping section is bolted to heavy wooden skids extending approximately 8 inches beyond all sides of the switchboard. The entire switchboard is then enclosed in a heavy duty plastic covering to protect the finish, and for protection against dirt and weather during shipment.

Immediately upon receipt of the switchboard, the plastic covering should be removed and a thorough inspection of each section should be made to detect any damage incurred during shipment; any damage should be reported at once to the carrier. It is recommended that the plastic cover be replaced after inspection for protection of the equipment until installation time.

B. Handling

Lifting facilities for handling by crane are bolted to the top of each shipping section. After the shipping section is positioned for installation, the lifting irons, plastic covering, and wooden skids may be removed. The mounting hardware for the lifting irons should be replaced to prevent the entrance of dirt. Where crane facilities are not available, the structure may be positioned by using rollers under the shipping skids. The skids should be left in place until a shipping section is in final position, then removed.

C. Storage

Indoor switchboards which cannot be installed and put into service immediately, should be stored in a dry, clean place, (preferably indoors, in a heated building.) Trouble and delay will be avoided by having good storage facilities arranged so the apparatus will be accessible only to authorized persons. Conditions such as dampness, changes in temperature, cement dust, and corrosive atmosphere should be carefully guarded against. If necessary to store outdoors, special precautions will be required to keep it clean and warm enough to control condensation. It will be necessary to cover the switchboard and install temporary heating equipment. Approximately 250 watts per unit are required for average conditions. During storage the shipping groups should be placed on level surfaces to prevent unnecessary strain and possible distortion.

D. Installation

Distribution switchboards are assembled at the factory on smooth and level surfaces to assure correct alignment of all parts. The foundation furnished by the purchaser must be true and level. An uneven foundation can cause misalignment of shipping sections, units and doors. If the foundation is subject to vibration, special mounting must be provided to prevent the transmission of vibration or shock to the equipment. The preferred method of anchoring the indoor switchboard is by fastening it to steel channels which are properly embedded in the concrete floor.

When large power center transformers are included with high voltage switching equipment, a large channel must be used. It is preferred that the channel be located with its web at top and horizontal.

Each unit must be fastened to the floor channels by either bolting or welding. If bolting is to be used, the mounting bolts must be placed in the floor steel before the concrete is poured to assure that the tapped holes will not fill with concrete. Welding is a quick and easy method of securing the switchboard in place and eliminates the layout of the mounting holes in the channels.

E. Joining Switchboard Sections

Where two or more shipping sections are to be joined they should first be aligned, leveled, and secured to the channel sills or foundation.

Provisions for splicing the main bus may vary depending on type of switchboard and configuration of the main bus assembly.

Some switchboards have provision for joining or splicing the main horizontal bus bars only between two adjacent shipping sections, while the bus in each shipping section is a single unspliced length. Others are designed with splicing means at every vertical juncture so any section may be shipped and installed individually.

In either design two basic methods for joining the adjacent bus bar ends are commonly used.

In one method, the adjacent bus bar ends are lapped and bolted. One end has an offset bend to allow for overlapping without causing an off-center alignment of structures.

In the other method of joining the bus bar ends no offset bend is required because separate splice plates are used which overlap both ends to be joined and are bolted in place. Slotted bolt holes are used in bus bars to allow adjustment to slight variations in alignment.

For shipping purposes all factory parts and hardware necessary to re-assemble the bus joints at installation will be packaged, identified and securely attached to one of the shipping sections.

F. On-Site Re-Assembly

Shipping sections should be joined in line with this procedure:

- 1 – Remove covers in sections adjacent to the shipping break necessary for access to the main bus assembly.
- 2 – Remove any temporary shipping braces or spacers from main bus.
- 3 – Align the switchboard sections and bolt to channel base or foundation, use half-inch bolts.
- 4 – Bolt adjacent structures together. Use 1/2-13 x 1-1/4 inch long bolts, nuts, and washers.
- 5 – Bolt bus splice together and torque bolts as specified by the manufacturer or as shown in Table 1 (page 2:5.9), or Table 2 (page

2:5.30). This tightening assures adequate electrical contact pressure.

- 6 – The neutral (when furnished) and ground bus should be connected in a similar way.
- 7 – Inspect interior of all enclosures to assure that no tools, metal scraps, loose hardware, or other foreign material such as cement, plaster, or dirt is left within the switchboard.
- 8 – Replace front and rear covers.
- 9 – When a section is to be added to an existing switchboard, the end cover should be removed from the existing structure prior to putting the new structure in place. It should be relocated on the end of the new structure with the existing hardware.
- 10 – When making an addition, if the existing bus is oxidized, a good contact area should be prepared by sanding lightly with aluminum oxide paper. Emery cloth or any abrasive containing emery should *never* be used.

G. Incoming Line Connections

Power is normally brought into a switchboard either by cable or bus. When cable connections are used, pressure type terminals approved for copper or aluminum are provided for terminating the cable on the line side of the main overcurrent device, current transformers, or main bus. Cables may enter through the top or bottom of the switchboard. Under certain conditions an underground cable pull section or top mounted pull box may be required on front accessible only switchboards, see Figure 13.

Where aluminum cables are used proper termination lubricants should be used and the lug screws torqued to recommended pressures, refer to manufacturer's recommendations or to Table 2. Strand clipping to fit large cable into small lugs is not recommended.

Busway service is usually brought in at the top of the switchboard service section. A cutout and drilled opening will be provided at the top of the section to receive the busway flange. Standardized busway extension conductors extend into the switchboard. Bus bars are provided by the switchboard manufacturer from the line side of the main device, and neutral when provided, to the busway entrance. This bus assembly is completely formed and drilled for connection to the busway extensions.

Temporary bracing provided for the bus assembly during shipment, must be removed after connections have been made. Connection bolts should be torqued as shown in Table 1.

H. Precautions

This list of precautions should be followed during handling, installation, and operation of switchboards:

- 1 – Warning: De-energize the switchboard before working on it. If it is necessary to work on a circuit in the rear cable compartment, the main bus should be de-energized and all other circuits checked for feed-back from other sources. If this is not possible, only the rear covers for the compartment involved should be removed and all live parts isolated (covered) with adequate, dry insulating material. Failure to heed this warning can cause severe injury or death by electric shock, and damage to property.**
- 2 – Only qualified personnel should be authorized to handle or operate the switchboard.**
- 3 – Switchboards should always be handled with care. Rough handling will damage delicate components.**
- 4 – If relays are included, remove blocking of relay armatures. Check control circuits for grounds or short circuits (except current and voltage transformer circuits) before applying control power.**
- 5 – Connect the switchgear to the station ground before applying any power.**
- 6 – Warning: In case of fire do not use liquid fire extinguishers until all circuits are de-energized. Failure to heed this warning can cause severe injury or death by electric shock, and damage to property.**
- 7 – If an outdoor switchboard is to be stored prior to installation provision must be made to energize the space heaters to control condensation of moisture in the switchgear.**

If an indoor switchboard is to be stored prior to installation it must be protected from the weather and kept free of condensation.

8 – All personnel responsible for supervision, installation, operation, and maintenance of the switchboard should be thoroughly familiar with the equipment and function and prepared to act quickly in event of emergency.

I. Inspect Before Energizing

Before energizing the switchboard conduct a thorough inspection to assure that all tools, scraps, wire, or other debris are removed. Any accumulation of dust or dirt should be removed, preferably with a vacuum cleaner.

Care should be exercised to prevent equipment from being connected to the power system while preliminary tests are being conducted. If disconnecting switches are not available line power should be disconnected to accomplish this.

Test equipment requirements will depend on the rating and type of installation. Portable voltmeters of the multi-scale type will be required. Ammeters, ohmmeters, megohmmeters, test lights, and test bells may be required.

Wire connections, accessible bolted bus connections, and insulated joints should be examined to make sure that they have not been loosened or damaged during shipment or installation. All circuit connections are tightened by the manufacturer at time of assembly by power driven tools with controlled torque. However, the vibrations experienced in transit may loosen some of these connections. It is recommended that at least 10% of the total connections be checked for tightness. Should this spot check reveal some loose connections, then it will be necessary to check all connection points. The connections include bus hardware, circuit breaker and switch terminals, contactor and relay terminals, and terminal blocks.

All relays should be inspected to make sure that any blocking for shipment is removed and that the armature moves freely. Power circuit fuses are normally furnished by the purchaser and must be installed in the field. Each fuse should be checked for correct rating in accordance with National Electrical Code application requirements. Finally, all mechanical latches, operating mechanisms, and door assemblies should be checked for proper alignment and operation. Mishandling in transit can cause misalignment.

5.13 Inspection and Maintenance

Warning: Fully de-energize switchboard before beginning inspection. Failure to de-energize the switchboard can cause severe personal injury or death, and substantial damage to property.

To assure high quality service, a definite maintenance schedule, systematically followed, is essential. Plant, operating, and local conditions vary to such an extent that the schedule must be prepared to suit the conditions. However, the maintenance schedule for individual devices such as circuit breakers, relays, meters, etc., should be based upon recommendations contained in the individual instruction book for the device. Inspection and test operations should be coordinated with the overall program to result in the least operating inconvenience and circuit shutdowns.

General Inspection

The switchboard installation should be given a thorough cleaning and maintenance check at least annually under normal operating conditions. Where conditions are abnormally unfavorable more frequent inspections and maintenance will be required. The following require attention:

1 – Buses and Connections

De-energize primary circuits and remove rear covers from cable compartment. Before cleaning measure the resistance between phases and to ground. Inspect for symptoms which might indicate overheating or weakened insulation. Remove dust from bus, connections, supports, and enclosure surfaces, preferably with a vacuum cleaner.

Warning: Wipe clean with a non-combustible solvent observing usual precautions against sparks, flames, breathing of vapor, or prolonged contact with skin. Failure to heed this warning can cause severe injury or death as some solvents are highly toxic and readily absorbed into the system.

After bus has been dusted and wiped clean again measure the resistance between phases and to ground. Keep a record of these readings, trends in successive readings will indicate any lowering of insulation resistance.

All bus connections should be torqued in accordance with the following tables:

Table 2. Torque Values for Copper Bar and Lug Connections

Bolt Size	Nominal Torque
#10	30 in.-lb.
1/4 in.	65 in.-lb.
5/16 in.	10.8 ft.-lb.
3/8 in.	20 ft.-lb.
1/2 in.	50 ft.-lb.

2 – Insulation

Insulating materials vary in characteristics with the mechanical and electrical uses to which they are put. In distribution switchboards insulation is used to support and brace bus bars, to insulate or isolate live parts, or to prevent live parts of opposite polarity from coming into contact.

Glass polyester is commonly used for bus supports and other applications where it is in direct contact with energized parts, because of its mechanical strength, its thermal endurance, and its resistance to the effects of moisture. Other materials such as ebony asbestos, Micarta® or other laminated plastics, are often used as safety barriers. Regardless of material the three cardinal rules for extending the operating usefulness of insulation are:

Keep it dry.

Keep it clean.

Do not subject it to higher than its rated voltage.

More detailed information on insulation and testing may be found in *Westinghouse Electrical Maintenance Hints, Volume 1 Chapter 6*.

3 – Devices

There is a great variety of standard switching and overcurrent devices used in distribution switchboards.

The manufacturer's product information will provide necessary data. The devices most commonly used as listed below:

Low Voltage Power Circuit Breakers
Molded Case Circuit Breakers, Fused and Unfused
Systems Circuit Breakers
Quick-make, Quick-break, Fusible Switches
Combination Motorstarters
Automatic Transfer Switches
Bolted Pressure Contact Switches

4 – Instruments, Relays, Panel Mounted Devices

Individual devices should be maintained according to the specific instructions supplied for each device. For enclosed relays, periodically remove covers and inspect for dirt. This should be done by qualified relay test personnel.

Switches, (control, transfer, and instrument) should have contacts inspected at regular intervals.

5 – Secondary Wiring

All secondary wiring connections should be checked¹ for tightness, including connections at current and voltage transformers, and at terminal blocks where circuits leave the switchboard.

All secondary wiring that should be connected to the switchgear ground bus should be checked for proper connection.

All secondary wiring should be inspected for pinched insulation or broken strands.

6 – Ventilation

All grill work, labyrinths, and air passages should be free from obstruction and accumulation of dirt. The air space under outdoor switchboards must be kept free of leaves, nests, debris, and other obstructions.

7 – Records

The condition of each switchboard unit should be recorded at each inspection. These records will provide a guide for anticipating the need for any replacements or special attention at the next inspection.

It is recommended that a series of quarterly inspections be made to measure the effects of local conditions to help in determining a long range schedule that will keep the equipment in good condition.

8 – Renewal Parts

When ordering renewal or spare parts, include as much information as possible. In many cases the style number of the new part can be obtained from identification on the old part. Always include a description of the part. Specify the rating, unit number, and shop order number and a description of the switchboard on which the part is to be used.

Motor Control Centers

NEMA Standards 2:6.1

Construction 2:6.6

Installation 2:6.10

Motor and Control Connections 2:6.18

Unit Components 2:6.20

 Overload Relays 2:6.21

 Overload Heater Application 2:6.22

 Heater Selection 2:6.23

Maintenance 2:6.27

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, or damage to property.

Motor Control Centers

Motor control centers are used wherever centralized control of a number of motors is feasible and desired. They provide a control location where incoming and outgoing lines to branch circuits can be consolidated. Motor control centers are built to NEMA and U.L. standards and their modular construction permits convenient grouping, flexibility and conservation of space and maintenance cost.

In addition to the obvious advantages of reduced installation cost, centralized control eliminates the need for time-consuming trips to remote areas in a plant to shut down equipment or restart a motor that has tripped out its circuit due to overload. In the event of a power failure, motor control centers provide a rapid, safe means of restoring power. Orderly and sequential start-up of process motors, fans, pumps, and blowers is critical. In some industrial operations, after a power interruption, automatic restart is dangerous.

6.1 NEMA Standards

The National Electrical Manufacturer's Association has established two categories of motor control centers:

Class I Control Centers are essentially a mechanical grouping of combination motor control, feeder tap, and other components arranged in a convenient modular assembly. They include connections from the common horizontal power bus to the units. They do not include interwiring or interlocking between units or to remotely located devices, nor do they include motor control system engineering. Only diagrams of the individual units and drawings showing the overall dimensions of the control center are supplied with the apparatus. When master terminal blocks are specified, a sketch showing the general location of terminals is provided.

Class II Control Centers are Class I apparatus but designed to form a complete control system. Necessary interwiring between units and interlocking provisions to remotely mounted devices are included. A connection diagram of the complete control assembly and drawings showing overall dimensions are provided. When master terminal blocks are specified, the terminal arrangement and all wiring connections are shown on the diagram.

NEMA has established three types of wiring for control centers: Type A includes no terminal blocks. Combination linestarters are factory wired and assembled in the structure in the most efficient arrangement. Auxiliary devices can be supplied but no wiring external to the unit will be furnished. All feeder circuit breaker or fusible disconnect units are in this classification.

Type B wiring is essentially Type A except that all control wires terminate at blocks in each unit. Plug-in type terminal blocks for all control wiring and all load wiring through size 2 and control wiring above size 2 can be supplied.

Type C utilizes Type B units but factory wiring of all control circuits and load wiring through size 3 and control wiring above size 3, is extended from the unit terminals to master terminal blocks located at the top or bottom of each vertical compartment.

NEMA Design Specifications

Determining the application requirements and writing the specifications for a motor control center is definitely an engineering function. To arrive at some semblance of uniformity between manufacturers, NEMA and U.L. have established certain standards to be met. Most of the motor control centers encountered by the electrical maintenance people will conform to these standards:

1. General

The design shall be in accordance with the latest applicable NEMA and U.L. Standards for Control Centers and Industrial Control. The design shall have been tested in a recognized high power laboratory to prove adequate mechanical and electrical capabilities. All major components shall have been individually design tested and guaranteed by the control center manufacturer.

2. Structure Arrangement

Structures shall be totally enclosed dead-front, free standing assemblies. They shall be 90 inches high. See Figures 1 and 2.

Each structure shall contain a main horizontal bus, which has been tested for the capacity specified. In no case shall the main bus have a rating less than 600 amperes.

Vertical busses feeding unit compartments shall be tin-plated and securely bolted to the main bus. No vertical bus shall have a rating less than 300 amperes.

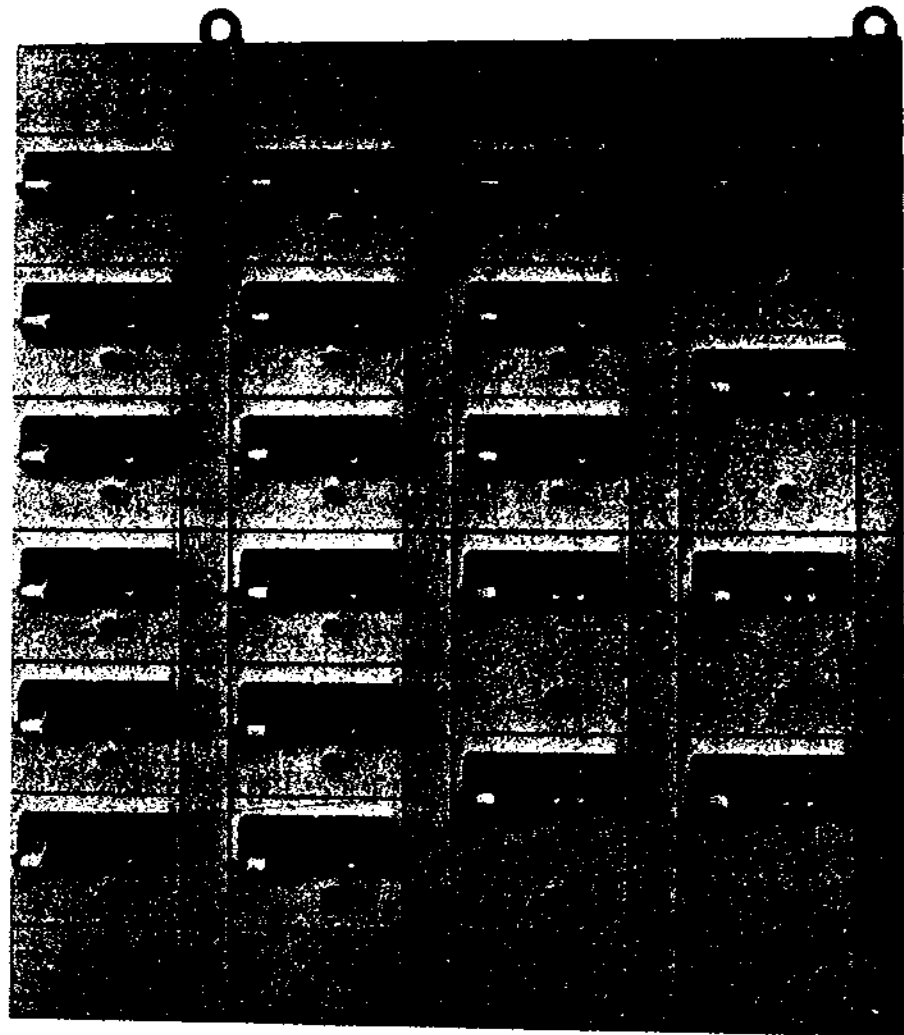


Fig. 1 – Typical Motor Control Center

Both vertical and horizontal busses should be held rigidly within the structure by bus supports which have high dielectric qualities, are moisture resistant, non-carbonizing, non-tracking, and have vertical creepage surfaces to prevent faults due to build-up of conductive dust. The bus assemblies must be braced to withstand bolted fault conditions of not less than 42,000 RMS symmetrical amperes.

Structures shall contain a horizontal wireway at the top, isolated from the horizontal bus and shall be readily accessible by removal of its cover plate. Adequate space for conduit and wiring to enter the top or bottom shall be provided without structural interference and safely accessible without disrupting service.

Compartments for mounting control units shall be incremented to allow a maximum of six starter units to be mounted in one vertical assembly and arranged to provide easy unit removal.

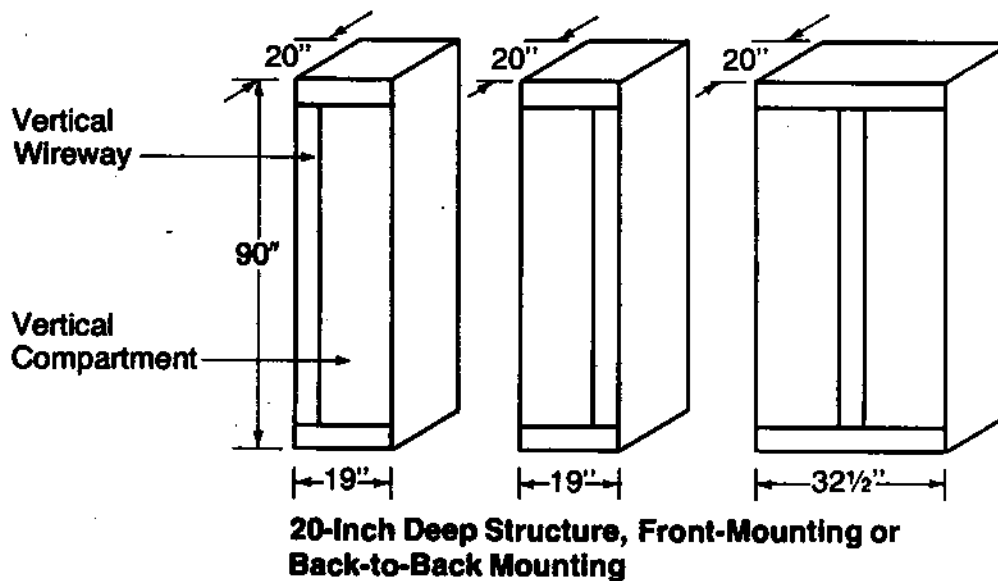
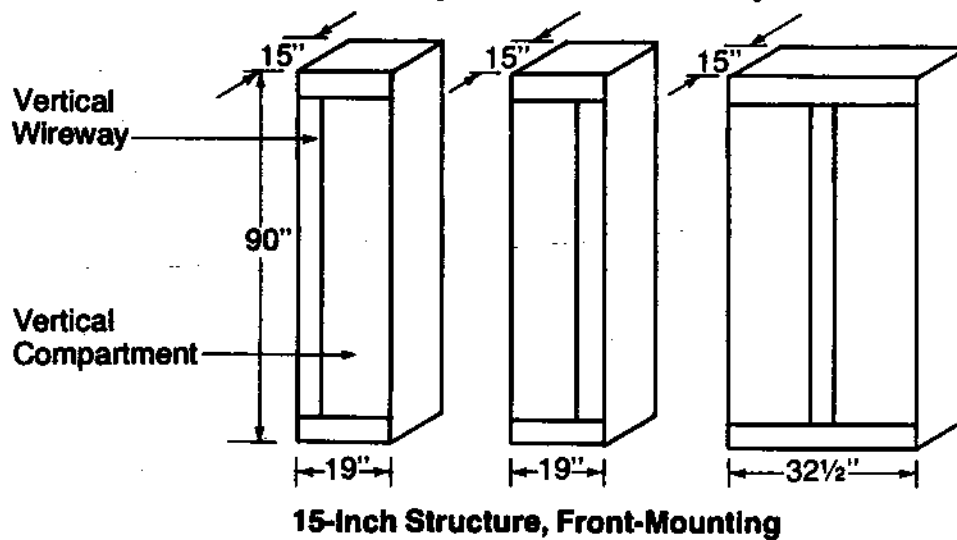
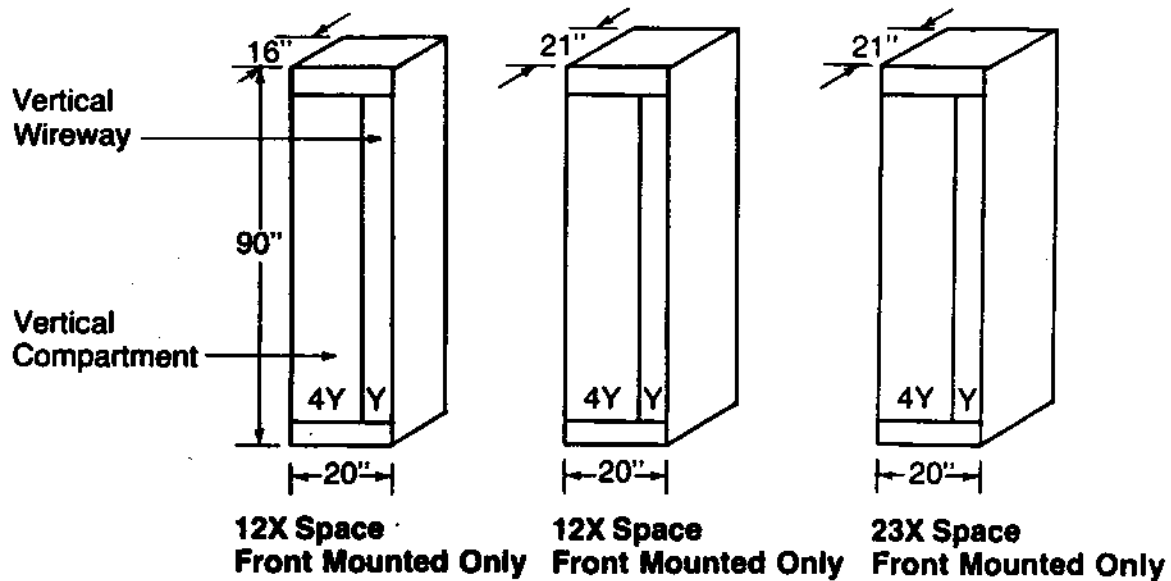


Fig. 2 – Typical Motor Control Center Structure Arrangements

A vertical wireway with a minimum of 50 square inches of cross-sectional area shall be adjacent to the right top of each vertical unit compartment and shall be covered by its own door. These vertical wireways shall be free of all live parts and shall contain cable supports.

3. Unit Construction Requirements

An operating mechanism shall be mounted on the primary disconnect. It shall be mechanically interlocked with the unit door to prevent access unless the disconnect is in the off position. A defeater shall be provided to by-pass this interlock.

With the door open, an interlock shall be provided to prevent inadvertent closing of the disconnect.

Padlocking facilities shall be provided to positively lock the disconnect in the off position with from one to three padlocks with the door open or closed. Circuit breakers or fusible switches shall be of the load break type. Circuit breakers shall have an interrupting capacity of not less than 14,000 RMS symmetrical amperes.

Linestarters shall be electrically operated, electrically held, three-pole assemblies with arc extinguishing characteristics and shall have silver-to-silver renewable contacts. They shall have provisions for adding a minimum of four normally open, or normally closed, electrical interlocks.

Drawout units shall have a plated stab assembly for connection to the vertical bus. No wiring to these stabs shall extend into the bus compartments.

Unit guides shall be provided to properly align stabs with the vertical bus without the possibility of misalignment.

All single-speed across-the-line starter units through Size 5 shall be of the drawout type.

All unit heights shall be of modular dimensions to allow for unit layout, in any combination, without structural interference.

Terminal blocks for NEMA Type B assemblies shall be mounted within the unit and shall be factory wired.

Terminal blocks for NEMA Type C assemblies shall be mounted at the bottom or top of each vertical compartment.

6.2 Construction

Standard structures, having standardized dimensions, can be bolted together to provide the desired configuration. Units can be positioned against a wall or mounted back-to-back with incoming power lines entering at top or bottom. Figure 3 shows a 16-inch and a 21-inch deep unit with end covers removed to reveal the internal construction.

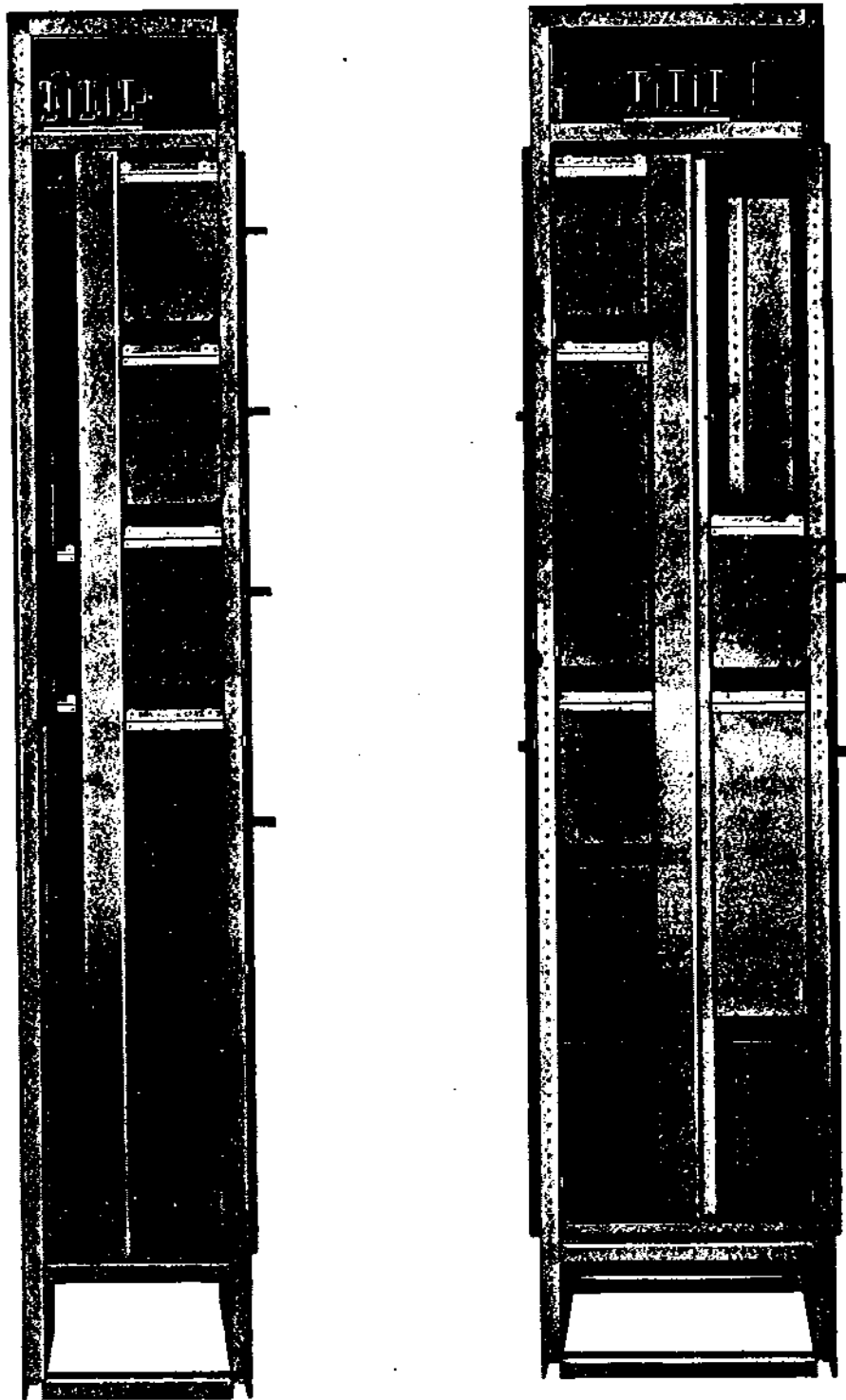


Fig. 3 - 16 and 21 Inch Deep Structures

Each control center contains a main horizontal bus which runs the entire length of the control center. It has a minimum capacity of 600 amperes. Vertical busses with a minimum rating of 300 amperes are connected to the horizontal bus to feed vertical compartments housing unit assemblies. Both the vertical and horizontal bus are held rigidly within the structure by bus supports which have high dielectric qualities. Refer to Figure 4.

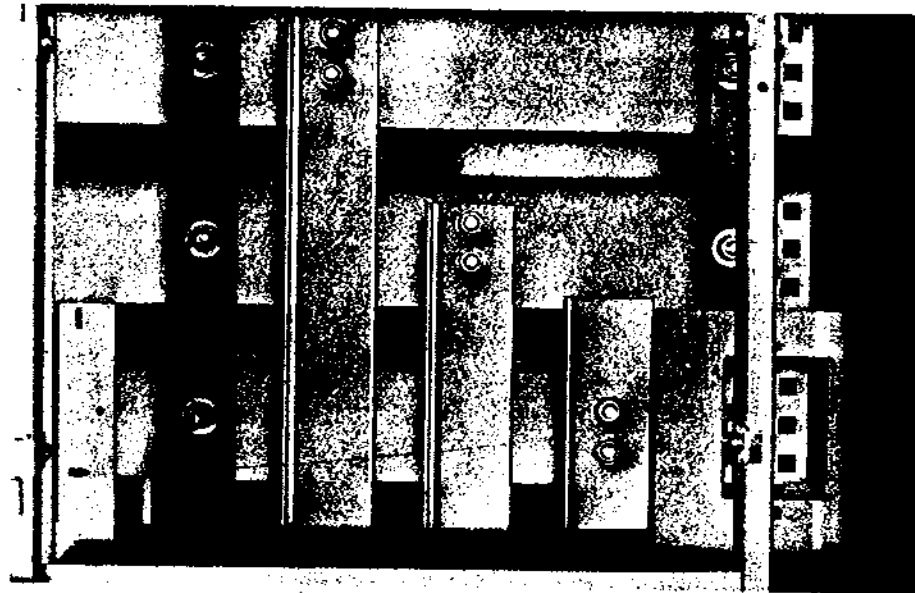


Fig. 4 – Horizontal Bus

Each structure contains a horizontal wireway at the top. It is isolated from the horizontal bus and is readily accessible by removal of the cover door. Space is provided for conduit and cables to enter from above. Refer to Figure 5.

A vertical wireway, free of components and live parts, is provided in each vertical structure. It is provided with cable tie supports, and covered by hinged doors. Refer to Figure 6.

A maximum of six starter units can be mounted in one front mounted vertical assembly; eleven in a back-to-back structure.

Drawout units for motor control consist of unit assembly complete with a stab arrangement for connection to the vertical bus, shown in Figure 7, and a circuit breaker or fused switch as a primary disconnect device with its operating mechanism, and a linestarter with overload relays. Refer to Figure 8.

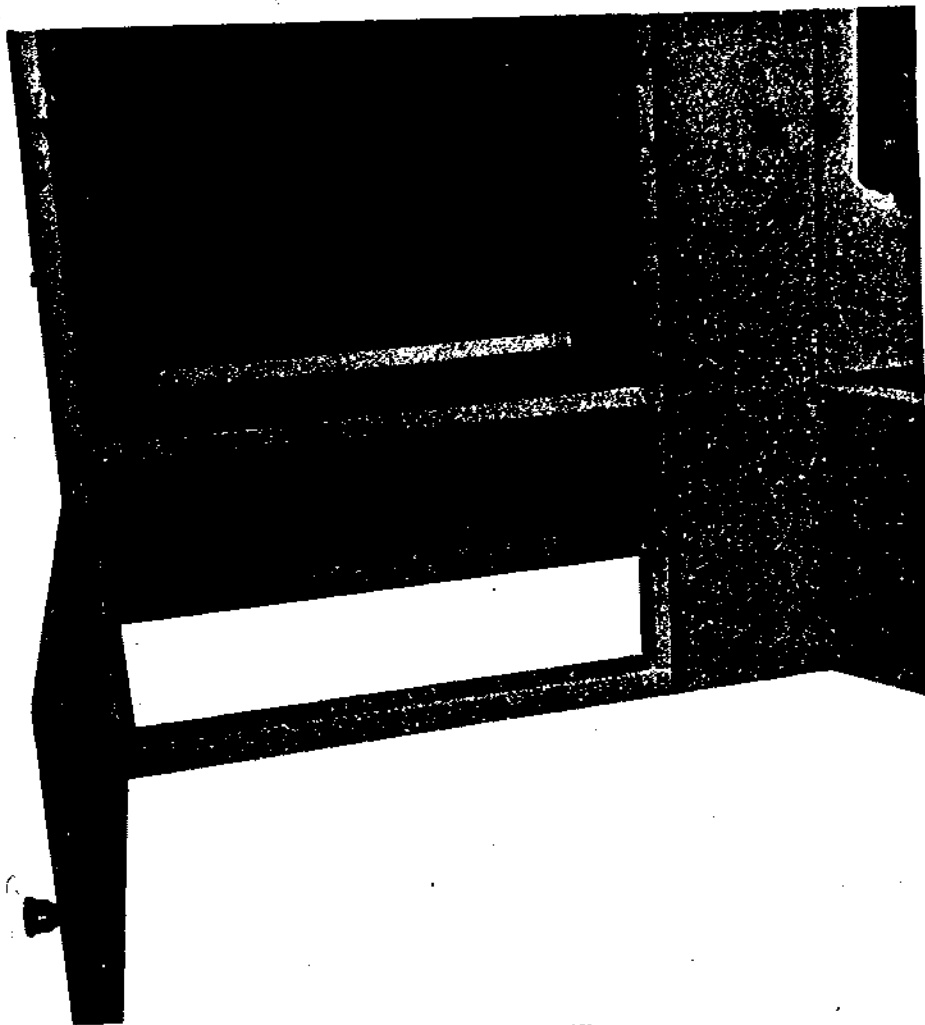
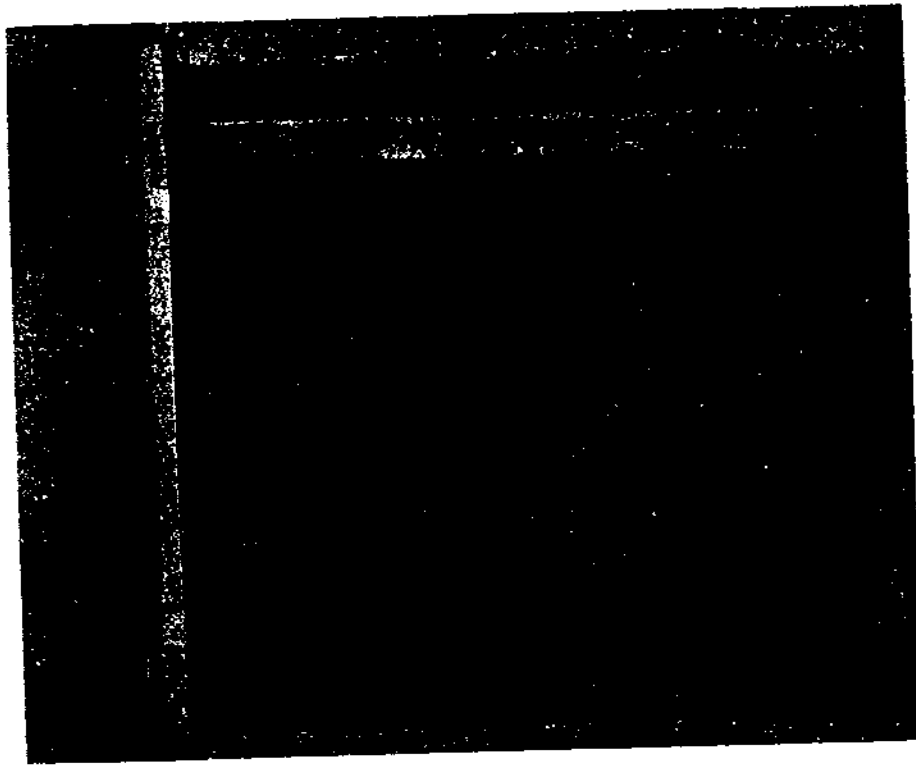


Fig. 5 – Horizontal Wireways

Vertical Wireways



Fig. 6 – Vertical Wireways

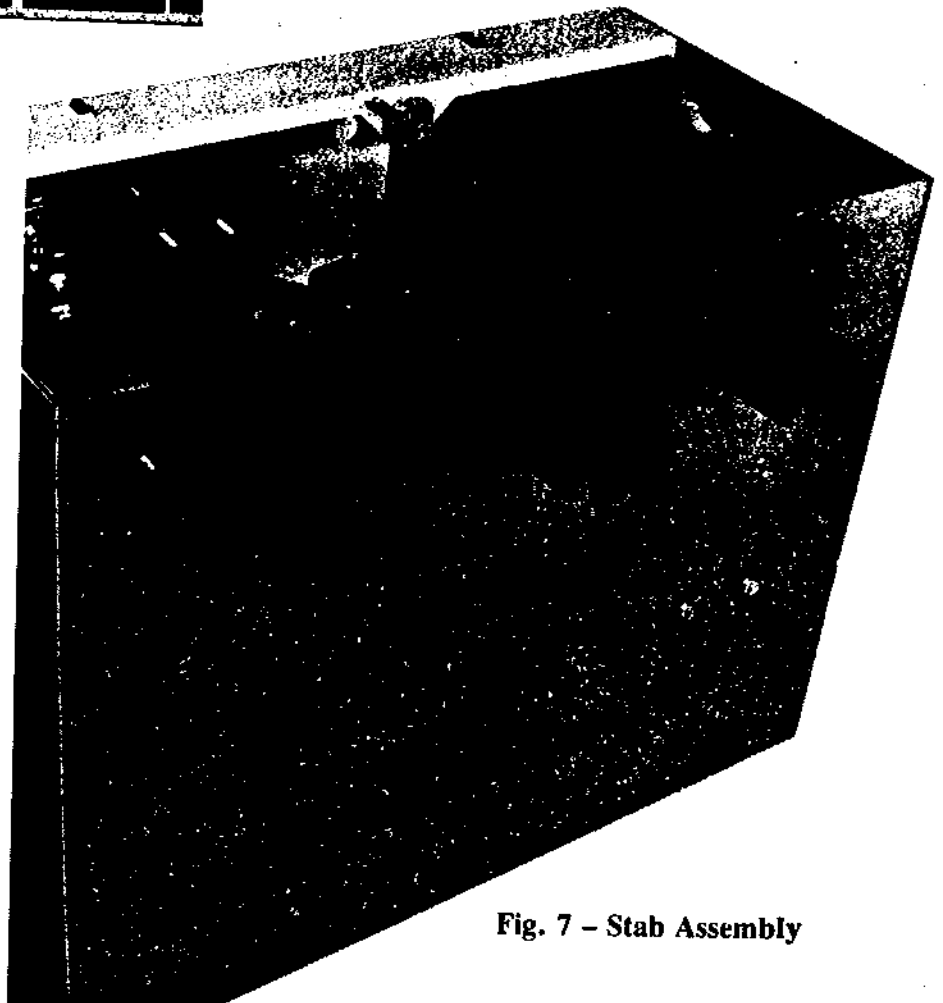


Fig. 7 – Stab Assembly

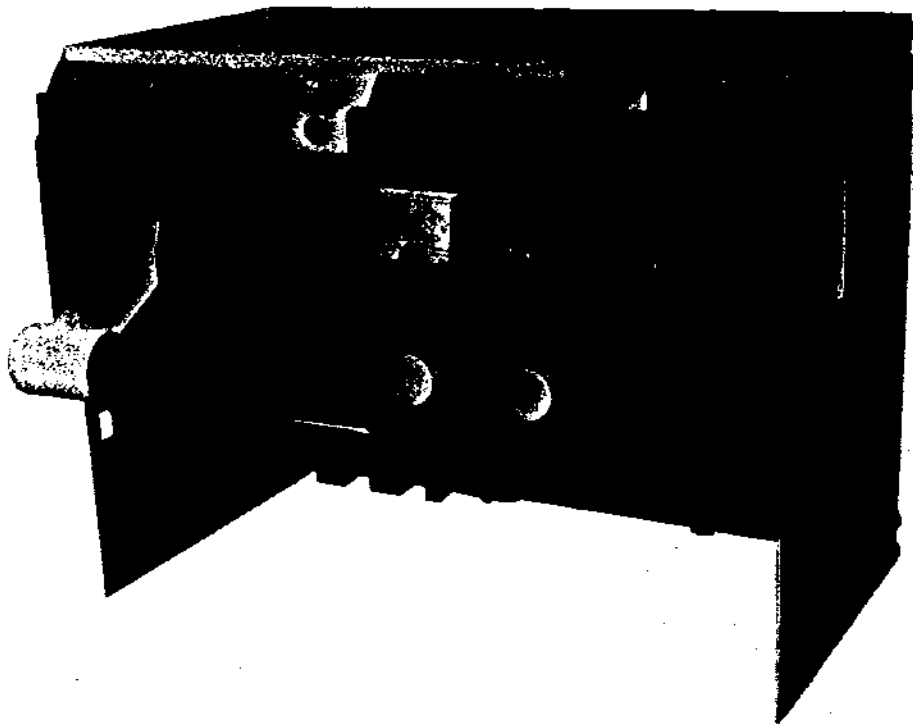


Fig. 8 – Typical Draw-out Starter Unit

6.3 Installation

Although the establishment of NEMA and U.L. standards have produced a considerable uniformity of design among manufacturers, the specific manufacturer's instructions should always be closely followed when installing or servicing a control center.

A. Foundations

An uneven foundation or one that is not level can cause misalignment of sections, units, and doors. It is recommended that levelled channel sills under both front and rear of the control center base be used to provide a level foundation. These channels should be drilled and tapped for half-inch mounting bolts in accordance with the applicable floor plan and then either installed level with or on top of the finished floor. If sills are grouted in concrete, the mounting bolts should be screwed in place and should remain until the concrete has hardened.

B. Joining Sections

As many as six compartments may be shipped in one shipping section. If two or more sections are to be joined into an integral assembly they should be bolted as shown in Figure 9 and the main bus should be connected with the splice plates provided. Bus splice plates and all connection hardware are packaged, identified, and shipped secured in one of the units.

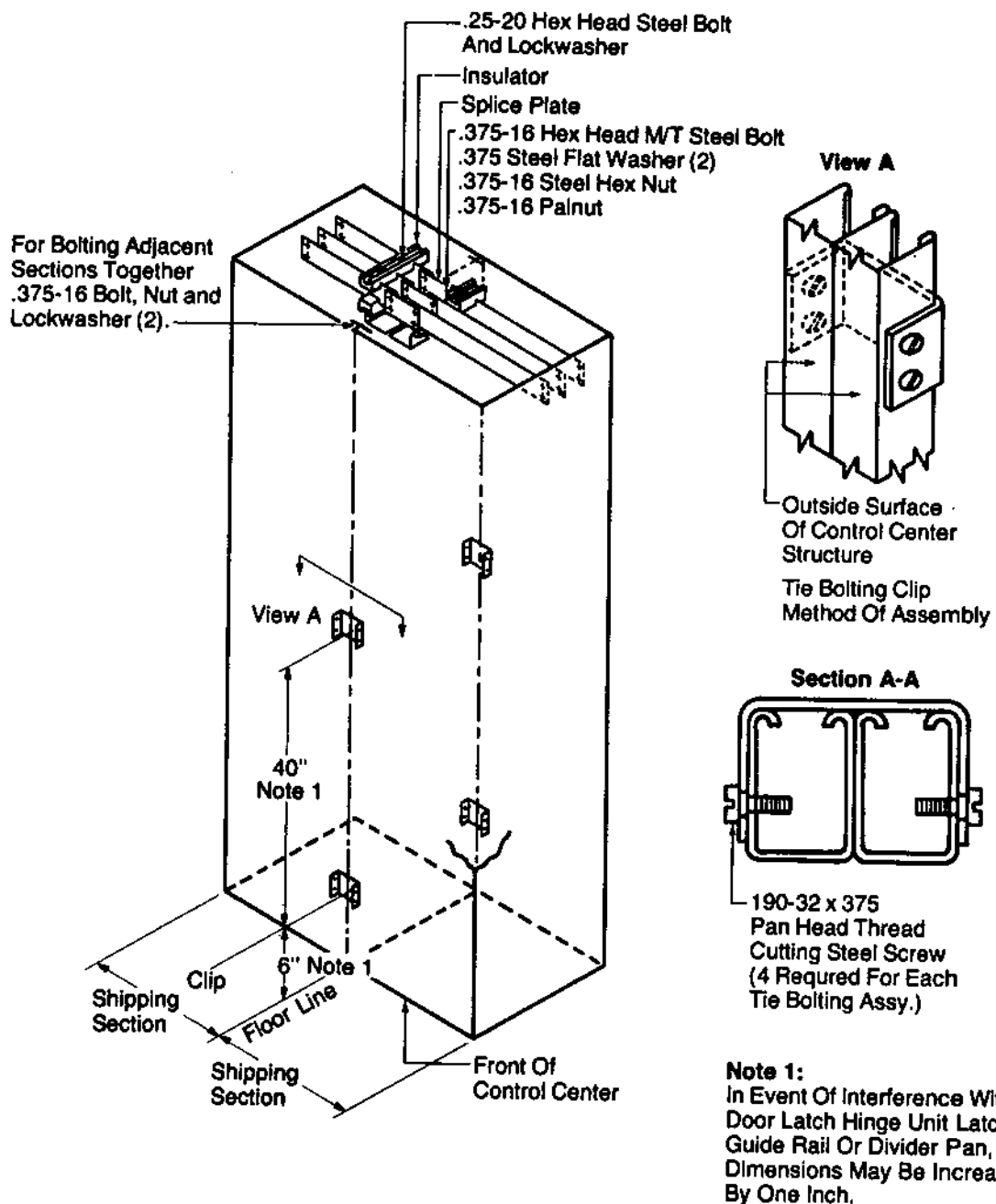


Fig. 9 – Typical Tie Bolting Assemblies

After the shipping sections to be joined are put in place and secured to the floor sills the tie bolting should be done. This procedure will vary with the different manufacturer's bus configurations so the manufacturer's procedures as supplied should be followed. Generally the sequence will be:

1. Open the front cover doors.
2. If rear is accessible, remove rear cover plates.
3. Remove horizontal bus barriers to give access to end frame and bus bars.

4. Bolt or clamp frames together.
5. Bolt bus splice plates to bus ends, including neutral and/or ground bus if present. Torque to specified pressure.
6. Inspect for loose hardware, left tools, or other extraneous material when work is completed.
7. Replace horizontal bus barriers, drawout units, coverplates.

When a section is being added to either end of an existing control center, the full length end cover on the existing structure should be removed prior to putting the new structure in place. This end cover should be relocated on the end of the new structure with the existing hardware.

If the existing bus bars are oxidized, (bare copper only) a good contact area should be prepared by sanding lightly with fine aluminum oxide paper.

Warning: Never use emery cloth or any abrasive containing metal. These abrasives leave conducting dusts that can lead to short circuits and burnouts. Failure to heed this warning can cause serious injury or death and damage to property.

C. Incoming Line Connections

For control centers having an incoming line circuit breaker or disconnect switch, the incoming line leads should be connected directly to the terminal lugs on the circuit breaker or switch. Figure 10 shows typical incoming lines entering from the bottom. Access to the terminals of the breaker or switch may be gained by opening the unit door covering it and unlatching the operating mechanism. It will then swing free on its hinges. See Figure 11. On circuit breakers 400 amperes and above, with interchangeable trip units, the breaker cover must also be removed.

Incoming line arrangements for connections directly to the bus differ based on size of cables, whether they must enter from the top or bottom and, accessibility to the rear. For #6 through 350 MCM cable sizes, either 1 or 2 cables per phase, pressure type terminals are mounted directly on the horizontal bus. They are accessible from the front of the control center by opening of the upper horizontal wireway door. For cables larger than 350 MCM the lugs are mounted on copper adapters extending from the bus.

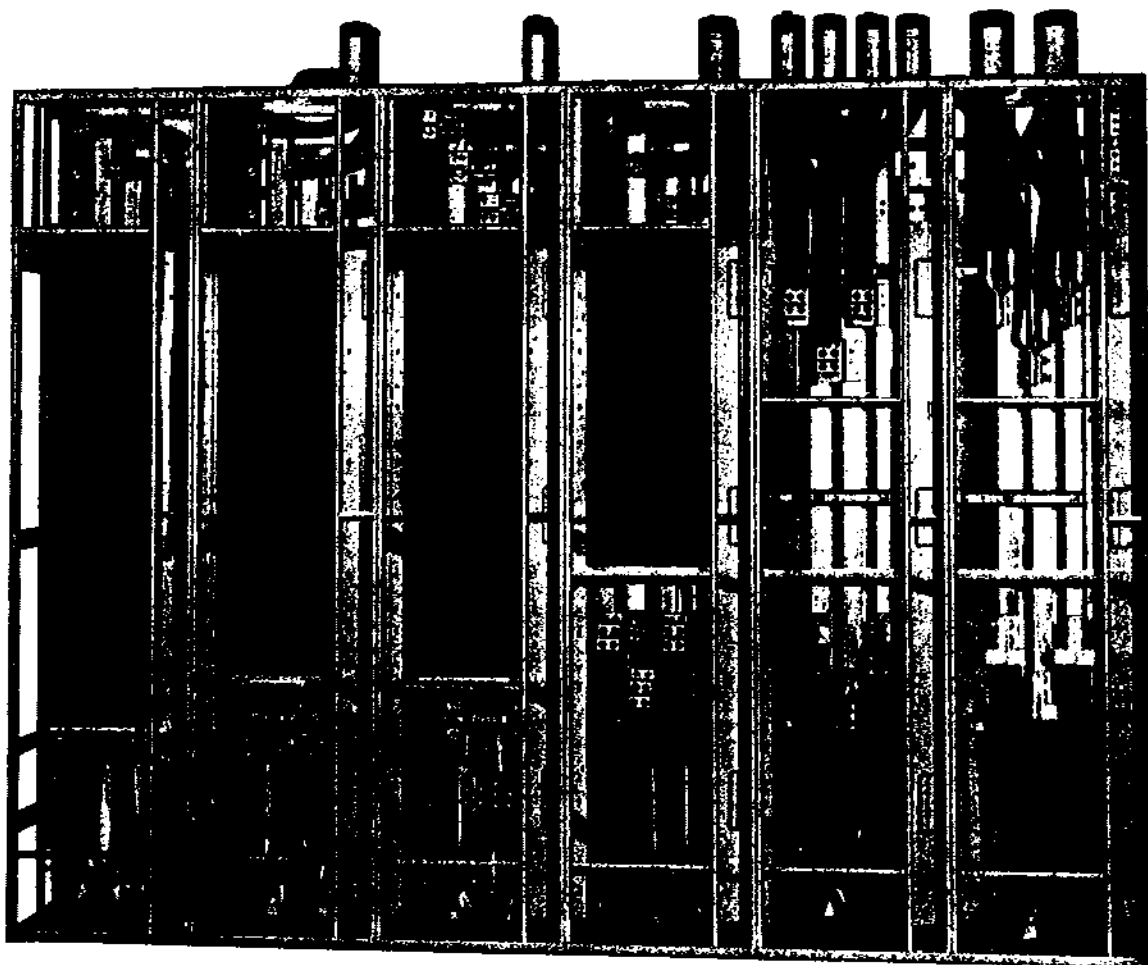


Fig. 10 – Incoming Line Connections

For incoming lines entering from the top to #6 through 350 MCM lugs, conduit entry should be made to the top cover above the vertical wireway or compartment adjacent to the lug section so cables bend only 90 degrees into side connected lugs.

Figures 12 through 17 illustrate some of the many incoming cable arrangements. Those shown are for Westinghouse Five-Star structures. Other manufacturer's designs will vary so it is necessary to consult their specific instructions for wiring arrangements.



Fig. 11 - Incoming Line Breaker with Mechanism Hinged Open

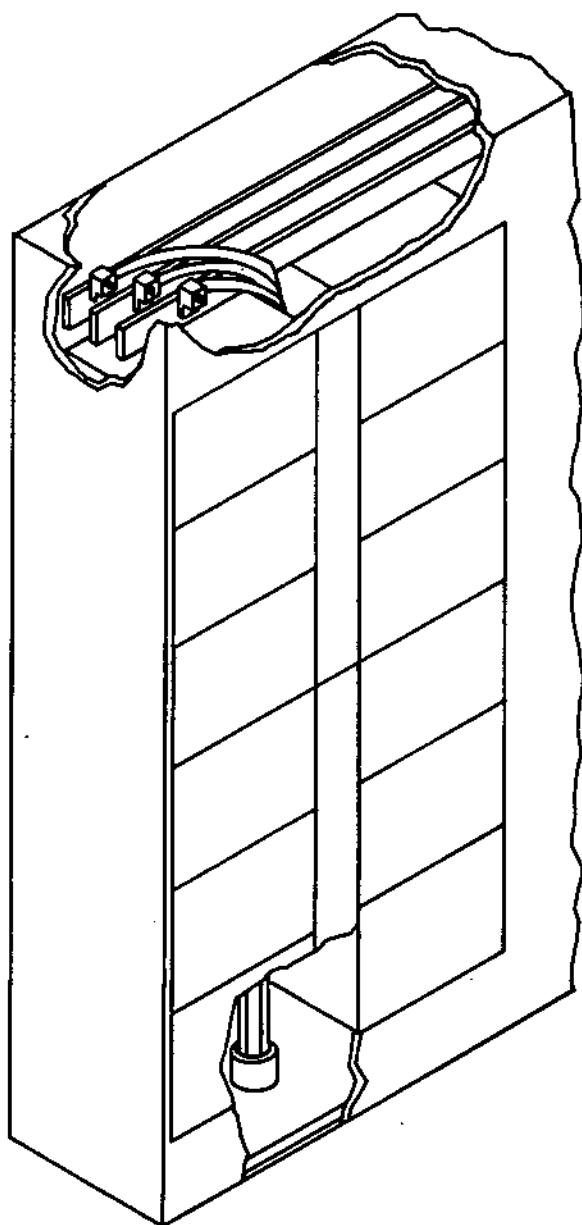


**Fig. 12 – Incoming Line Arrangement
No. 1, 21- or 16-inch Deep
Structure, Bottom Entry.
Cable Range: Up to 350 MCM,
1 or 2 per Phase**

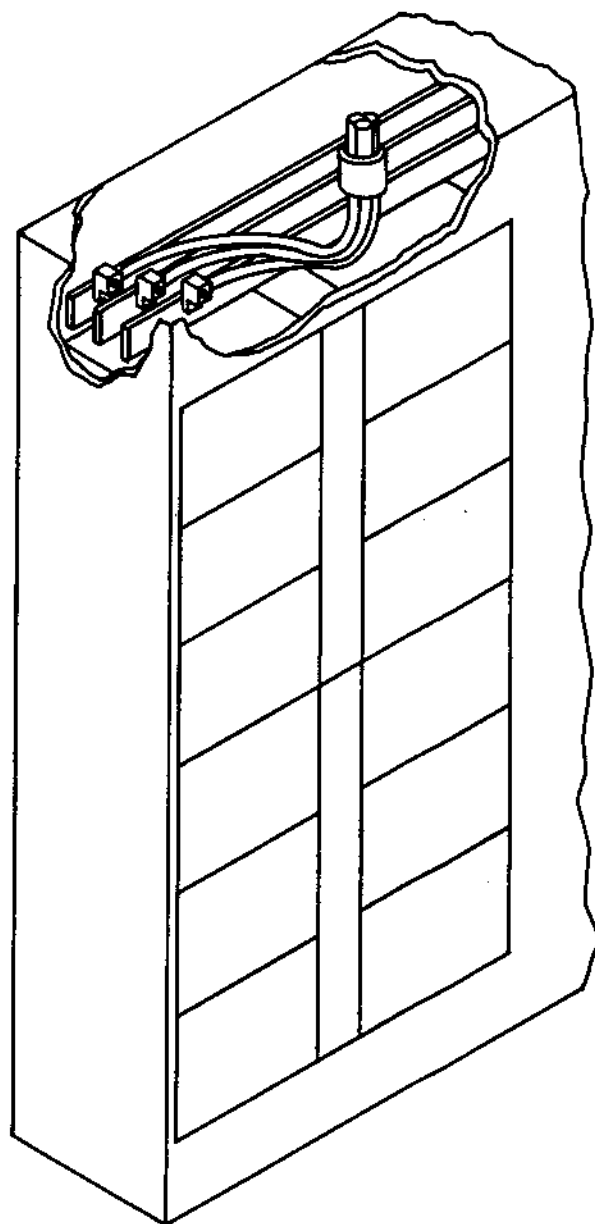


**Fig. 13 – Incoming Line Arrangement
No. 2, 21- or 16-inch Deep
Structure, Top Entry.
Cable Range: Up to 350 MCM,
1 or 2 per Phase**

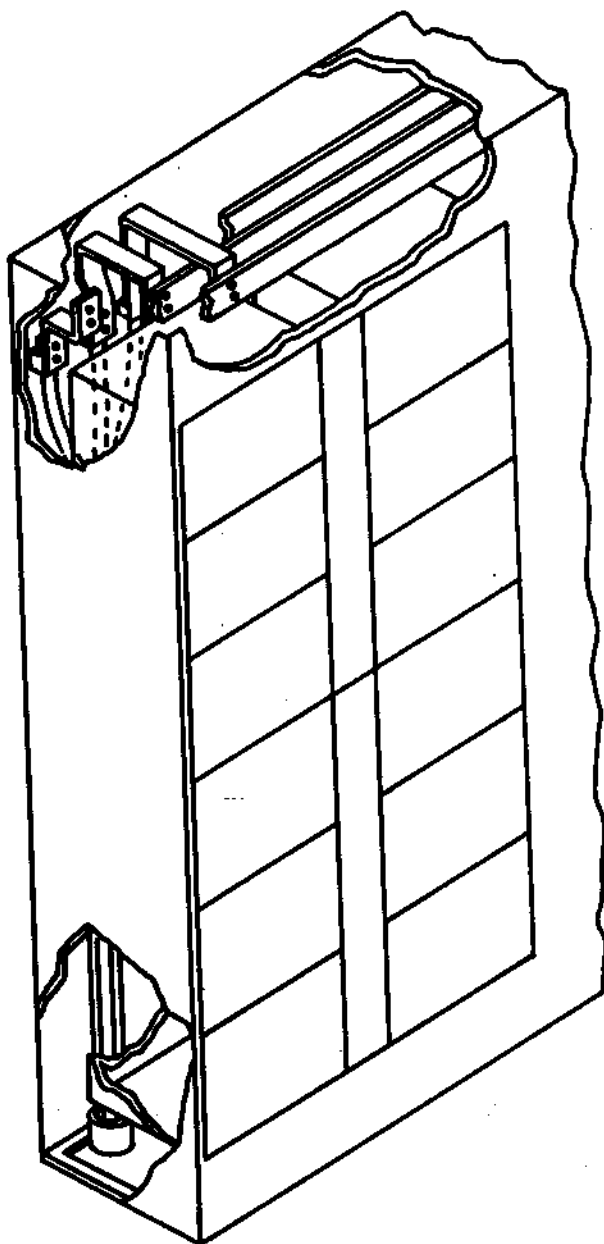


**Fig. 14 – Incoming Line Arrangement
No. 3 21-inch Deep Structure,
Rear Accessible, Bottom
Entry.
Cable Range: 350 to 750
MCM, 1 or 2 Phase**

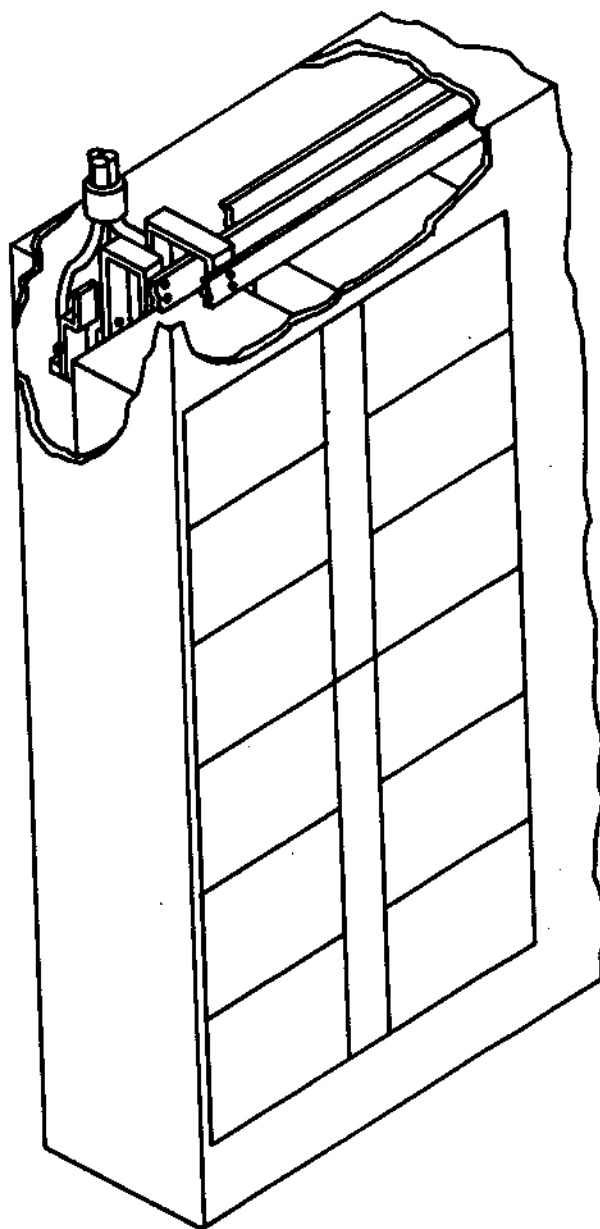


**Fig. 15 – Incoming Line Arrangement
No. 4 21-inch Deep Structure,
Rear Accessible, Top Entry.
Cable Range: 350 to 750
MCM, 1 or 2 Phase**

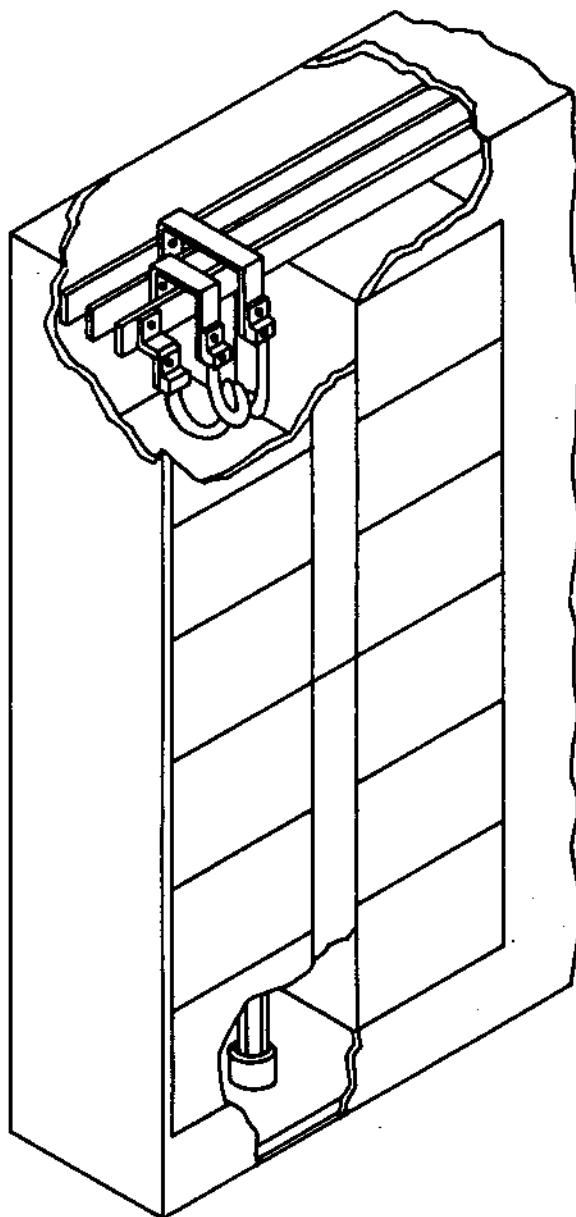


**Fig. 16 – Incoming Line Arrangement
No. 5 21- or 16-inch Deep
Structures, Rear Accessible,
Bottom Entry.
Cable Range: 350 to 750
MCM, 1 or 2 Phase**

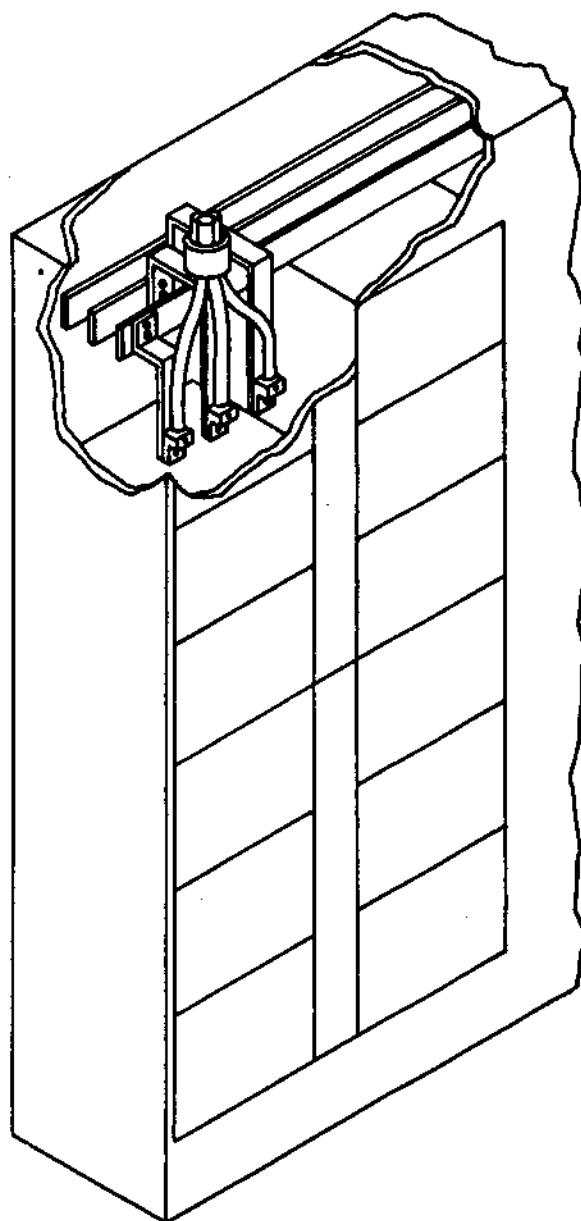


**Fig. 17 – Incoming Line Arrangement
No. 6 21- or 16-inch Deep
Structure, Rear Accessible,
Top Entry.
Cable Range: 350 to 750
MCM, 1 or 2 Phase**

6.4 Motor and Control Connections

Figure 18 shows a two compartment structure with the vertical wireway doors removed to provide maximum access for pulling cables and making wiring connections. The left hand unit has fixed terminal blocks for the control terminations and with the motor leads T1-T2-T3 connected directly to the controller. This arrangement is standard for all drawout units with fixed type terminal blocks.

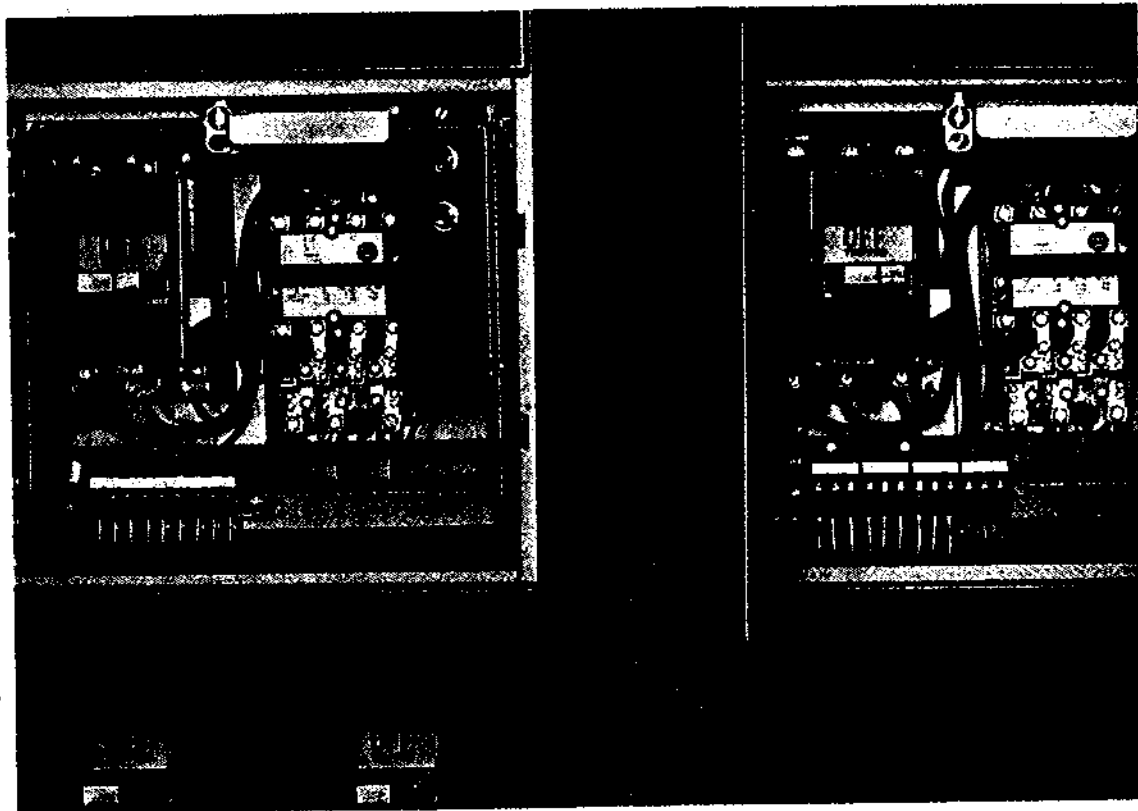


Fig. 18 – Vertical Wireway with Units Right and Left

The right hand unit is equipped with pull apart terminal blocks. When these terminals are specified, the motor leads of starter sizes 1 and 2 are also terminated and disconnectable with the adjacent control terminals.

For control circuit connections refer to the unit wiring drawings which are furnished with each control center. Connections to feeder tap units are made directly to the load terminals of the circuit breaker or fused disconnect switch.

For making NEMA Type C Wiring connections it is necessary to refer to the master terminal block arrangement drawing. The terminal block markings designate the unit and wire number. Figure 19 shows a typical terminal block assembly.

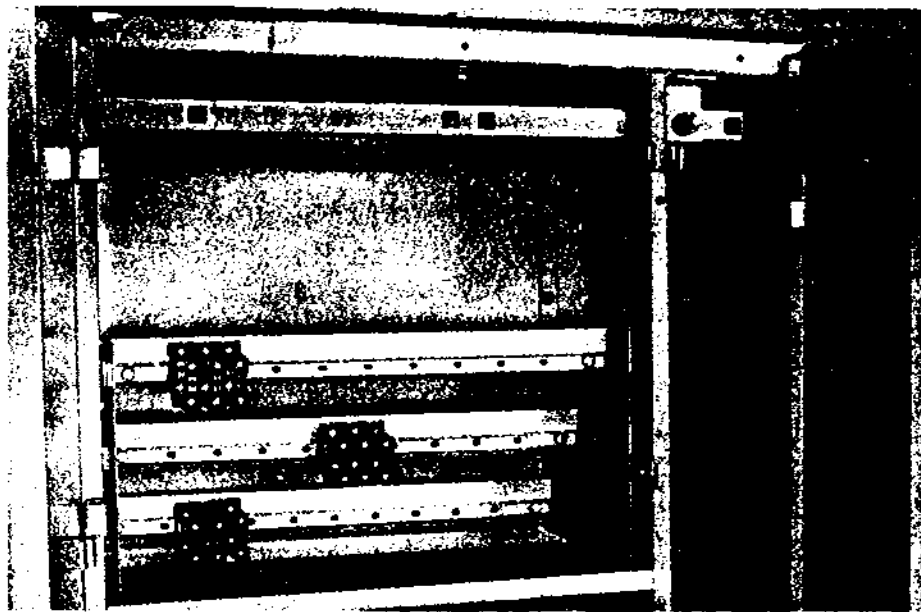


Fig. 19 - Typical Terminal Block

Inspection Before Energizing

Caution: Before energizing, a thorough inspection must be conducted to make certain that all foreign materials such as tools, wire or insulation scraps, or building debris are removed from all units and structures. Any accumulation of dust and dirt must be removed with a vacuum cleaner if possible, if not, this debris can be blown out with an air hose or the control center can be manually cleaned. Failure to do this could cause equipment failure with possible result of severe injury and damage to property.

All circuit connections are tightened at time of assembly by power driven tools with controlled torque. However, the vibrations experienced in transit may loosen some of these connections. It is recommended that at least 10 percent of the total connections be checked for a tight connection. Should this spot check reveal some loose connections then it will be necessary to check all connection points. The connections include bus hardware, circuit breaker and switch terminals, contactor and relay terminals and terminal blocks. A necessary check in any event should include the incoming line connections.

All relays should be inspected to make sure that any blocking for shipment is removed and that the armature moves freely.

Power circuit fuses are normally furnished by the purchaser and must be installed in the field. Each fuse should be checked for correct rating in accordance with National Electric Code application requirements.

All mechanical latches, operating mechanisms, and door assemblies should be checked for proper alignment and operation. While all doors and operating mechanisms were in proper functioning condition when the control center left the manufacturer, there is always a possibility of damage in transit. Doors can be adjusted by shifting the hinge leaves attached to the structural members.

Any final check must include the assurance that the disconnect operating mechanism functions properly without mechanical interference in either the ON or OFF position.

Warning: Make sure the door cannot be opened when the mechanism is in the ON position, if it can be there is danger of serious injury or death by electric shock and damage to property. The manufacturer's instructions for adjustment and operation must be carefully followed.

6.5 Unit Components

A typical control center unit is illustrated in Figure 20. This unit consists of size 1 linestarter, motor circuit protector, indicating light, push-buttons, and terminal block. Main incoming power circuit breakers or dry type transformers are housed in larger compartments.

Motor Circuit Protectors are adjustable, magnetic only, circuit breakers used in combination starters specifically for fault protection of motor circuits. Because each motor circuit protector must be adjusted by actual motor full load amps, it is supplied from the factory unadjusted. At installation it is necessary to set it for tripping at some value of current that exceeds the inrush. This provides low level fault protection. Adjustment should never exceed 13 times full load amperes, in accordance with N.E.C. requirements for magnetic only breakers.

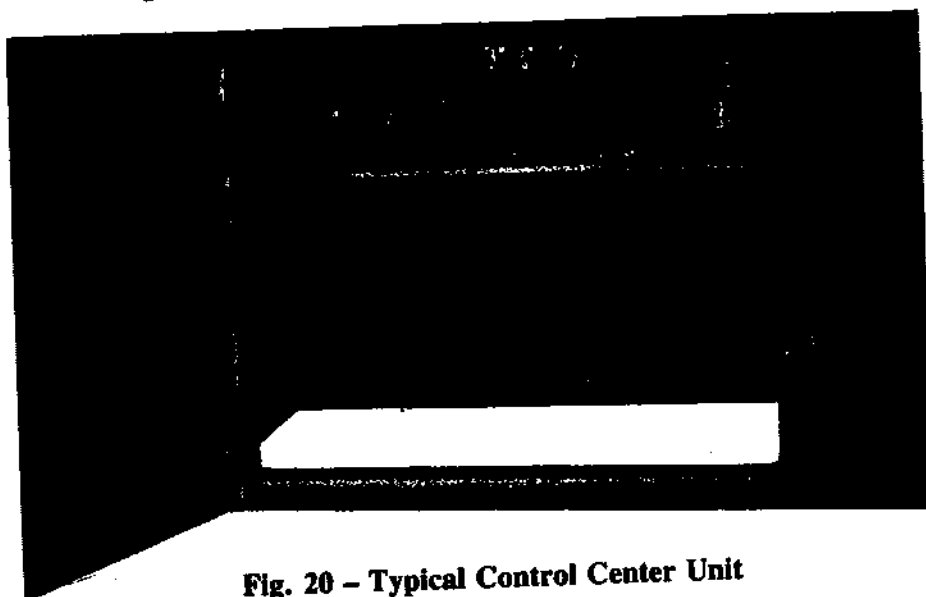


Fig. 20 - Typical Control Center Unit

The motor circuit protector may also be furnished with current limiting characteristics. The current limiter provides interrupting capacity above the range handled by the MCP in motor starters or by thermal magnetic feeder breakers. Each MCP protective device can have its own current limiter to provide coordinated protection against faults up to 100,000 amperes, RMS. Refer to Figure 21.

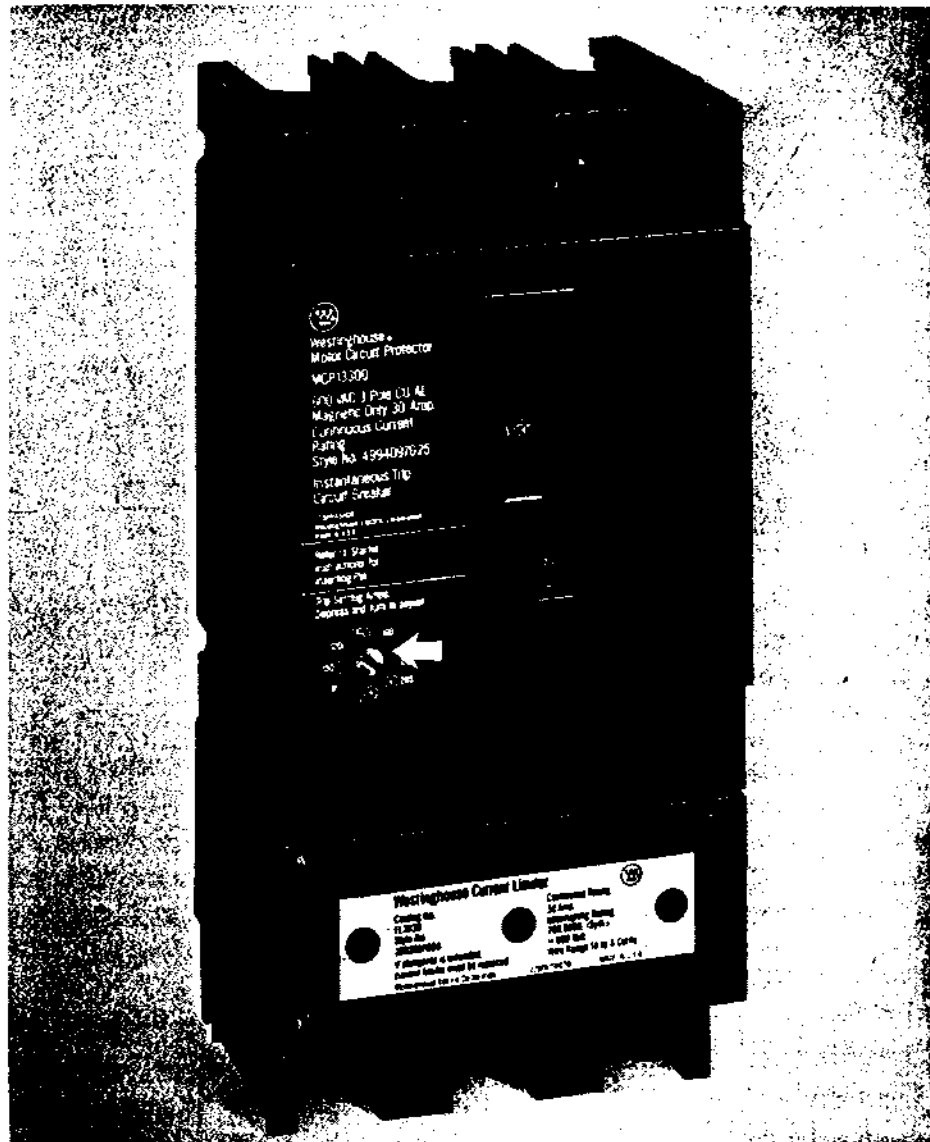
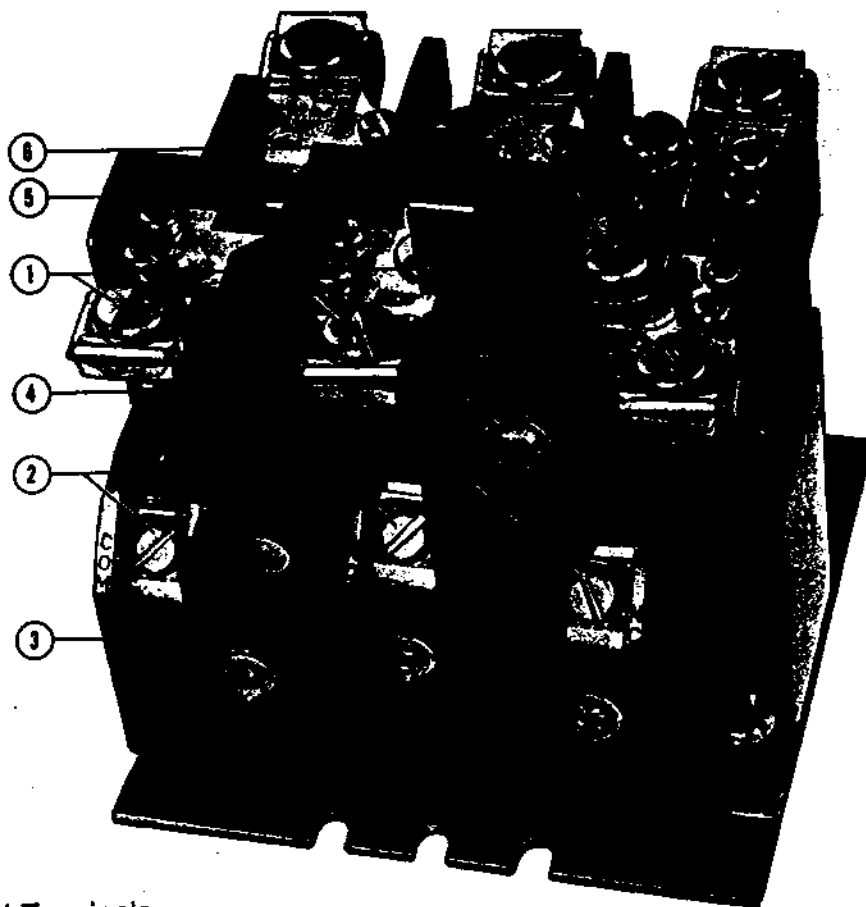


Fig. 21 – MCP with Current Limiter

A. Overload Relays

Various types of overload relays will be encountered, a commonly used relay is the Westinghouse Type A shown in Figure 22. Overload heaters in the relay monitor the current flowing in each phase of the motor it is protecting. By selection of heaters it is possible to change the thermal tripping characteristics so the control center becomes more flexible and can provide a broad range of individual motor protection without replacing starters.



1. Load Terminals
2. Control Contact Terminals
3. $\pm 15\%$ Adjustment Knob
4. Hand or Automatic Reset Adjustment
5. Heater Terminals (One Heater Shown)
6. Reset Rod

Fig. 22 – A Type A Overload Relay

B. Overload Heater Application

Relays may be shipped with heaters installed or with heaters separate for field installation. Heaters are selected for 40C rise open motors having full load current values as shown on the NEC Table 430-150 unless specific motor information is furnished with the order. The heater code numbers for each starter are recorded on the unit data drawing furnished with the order. Figure 23 shows a heater being installed in a Westinghouse Type B Overload Relay. The manufacturers instructions should be carefully followed in installing overload relay heaters.

Before energizing a starter the full-load current shown on each motor nameplate should be checked with the control manufacturers heater application tables to assure that heater furnished meets actual protection requirements.



Fig. 23 – Installing a Heater in a Westinghouse Type A Overload Relay

Warning: Never remove heaters from starters size 5 and larger to check unit operation. These starters use current transformers to drop the current to the size 1 overload relay and operation with heaters removed will not interrupt voltage to the motor and will generate dangerous voltages in the open secondary of the current transformer. Failure to follow this precaution can cause severe injury or death by electric shock and damage to property.

C. Heater Selection

If the manufacturer's heater selection tables provide 115 to 125 percent protection for motors rated 40C having a service factor of 1.15 to 1.25, use one size smaller heater if the motor is:

Rated 50C or 55C.

Has a service factor of 1.00

Adequately protected at 115%.

D. For Non-Compensated Overload Relays

When the motor operates at significantly higher or lower ambient temperature than the control center, an adjusted motor current should be used for selection of heaters. Adjusted values are obtained as follows:

Decrease the motor current by 1 percent for each degree Celsius the motor ambient exceeds the normal ambient temperature where the control center is located.

Increase the rated motor current 1 percent for each degree Celsius the control center ambient exceeds the motor ambient.

E. For Ambient Compensated Overload Relays

Select heaters based on motor current disregarding any ambient temperature differences.

Heater selection information applicable to the units in a control center should be obtained from the manufacturer and filed with the equipment records in the maintenance department.

There may be occasions when the heater selection information is not readily available. The following are heater selection tables applicable to the overload relays used in Westinghouse Control Centers.

FOR STARTER SIZE 1

Compensated Ambient (Black reset rod)	Non Compensated (Red reset rod)	Heater Code Marking
.51 - .55	.48 - .51	FH10
.56 - .62	.52 - .57	FH11
.63 - .68	.58 - .63	FH12
.69 - .75	.64 - .70	FH13
.76 - .83	.71 - .77	FH14
.84 - .91	.78 - .85	FH15
.92 - 1.00	.86 - .93	FH16
1.01 - 1.11	.94 - 1.03	FH17
1.12 - 1.22	1.04 - 1.13	FH18
1.23 - 1.34	1.14 - 1.25	FH19
1.35 - 1.47	1.26 - 1.37	FH20
1.48 - 1.62	1.38 - 1.51	FH21
1.63 - 1.78	1.52 - 1.65	FH22
1.79 - 1.95	1.66 - 1.81	FH23
1.96 - 2.15	1.82 - 1.99	FH24

FOR STARTER SIZES 1 & 2

Compensated Ambient (Black reset rod)	Non Compensated (Red reset rod)	Heater Code Marking
2.16 - 2.35	2.00 - 2.19	FH25
2.36 - 2.58	2.20 - 2.39	FH26
2.59 - 2.83	2.40 - 2.63	FH27
2.84 - 3.11	2.64 - 2.89	FH28
3.12 - 3.42	2.90 - 3.17	FH29
3.43 - 3.73	3.18 - 3.47	FH30
3.74 - 4.07	3.48 - 3.79	FH31
4.08 - 4.39	3.80 - 4.11	FH32
4.40 - 4.87	4.12 - 4.55	FH33
4.88 - 5.3	4.56 - 5.0	FH34
5.4 - 5.9	5.1 - 5.5	FH35
6.0 - 6.4	5.6 - 5.9	FH36
6.5 - 7.1	6.0 - 6.6	FH37
7.2 - 7.8	6.7 - 7.2	FH38
7.9 - 8.5	7.3 - 7.9	FH39
8.6 - 9.4	8.0 - 8.7	FH40
9.5 - 10.3	8.8 - 9.5	FH41
10.4 - 11.3	9.6 - 10.5	FH42
11.4 - 12.4	10.6 - 11.5	FH43
12.5 - 13.5	11.6 - 12.6	FH44
13.6 - 14.9	12.7 - 13.8	FH45
15.0 - 16.3	13.9 - 15.1	FH46
16.4 - 18.0	15.2 - 16.7	FH47
18.1 - 19.1	16.8 - 18.3	FH48
19.9 - 21.7	18.4 - 20.2	FH49
21.8 - 23.9	20.3 - 22.2	FH50
24.0 - 26.2	22.3 - 24.3	FH51
26.3 - 28.7	24.4 - 26.6	FH52

FOR STARTER SIZE 2

28.8 - 31.4	26.7 - 29.1	FH53
31.5 - 34.5	29.2 - 32.0	FH54
34.6 - 37.9	32.1 - 35.2	FH55
38.0 - 41.5	35.3 - 38.5	FH56
41.6 - 45.0	38.6 - 42.3	FH57

FOR STARTER SIZES 3 & 4

19.0 - 20.8	17.5 - 19.1	FH72
20.9 - 22.9	19.2 - 21.1	FH73
23.0 - 25.2	21.2 - 23.2	FH74
25.3 - 27.8	23.3 - 25.6	FH75
27.9 - 30.6	25.7 - 28.1	FH76
30.7 - 33.5	28.2 - 30.8	FH77
33.6 - 37.5	30.9 - 34.5	FH78
37.6 - 41.5	34.6 - 38.2	FH79
41.6 - 46.3	38.3 - 42.6	FH80

FOR STARTER SIZES 3 & 4 (continued)

Compensated Ambient (Black reset rod)

46.4 - 50
51 - 55
56 - 61
62 - 66
67 - 73
74 - 79
80 - 87
88 - 90

Non Compensated (Red reset rod)

42.7 - 46
47 - 51
52 - 56
57 - 61
62 - 67
68 - 73
74 - 80
81 - 87

Heater Code Marking

FH81
FH82
FH83
FH84
FH85
FH86
FH87
FH88

FOR STARTER SIZE 4

88 - 95
96 - 105
106 - 116
117 - 128

88 - 95
96 - 105
106 - 116

FH88
FH89
FH90
FH91

FOR STARTER SIZE GCA 5 (300/5 CT ratio)

118 - 129
130 - 141
142 - 155
156 - 170
171 - 187
188 - 205
206 - 224
225 - 244
245 - 263
264 - 270

110 - 119
120 - 131
132 - 143
144 - 158
159 - 173
174 - 190
191 - 208
209 - 227
228 - 247
248 - 270

FH24
FH25
FH26
FH27
FH28
FH29
FH30
FH31
FH32
FH33

FOR STARTER SIZE GCA 6 (600/5 CT ratio)

236 - 259
260 - 283
284 - 310
311 - 340
341 - 374
375 - 411
412 - 448
449 - 489
490 - 527
528 - 540

219 - 239
240 - 263
264 - 287
288 - 316
317 - 347
348 - 381
382 - 417
418 - 455
456 - 494
495 - 540

FH24
FH25
FH26
FH27
FH28
FH29
FH30
FH31
FH32
FH33

6.6 Maintenance

When servicing, inspecting, or adjusting any part of the electrical equipment refer to the applicable drawings covering the specific control center and any interconnection drawings. Follow the instructions supplied by the manufacturer for each device. The manufacturer's instruction book for the control center will contain the individual instruction leaflets for all the component devices or at least a list of the applicable instruction publications.

Warning: Before any work is undertaken, all circuits must be de-energized and disconnect devices locked open. Failure to disconnect and de-energize all circuits and devices can cause severe injury or death by electric shock and damage to property.

A. Servicing Recommendations

Equipment should be kept clean at all times.

1. Any accumulation of dust or dirt should be removed, with a vacuum cleaner if possible, or manual cleaning.

Warning: The bus must be de-energized while this cleaning is done. Not to de-energize will result in severe injury or death by electric shock.

2. Periodic inspection should be made of all devices to insure that the equipment is functioning and in good operating condition.

3. Badly worn or pitted contacts should be replaced for both preventive maintenance and safety reasons.

4. Do not lubricate any part of an electrical device in a control center.

5. Do not use emery paper, sandpaper, or a file to clean or dress any part of electrical equipment in a control center. Where sanding is required, use aluminum oxide paper, it will not leave sander or metal particles on contact surface areas.

6. Silver cadmium contact points of linestarters must not be sanded. In the event of contact wear, replace all contacts as a group to avoid misalignment problems.

7. Keep connections tight. Special attention should be given to the overload relay thermal element (heater) connections.

Warning: Do not use provision for overriding or defeating safety interlock mechanisms except when absolutely necessary. Use of these provisions makes the automatic safety system inoperable and can expose personnel to severe injury and property to damage.

B. Unit Removal and Replacement

Specific steps for removal and replacement of units vary with the manufacturer. The individual control center manufacturer's instructions and procedures should be followed carefully. All removal and replacement procedures start with the disconnect in the OFF position.

Care should be taken to identify and tag all wires before disconnecting and to make sure all reconnections are correct.

Caution: Before disconnecting any wires be sure that no portion of the control circuit or electrical interlocks is energized from a remote source. If there is any doubt, test with a voltage meter.

When a unit is out of the control center never rest it on its back supported only by the stabs, they can be damaged and misaligned by this treatment.

6.7 Receiving and Handling Precautions

All apparatus should be unpacked and thoroughly examined upon delivery. Damaged goods should not be accepted. Delay in this inspection may work to exonerate the carrier.

As inspection before energizing is a standard safety procedure, conducting the inspection upon delivery accomplishes two objectives.

Lifting lugs, eye bolts, or other provisions are made for each shipping section. When the shipping section is near its final location the lifting eyes should be removed and discarded. The mounting hardware should be replaced to prevent entrance of dirt. Where crane facilities are not available the structure can be positioned by using rollers under the shipping skids. Control centers may be positioned by fork truck but should be strapped at the top as control centers generally have a high center of gravity and may tip over if not secured. The skids upon which the section was shipped should be left in place until the structure is in position. They should then be removed.

Inquiries

When ordering parts or making inquiries concerning control centers or components, always furnish the manufacturer's identifying number for the apparatus. This will be a number stamped on the apparatus nameplate. There may be nameplates located in several places on the equipment. If the question refers to a specific unit the unit designation shown on the unit data drawing should be given.

Alternating-Current Motors

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Alternating-Current Motors

Most motors now in use are of the alternating-current type. The two most frequently encountered types of construction are squirrel cage and wound rotor. Motors generally are grouped by size; small, medium, and large motors, and specialized heavy industry motors.

7.1 Useful Definitions

Slip – represents the difference between rotor or shaft rpm and the rpm of the rotating magnetic field in the stator (synchronous speed), and is normally expressed as a percent of synchronous speed.

Power factor is a term relating apparent power to measured power. In a 3-phase system power factor is:

$$\frac{\text{watts (input)}}{\sqrt{3} \times \text{volts (line)} \times \text{Amps (line)}}$$

kVA code identifies the NEMA standard locked rotor kVA rating per horsepower.

Ambient Temperature. Standard motors are designed for operation in an ambient not exceeding 40C (104F).

Altitude. Standard motors are designed for operation at altitudes not exceeding 3300 feet (1000 meters).

A. Service Factor

Service factor applies to horsepower. When voltage and frequency are at nameplate values the motor may be operated at the value obtained by multiplying the rated horsepower by the service factor shown on the nameplate, but only at the rated ambient temperature. Motor thermal capability is generally inversely effected by changing ambient temperatures; lower temperatures increase the motor thermal capability and higher temperatures decrease the motor thermal capability. Refer to Figure 1.

Motor load can normally be estimated by measuring the line current with a tong meter.

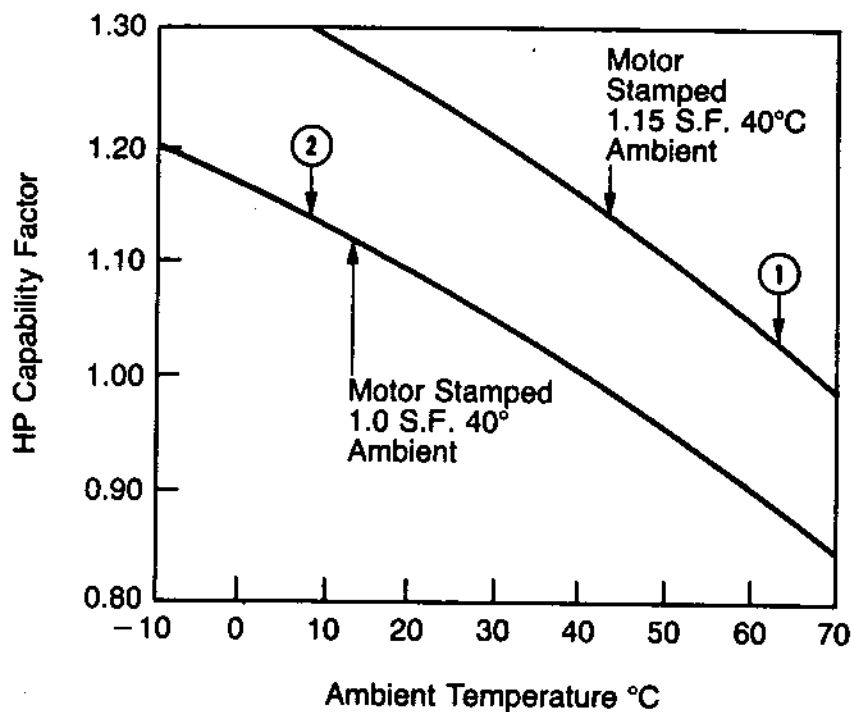


Fig. 1 - A Service Factor Comparison Chart

Notice: Do not directly relate service factor to amperes unless the motor is operating at rated voltage. A motor is already on overload if it is running at rated amperes from a power source which has higher than rated voltage.

B. Voltage and Frequency - Allowable Variations

A-c motors operate successfully at rated load with a voltage variation up to 10%, assuming no change in frequency. A change from 60 to 50 hertz at the same voltage is an increase of 20% in magnetization. This is usually unsatisfactory in standard motors. The objection to a large rise in line volts or a reduction in hertz on a given motor is that it increases the magnetic flux per pole in the machine and inordinately raises the magnetizing or no-load current. This increases the full load amperes and may cause the motor to overheat at the expected or rated output.

The best a-c motor performance is to be expected on rated voltage and frequency. They can always operate on reduced voltage at rated frequency since this is reduced magnetization; reduced voltage starting is very common. Starting and breakdown torque vary as the square of the voltage; this must be taken into consideration when deciding what the motor running capability is at reduced voltage. For example, a 230 volt, 10 hp motor could be properly rated according to nameplate standards at $(208/230)^2 \times 10$, or 8.2 horsepower for application on 208 volts; (the same service factor would apply). Curves showing relationship of starting and pullout torque and torque vs. speed are shown in Figures 2 and 3.

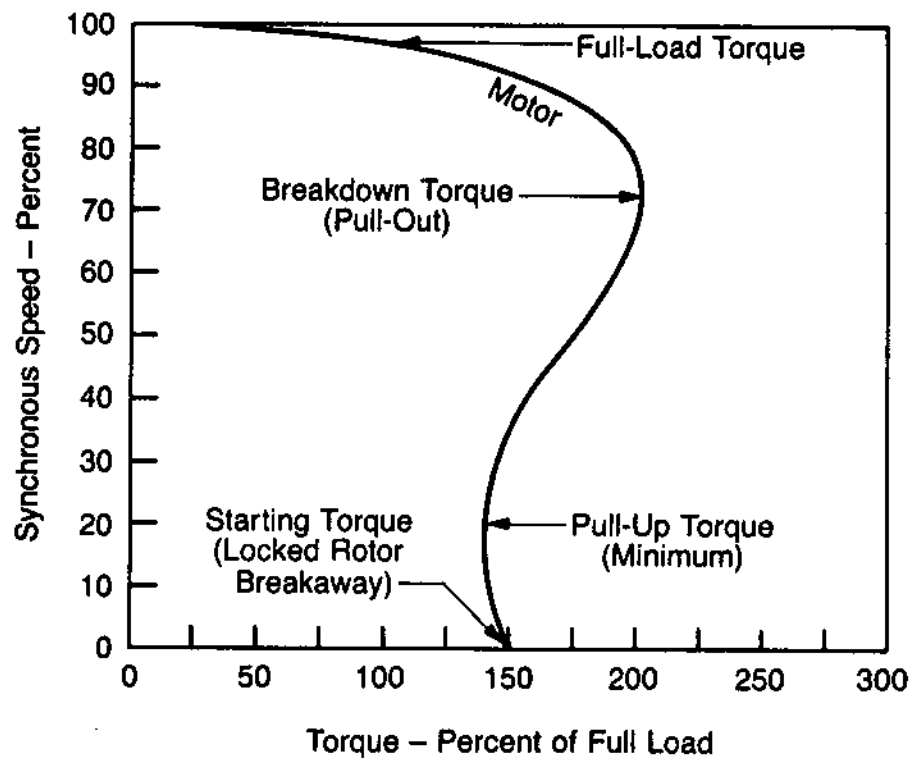


Fig. 2 - Torque Terminology

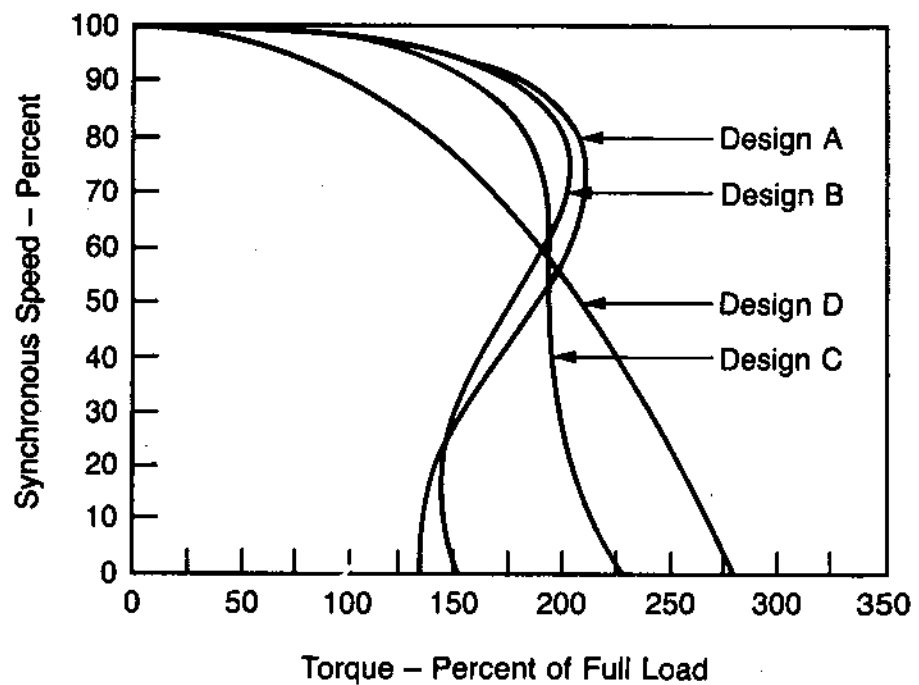


Fig. 3 - Typical Speed Torque Curves (Letters Indicate NEMA Design)

Voltage balance (between phases) should be equal when measured with a reliable voltmeter. Voltage balance is important when rating an a-c machine. Even small amounts of voltage unbalance produce very injurious heating due to circulation of negative sequence currents. Two or three percent voltage unbalance at rated load output produces the same heating as if the machine were operating at 10% overload, Where the unbalance exceeds 4%, derating factors should be used in applying the motors.

Frequency. Induction motors are being used more and more for variable speed drives. The general application rule is that standard a-c motors are good for constant torque running output over a wide frequency range (15 to 100 hertz), providing that the power supply has constant volts per hertz. At lower than 15 hertz some increase in magnetization is desirable.

Standard 60 hertz motors are suitable on power supplies of other frequencies at the same magnetization or volts per hertz. For example, a 3 hp, 460 volt, 60 hertz motor is properly rated 2.5 hp on 380 volts, 50 hertz. The same motor is rated at 2.0 hp on 320 volts, 42 hertz and only 1½ hp on 190 volts, 25 hertz. It will also produce 3.9 hp on 600 volts at 78 hertz. When the output voltage of the power supply is non-sinusoidal (as is the case with solid state inverters) the application should be referred to the motor manufacturer.

C. NEMA Designs

NEMA Design A or B (normal torque, low slip)

These designs have starting torques good for accelerating a wide variety of industrial machine drives. They are applied where slightly more than full load starting torque and low slip are required and, where relatively high breakdown torque is needed to sustain occasional emergency overloads.

Notice: Design B starting currents are limited by NEMA while Design A starting currents are not. Applications cover an extremely wide range, including drives for fans, pumps, drill presses, lathes, grinders, generators, certain types of machine tools, conveyors and compressors and similar equipment.

NEMA Design C (High starting torque, low starting current, low slip)
Applications of this design are similar to those of Design B motors. The only difference is that the starting torque must be 200 percent minimum. Applications for this design are machines in which the torque requirements are high at starting. These motors are normally run at

rated full load and are not subjected to high overload demands after they have reached full running speed. Typical applications include compressors, conveyors, pulverizers, electric stairways and similar devices.

NEMA Design D (high starting torque, high starting current, high slip) Applications of this design are in cranes and hoists where variations in torque and speed are encountered.

Warning: Make sure to select a proper enclosure to meet all code requirements for motor applications and unusual environmental conditions. Failure to heed this warning can cause severe personal injury and damage to property.

D. Enclosures

Drip-proof, for installation in non-hazardous, reasonably clean surroundings, free of any abrasive or conducting dust and chemical fumes. Moderate amounts of moisture or dust and falling particles or liquids can be tolerated.

Totally enclosed non-ventilated or fan cooled, for installation in non-hazardous atmospheres containing abrasives or conducting dusts, high concentrations of chemical or oil vapors, and outdoor service.

Totally enclosed explosion proof for installation in hazardous atmospheres.

NEMA Class I, Group D, acetone, acrylonitrile, alcohol, ammonia, benzene, benzol, butane, ethylene dichloride, gasoline, hexane, lacquer solvent vapors, naphtha, natural gas, propane, propylene, styrene, vinyl acetate, vinyl chloride or xylenes;

NEMA Class II Hazardous Duty Motors are classified as dust ignition proof;

NEMA Class II, Group G, flour, starch, or grain dust;

NEMA Class II, Group F, carbon black, coal, or coke dust;

NEMA Class II, Group E, metal dust including magnesium and aluminum or their commercial alloys.

Under Class I only, there are two divisions which allow some latitude on motor selection:

Generally, Class I, Division 1, locations are those in which the atmosphere is or may be hazardous under normal operating conditions. Included are the locations which can become hazardous during normal maintenance. An explosion-proof motor is mandatory for Division 1 locations.

Class I, Division 2, refers to locations where the atmosphere may become hazardous only under abnormal or unusual conditions (breaking of a pipe, for example). In general, motors in standard enclosures can be installed in Division 2 locations if the motor has no normally sparking parts. Thus, open or standard totally enclosed squirrel-cage motors are acceptable. Motors with open slip rings or commutators (wound rotor, single phase, synchronous or d-c) are not allowed unless the commutators or slip rings are in an explosion-proof enclosure. Application of motors in Division 2 locations is the responsibility of the user, the motor manufacturer provides only advisory and guidance information.

E. Mounting

Horizontal ball bearing, grease-lubricated motors may be mounted at any angle.

The general purpose motor is usually foot mounted on the floor or adjustable base with the lead conduit box on the left side when facing the shaft end of the motor. This is standard assembly, F-1; Refer to Figure 4. Other assemblies can be supplied for floor, ceiling or wall mounting.

There are three standardized brackets for bracket mounting:

Type C face bracket has holes drilled and tapped in the face for mounting bolts.

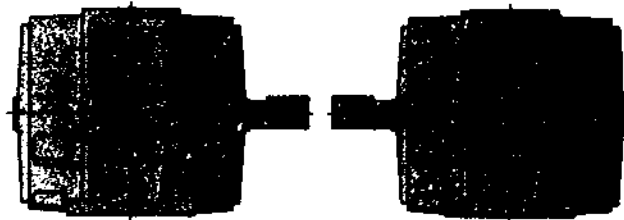
Type D flange bracket has holes in the flange for through-bolts.

Type P base is used primarily for vertical motors.

F. Rotation

The direction of rotation is given by facing the front end of the motor. The front end of a motor is defined as the end opposite the shaft or drive end.

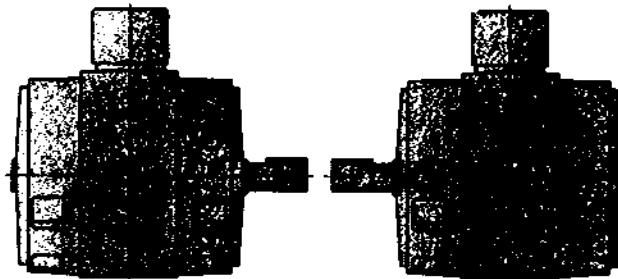
Floor Mounting



F-1 (Standard)

F-2

Wall Mounting, Shaft Horizontal



W-1

W-2

Ceiling Mounting



C-1

C-2

Fig. 4 – Motor Mounting Assembly Symbols

7.2 Fractional HP Motors

These are generally the least complicated motors consisting chiefly of end bells, stator, rotor, fan assembly, and mounting bracket. Refer to Figure 5. If a major fault is encountered in a fractional hp motor it is generally less expensive in time and money to replace the motor rather than attempt repair.

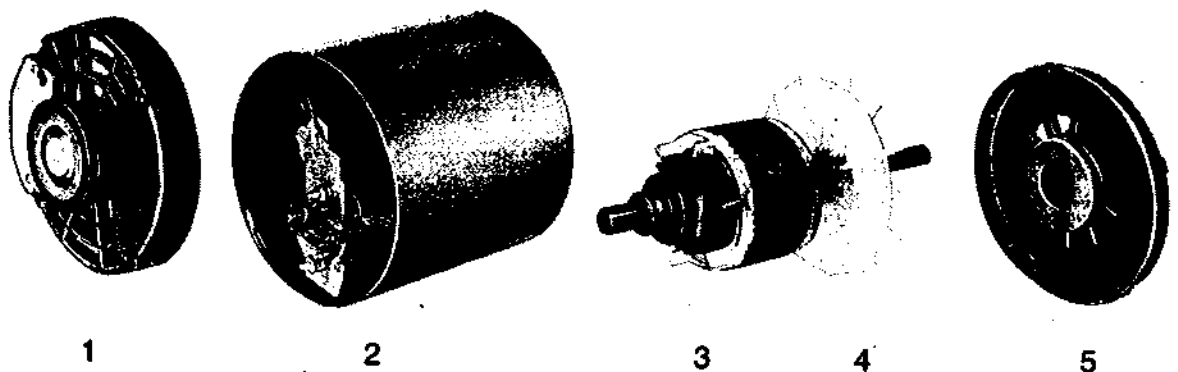


Fig. 5 – Disassembled View of a Small Motor Showing End Bells (1&5), Stator (2), Rotor (3), and Fan Assembly (4)

The end bells, in which the shaft bearings are mounted, provide support for the motor shaft. End bells are usually made of cast metal, iron for larger motors and aluminum for motors under 5 horsepower rating. They are seldom a cause of field trouble and on the rare occasion of failure, replacement of the end bell is usually the most effective remedy. Refer to Figure 6.

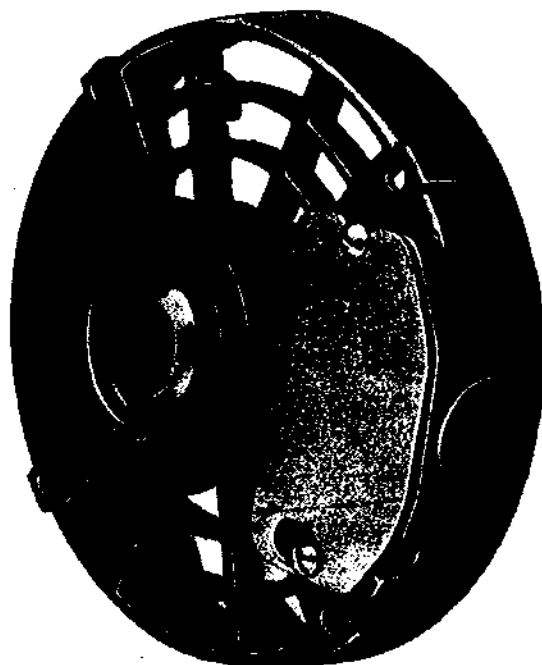


Fig. 6 – Typical Small Motor End Bell

A. Bearings

The two most commonly encountered bearing types are sleeve and anti-friction ball bearings. Sleeve bearings are the type most frequently used in small motors. When correctly maintained by periodic lubrication these bearings give years of trouble-free service. Some older bearing designs require that the motor be operated in a horizontal position. Modern general purpose wick lubricated sleeve bearing motors are designed for operation in all positions.

The typical sleeve bearing is designed with an opening called a bearing window. This window is a semi-circular opening in one side of the bearing containing wicking material. The wicking material carries oil by capillary attraction to the shaft from the oil reservoir. The rotating shaft wipes the oil from the wick and lubricates the bearing. Refer to Figure 7.

When motors with sleeve bearings are connected to loads by belts or chains which tend to pull the shaft to one side, care should be taken that

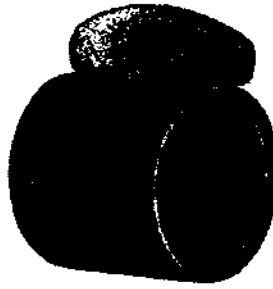


Fig. 7 – Sleeve Bearing with Feed Wick

the shaft is not pulled toward the bearing window. Refer to Figure 8. The bearing window is generally located above the shaft and under the oil hole. The most reliable method is to make sure the belt pull is away from the oil hole.

Anti-friction ball bearings used in small motors are generally designed to take both thrust and radial loads, and are delivered pre-lubricated and sealed. Motors equipped with these bearings can be used where the shaft is not horizontal.

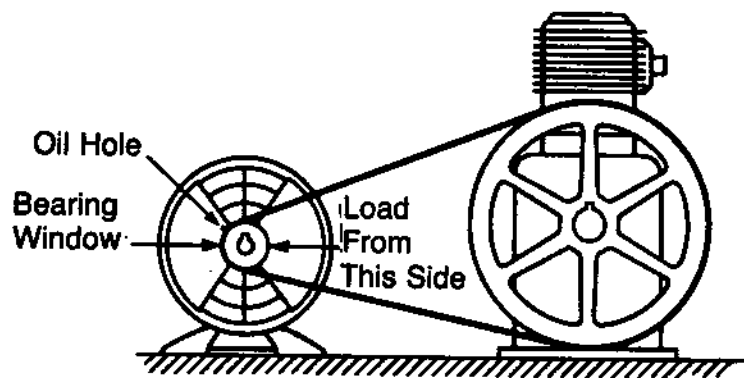


Fig. 8 – The Belt Pull Should Be Away from the Bearing Window

B. Motor Mounting

The four most commonly used methods of mounting are: rigid, resilient, stud, and flange.

Rigid Mount. This most frequently used type of mounting is a rectangular steel plate which conforms to the bottom of the motor and provides a platform for the motor. It is called Rigid Mounting because the frame of the motor is welded to it. See Figure 9.

Resilient Mount. This design is a metal cradle or base in which the end bells rest, cushioned by rubber rings. The rings are bonded to metal

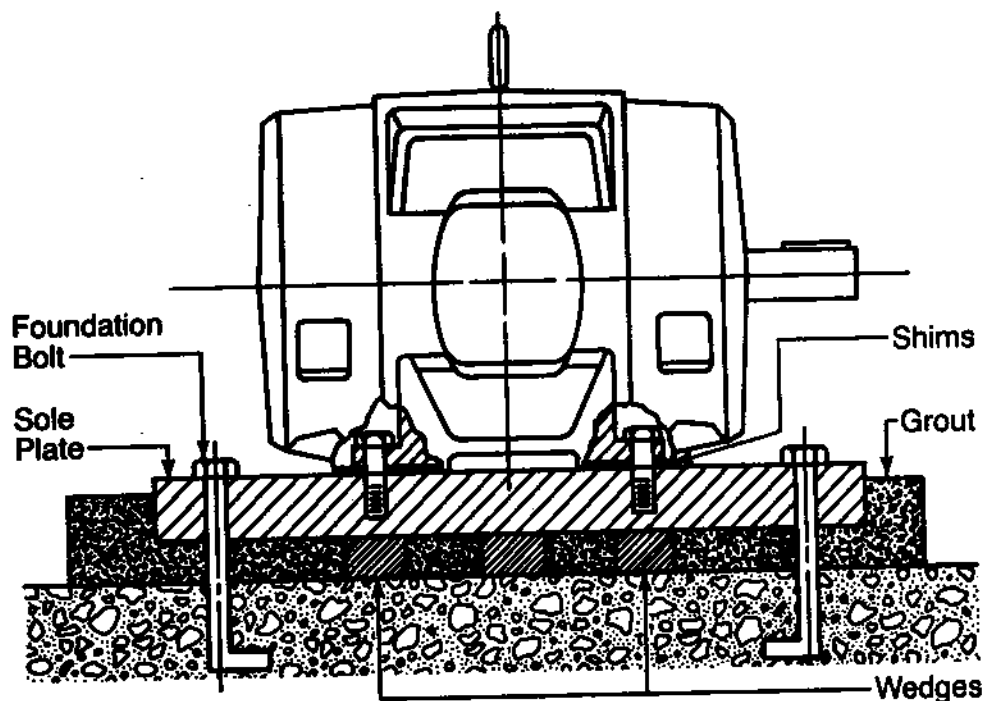


Fig. 9 - Mounting of a Motor

bands which fit the cradle and are secured by a screw operated clamp. See Figure 10. Resilient mounting isolates the vibration and noise generated by the motor. The rubber rings, in addition to isolating the motor, also afford a torque cushion to dampen the shock of starting and stopping.

Stud Mount. This mounting method is used in such direct drive applications as small fan motors. In this design illustrated motor is held together by two long bolts which project from the end bell at the shaft end of the motor. A cross bar of the housing of the driven machine is secured to these projecting bolts with lock washers and nuts. See Figure 11.

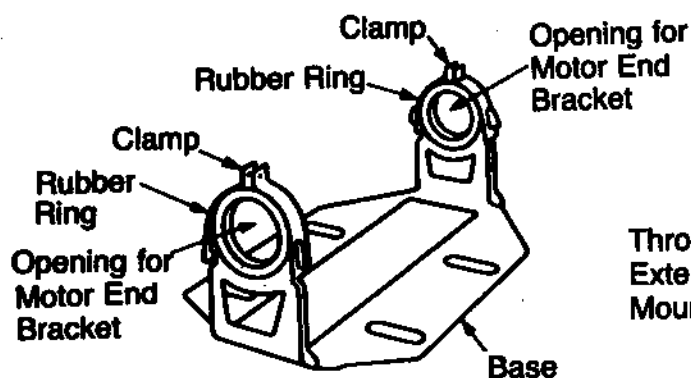


Fig. 10 - Resilient Mounting of Small Motors

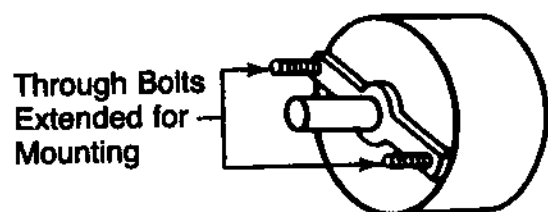


Fig. 11 - Stud Mounting of Small Motors

Flange Mount. In this mounting a special flange machined flat and drilled for bolting is used on the shaft end. This method permits direct mounting of the motor on the driven machine. See Figure 12.

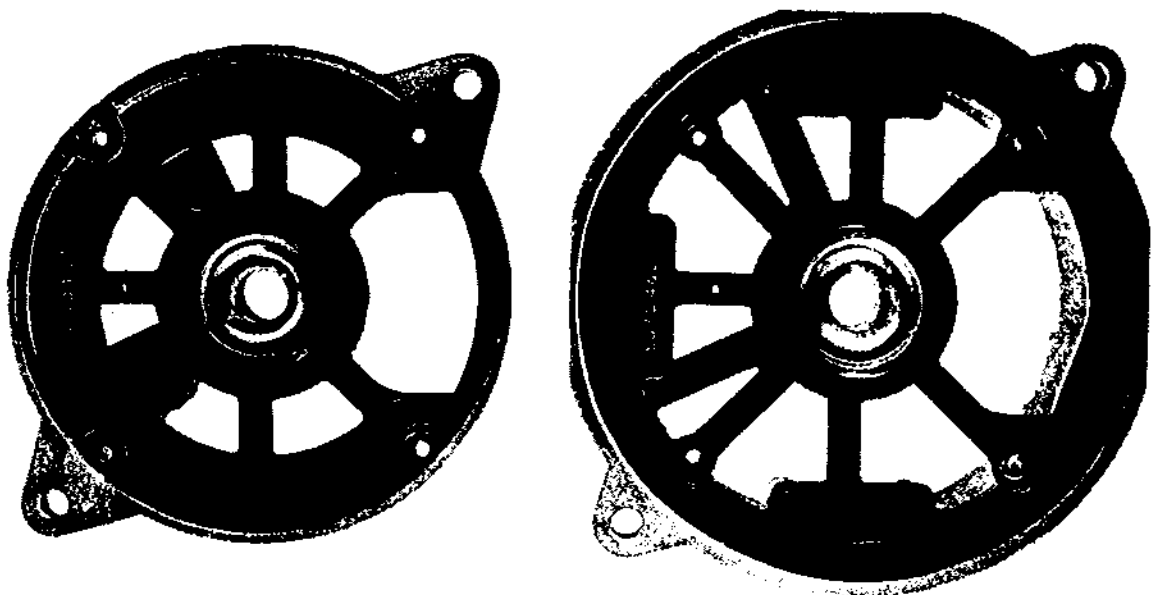


Fig. 12 – Flange Mountings for Small Motors

C. Nameplate Information

The nameplate permanently attached to the motor in a readily visible location provides vital information:

Manufacturer's Name and Motor Identification Number

Frame size

Type of Power, current, alternating or direct.

Single or three phase. Motors indicated as series Universal operate on either alternating or direct current.

Horsepower at rated speed.

Speed in revolutions per minute. Most commonly one of four approximate speeds 3450 rpm (2 pole), 1750 rpm (4 pole), 1170 rpm (6 pole), 860 rpm (8 pole).

Frequency at which motor is to be operated. Normally 60 hertz or 50 hertz.

Voltage at which motor is to be operated. Usually 115 volts, 230 volts, 115/230 volts, or 230/460 volts. If the motor has a conduit box additional information may be found on the back of the cover.

Normal Current drawn at rated load, voltage, and frequency.

Temperature Rise the amount in degrees centigrade by which the motor temperatures will rise above the ambient when operating at rated load and speed. 40C and 50C may be shown for some hazardous duty motors.

Duty Rating. Length of time the motor may be operated without overheating. Generally this will be continuously.

Code. This is a NEMA code letter designating the locked rotor kVA per horsepower. For example, the letter M allows for 10 to 11.2 kVA per horsepower.

SF Amps is the current the motor will draw when loaded to its full service factor.

Housing, type of enclosure.

Type Code indicates construction and power such as split phase, capacitor start, shaded pole, polyphase power, etc.

Type of Overcurrent Protection in the motor.

Table A – Small Motor Trouble Shooting Chart

This chart does not cover all possible problems. It lists only the more frequently encountered troubles.

Trouble	Cause	What to Do
Motor Fails to Start	Blown Fuses	Replace fuses at least 125 per cent of nameplate amperes.
	Overload Trips	Check and reset overload in starter.
	Improper current supply	Check to see that power supplied agrees with motor nameplate and load factor.
	Improper line connections	Check connections with diagram supplied with motor.
	Open circuit in winding or starting switch	Indicated by humming sound when switch is closed. Repulsion induction motors may spark at brushes. Check for loose wiring connections; also see if starting inside motor is closed.
	Mechanical failure	Check to see if motor and drive turn freely. Check bearings and lubrication.
	Short circuited stator	Indicated by blown fuses. Motor must be rewound.
	Poor stator coil connection	Remove end bells, locate with test lamp.
	Rotor defective	Look for broken bars or end rings.
	Motor may be overloaded	Reduce load.
	If 3 phase, one phase may be open	Check lines for open phase.
	Defective capacitor	Check for short circuit, grounded or open capacitor, replace if necessary.
Motor Stalls	Worn or sticking brushes on repulsion induction motors	Check for wear and correct brush pressure. Clean commutator if dirty.
	Wrong application	Change type or size. Consult manufacturer.
	Overloaded motor	Reduce load.
	Low motor voltage	See that nameplate voltage is maintained.
	Open circuit	Fuses blown, check overload relay, stator and pushbuttons.
	Incorrect control resistance of wound rotor.	Check control sequence. Replace broken resistors. Repair open circuits.

Table A - Small Motor Trouble Shooting Chart (Continued)

Trouble	Cause	What to Do
Motor Runs and then dies down	Power failure	Check for loose connections to line, to fuses and to control.
	Not applied properly	Consult supplier for proper type.
	Voltage too low at motor terminals because of line drop	Use higher voltage on transformer terminals or reduce load.
	If wound rotor, improper control operation of secondary resistance	Correct secondary control.
	Starting load too high	Check load motor is supposed to carry at start.
	Broken rotor bars	Look for cracks near the rings. A new rotor may be required as repairs are usually temporary.
	Open primary circuit	Locate fault with testing device and repair.
Motor takes too long to accelerate	Excess loading	Reduce load
	Poor circuit	Check for high resistance.
	Defective squirrel cage rotor	Replace with new rotor
	Applied voltage too low	Get power company to increase power tap.
Wrong rotation	Wrong sequence of phases	Reverse connections at motor or at switchboard.
Motor overheats while running under load	Overload	Reduce load
	Wrong blowers or air shields, may be clogged with dirt and prevent proper ventilation of motor	Good ventilation is manifest when a continuous stream of air leaves the motor. If it does not after cleaning check manufacturer.
	Motor may have one phase open	Check to make sure that all leads are well connected.
	Grounded coil	Locate and repair.
	Unbalanced terminal voltage	Check for faulty leads, connections and transformers.
	Shorted stator coil	Replace and then check wattmeter reading.
	Faulty connection	Indicated by high resistance.
	High voltage	Check terminals of motor with a voltmeter.

Table A – Small Motor Trouble Shooting Chart (Continued)

Trouble	Cause	What to Do
Motor overheats while running under load.	Low voltage	Check terminals of motor with a voltmeter.
	Rotor rubs stator bore	If not poor machining, replace worn bearings.
Motor vibrates after corrections have been made	Motor misaligned	Realign
	Weak foundations	Strengthen base
	Coupling out of balance	Balance coupling
	Driven equipment unbalanced	Rebalance driven equipment
	Defective ball bearing	Replace bearing
	Bearings not in line	Line up properly
	Balancing weights shifted	Rebalance rotor
	Wound rotor coils replaced	Rebalance rotor
	Poly phase motor running single phase	Check for open circuit
Unbalanced line current on polyphase motors during normal operation	Excessive end play	Adjust bearing or add washer
	Unequal terminal volts	Check leads and connections
	Single phase operation	Check for open contacts
	Poor rotor contacts in control wound rotor resistance	Check control devices
Scraping noise	Brushes not in proper position on wound rotor	See that brushes are properly seated and shunts in good condition.
	Fan rubbing air shield	Remove interference
	Fan striking insulation	Clear fan
Noisy operation	Loose on bedplate	Tighten holding bolts
	Airgap not uniform	Check and correct bracket fits or bearing
	Rotor unbalance	Rebalance
Hot bearings general	Bent or sprung shaft	Straighten or replace shaft
	Excessive belt pull	Decrease belt tension
	Pulleys too far away	Move pulley closer to motor bearing
	Pulley dia. too small	Use larger pulleys
	Misalignment	Correct by realignment of drive

Table A – Small Motor Trouble Shooting Chart (Continued)

Trouble	Cause	What to Do
Hot bearings sleeve	Oil grooving in bearing obstructed by dirt	Remove bracket or pedestal with bearing and clean bearing housing and oil grooves; renew oil
	Oil too heavy	Use recommended lighter oil
	Oil too light	Use recommended heavier oil
	Too much end thrust	Reduce thrust induced by drive, or supply external means to carry thrust
	Badly worn bearing	Replace bearing
Hot bearings ball	Insufficient grease	Maintain proper quantity of grease in bearing
	Deterioration of grease or lubricant contaminated	Remove old grease, wash bearings thoroughly in kerosene and replace with new grease
	Excess lubricant	Reduce quantity of grease bearing should not be more than 1/2 filled
	Overloaded bearing	Check alignment, side and end thrust
	Broken ball or rough races	Replace bearing, first clean housing thoroughly

D. Motor Replacement

In most instances where a replacement motor is to be purchased it may be specified from the nameplate information on the original motor, this will provide a new motor identical to the original. Since motors conform to NEMA standards and have standard ratings and dimensions, etc., a motor of a different manufacture may satisfactorily replace the original motor.

Caution: If the original motor was special, the nameplate will usually reveal this, direct replacement by a duplicate motor must be made. Failure to heed this caution may cause personal injury and damage to property.

One circumstance in which replacement by an identical motor may not be wise is when there has been a premature failure of the original motor. If the failed motor is less than five years old it has probably failed for lack of maintenance or misuse, however, a large number of causes for failure may be involved. In the event of premature failure, care must be taken to make certain that the original motor selection was the proper one.

Assure that:

The motor was correctly installed, particularly the electrical connections.

The power supply was correct.

The motor was of the size (speed and horsepower) to do the job.

If any of these conditions was not met the motor was not correctly selected. Use of the trouble shooting chart (D. above) in identifying the cause of failure and selecting the replacement motor will help lead to long trouble-free service.

7.3 Medium and Large A-C Motors

A. Safety Precautions

The following safety precautions should be observed:

1. Electric rotating machinery and high voltage can cause serious or fatal injury if improperly installed, operated, or maintained. Responsible personnel should be familiarized with NEMA MG2, safety standards for construction and guide for selection, installation and use of electric motors and generators, National Electrical Code, and all local safety requirements.

2. When servicing the motor, all power sources to the motor and to the accessory devices should be de-energized and disconnected and all rotating parts should be at standstill.
3. Lifting means, when supplied, are intended for lifting the motor only. When two lifting devices are supplied with the motor a dual chain must be used.
4. Suitable protection must be used when working near machinery with high noise levels.
5. Safeguard or protective devices must not be by-passed or rendered inoperative.
6. The frame of the machine must be grounded in accordance with the National Electrical Code and applicable local codes.
7. Avoid contact with start or run capacitors in single-phase motors until a safe discharge procedure has been followed.
8. A suitable enclosure should be provided to prevent access to the motor by other than authorized personnel. Extra caution should be observed around motors that are automatically controlled or have automatic re-setting relays as they may restart unexpectedly.
9. Enclose all belts to prevent injury from broken belts or entanglement.
10. Shaft key must be fully captive before motor is started.
11. Provide proper safeguards for personnel against possible failure of motor-mounted brake, particularly on applications involving over-hauling loads.

B. Storage

Only indoor storage is recommended. Indoor storage for 90 days or less:

Store in a clean, dry location with factory packaging intact. Storage should be maintained at constant temperature as nearly as possible to prevent condensation. If condensation does occur, do not energize until thoroughly dry. Before applying power, check motor insulation resistance with a megohmmeter. The minimum resistance should be 1.0 megohm for motors rated 600 volts and less and 3.0 megohms for 2300 volt motors.

1. *Indoor storage for more than 90 days:*

Store in a clean, dry location with a temperature as nearly constant as possible to prevent condensation.

Coat all machined parts with moisture resistant protective coating (cosmolyne or similar material) if not shipped with this protection from the factory.

Motors with grease lubricated bearings should have rust inhibitors in the grease. The shaft should be rotated slowly by hand at least once every sixty days. This will distribute the grease in the bearings.

Motors with oil lubricated bearings should have the oil reservoir filled with rust inhibiting oil. The shaft should be slowly rotated by hand at least every thirty days to keep the bearing lubricated.

Before shipping, oil is drained from bearing housings so refilling should be done when the motor goes in to storage.

At termination of storage the motor insulation resistance should be measured with a megohmmeter before applying power. Minimum resistance readings should be 1 megohm for motors 600 volts and less and 3 megohms for 2300 volt motors.

2. *Outdoor Storage*

Outdoor storage is not recommended. When storage in an enclosure is not possible the following procedures should be observed:

Coat all machined parts with Cosmolyne or similar material if not already protected.

Motors should be elevated a minimum of six inches above the ground.

Remove plastic covering or carton and cover motor with tarpaulin. This will protect the motor from the weather while minimizing condensation.

Keep the motor warm. If the motors are equipped with space heaters, keep them continuously energized. If motors are not equipped with heaters, auxiliary heat must be supplied to keep the motor windings warm and free from condensation.

Motors with grease lubricated bearings should have rust inhibitors in the grease. The shaft should be rotated slowly by hand at least every sixty days to distribute the grease in the bearings.

Motors with oil lubricated bearings should have the oil reservoir filled with rust inhibiting oil. The shaft should be rotated slowly by hand at least every thirty days to keep the bearings lubricated. Before shipment bearings are drained so the reservoirs should be filled upon going into storage.

At termination of storage the motor insulation resistance should be measured with a megohmmeter before applying power. Minimum resistance readings should be 1 megohm for motors 600 volts and less and 3 megohms for 2300 volt motors.

C. Installation

In all motor installation, assure that no surrounding structure will obstruct normal flow of ventilating air over or through the motor.

1. Foundations

Foundations should be of ample size and strength to support the motor with maximum stability. The foundation should be level and of a height to make maintenance of the motor convenient.

The top of a concrete foundation must be approximately one inch lower than the bottom of the base to allow space for grout. The top of the foundation must be left rough to provide good anchorage for the grout.

2. Bases

Bases should be designed and selected to support the motor without auxiliary bracing or other support.

3. Mounting

The motor should be securely mounted on a bedplate, base, or platform that is rigid enough to prevent any vibration of the unit and to prevent transmission of vibration to the unit. The base must not impose bending or twisting strains on the motor.

The following procedure for mounting a motor is recommended:

Using maximum size mounting bolts.

Step 1. Add slotted shims under the lowest mounting foot and tighten mounting foot bolt.

Step 2. Insert required shims under other foot as determined by measurement with feeler gauges, and tighten mounting foot bolts. Use thickest possible shims to meet the requirement.

Step 3. Measure alignment using procedure given under Alignment of Direct Connected Shafts.

Slotted shims should be used as it may be necessary to remove or add shims when aligning shafts.

4. Grouting

After the unit is correctly aligned and bolted down, wash the top of the foundation and pour and pack the grout.

5. Alignment of Direct Connected Shafts angular misalignment and run-out between direct connected shafts will cause increased bearing loads and vibration even when connection is made by means of a flexible coupling. Shaft alignment is especially critical if the motor is to be run at high speeds. The alignment of direct connected shafts should be checked with a dial indicator after coupling hubs have been installed.

To check for angular alignment clamp the dial indicator to the side of one coupling hub and place the finger or button of the indicator against the finished face of the other hub. Refer to Figure 13.

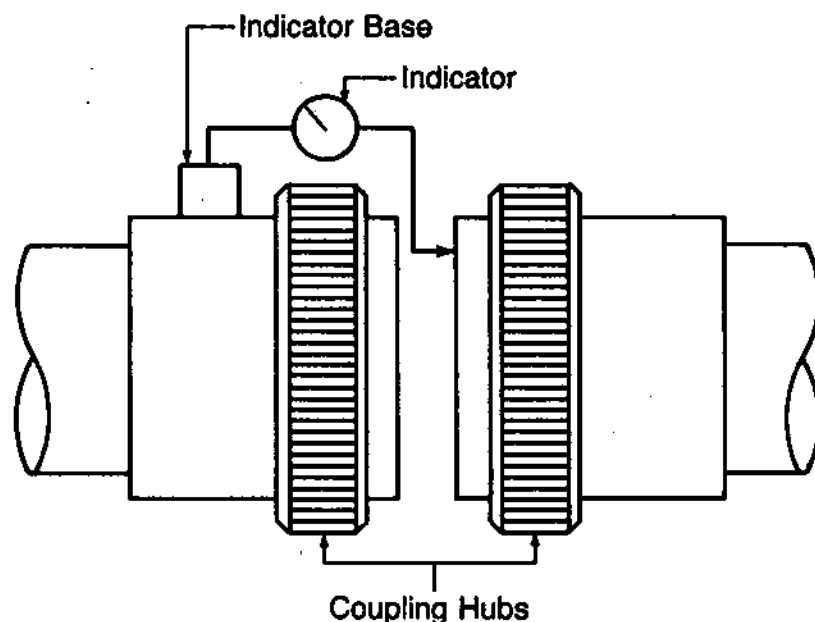


Fig. 13 – Checking for Angular Alignment of Direct Connected Shafts Using a Dial Indicator

Scribe a reference mark on the coupling hub at the indicator button to mark its position on the hub. Rotate both shafts simultaneously, keeping the indicator button at the reference mark on the coupling hub, and note the reading on the indicator dial at each one-quarter revolution.

Note: Angular misalignment of the shafts must not exceed a total indicator reading of .001 inch for each inch of radius of the coupling hub.

After the shafts have been checked for angular misalignment and are parallel within the limits specified in the preceding paragraph, check the shafts for run-out to assure concentricity of the shafts. Most flexible coupling hubs are provided with a ground or accurately machined diameter to facilitate the checking of run-out with a dial indicator. Clamp the indicator to one coupling hub and place the indicator button on the machined diameter of the other hub as shown in Figure 14.

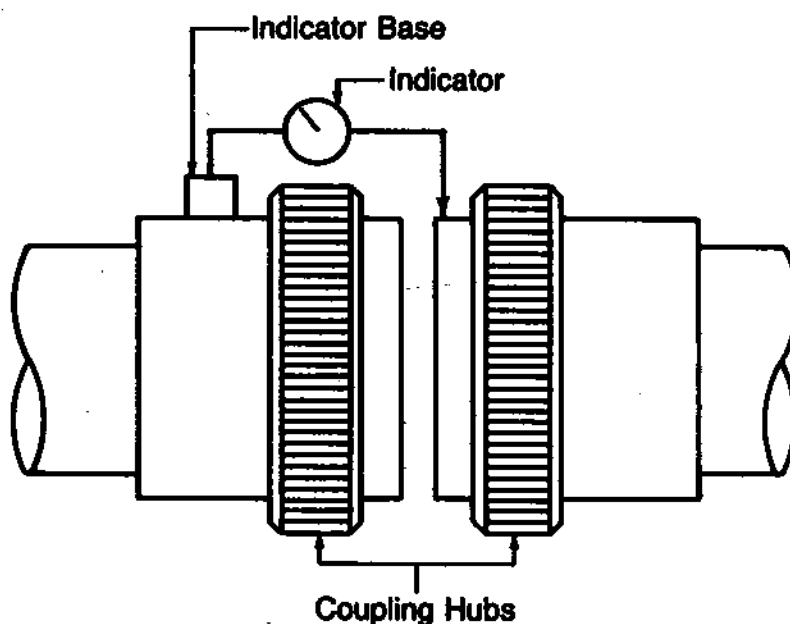


Fig. 14 – Checking for Run-Out of Direct Connected Shafts Using a Dial Indicator

Scribe a reference mark on the machined diameter of the coupling hub at the indicator button. Rotate both shafts simultaneously, keeping the indicator button at the reference mark on the hub and note the reading on the indicator dial at each one-quarter revolution.

Note: Total run-out between the hubs should not exceed .002 inch.

If it is not possible to rotate both shafts when checking alignment, the indicator should be clamped to the hub of the rotating shaft and the indicator button should sweep the ground diameter and face of the stationary hub. Distorted or cocked coupling hubs may cause errors in checking by this method, however, and the former method is preferred where possible.

After the alignment has been checked, and if necessary adjusted, secure the mounting bolts on the motor and the driven equipment, then recheck alignment before engaging the coupling.

a. Balance, Direct Connected Units

Motors are factory balanced to standard NEMA commercial tolerances. If direct coupled units have been disassembled in the field an unbalance may occur upon re-assembly if shafts are not re-assembled in the same relative positions as originally. If this occurs, disconnect the coupling halves and rotate one shaft ninety degrees relative to the other, reconnect and run the unit. If unbalance has not disappeared, repeat above procedure until balance is attained.

b. Alignment of Belted Drives

To check alignment place a straight edge across the faces of the driving and driven sheaves. If properly aligned the straight edge will contact both sheave faces squarely. Refer to Figure 15.

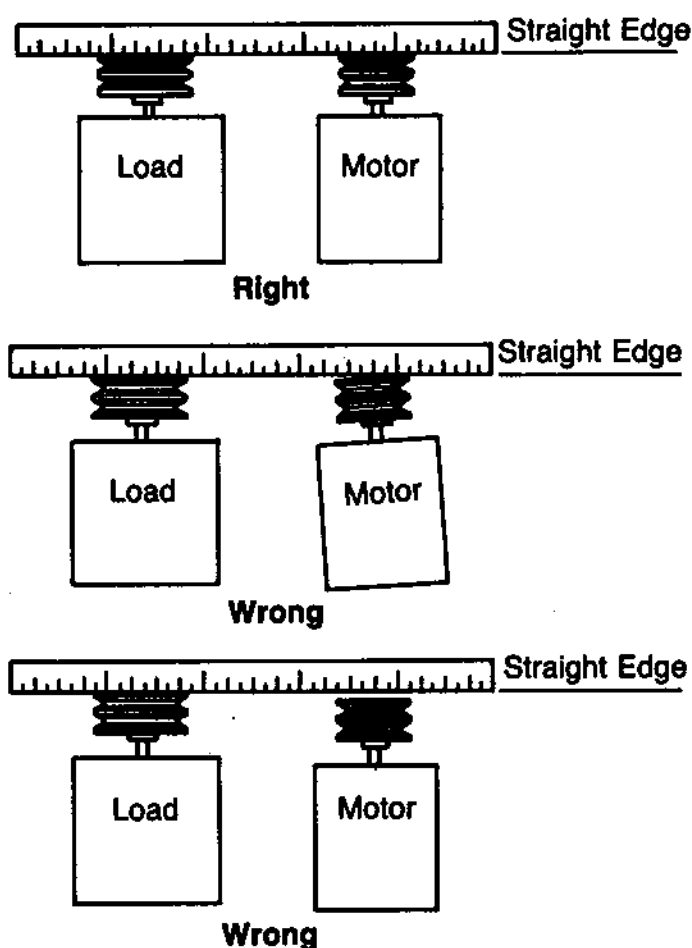


Fig. 15 – Alignment of Driving and Driven Sheaves for Belt Drives

Application of V-belt dimensions to alternating-current general purpose motors are given in Table B below. V-belt sheave pitch diameters should not be less than the diameters shown.

Table B Sheave Dimensions for V-belt Drive

Frame	Horsepower at				V-belt Sheave (Inches)			
					Conventional		Narrow	
	Synchronous Speed, Rpm				A, B, C, D, & E Sections		3V, 5V & 8V Sections	
	3600	1800	1200	900	Min. Pitch Dia.	Max. Width	Min. Pitch Dia.	Max. Width
143T	1½	1	¾	½	2.2	4¼	2.2	2¼
145T	2-3	1½-2	1	¾	2.4	4¼	2.4	2¼
182T	3	3	1½	1	2.4	5¼	2.4	2¾
182T	5	...	...	...	2.6	5¼	2.4	2¾
184T	...	...	2	1½	2.4	5¼	2.4	2¾
184T	5	...	...	...	2.6	5¼	2.4	2¾
184T	7½	5	...	...	3.0	5¼	3.0	2¾
213T	7½-10	7½	3	2	3.0	6½	3.0	3¾
215T	10	...	5	3	3.0	6½	3.0	3¾
215T	15	10	...	...	3.8	6½	3.8	3¾
254T	15	...	7½	5	3.8	7¾	3.8	4
254T	20	15	...	...	4.4	7¾	4.4	4
256T	20-25	...	10	7½	4.4	7¾	4.4	4
256T	...	20	...	...	4.6	7¾	4.4	4
284T	30	...	...	...	4.4	9	4.4	4⅝
284T	...	...	15	10	4.6	9	4.4	4⅝
284T	...	25	...	...	5.0	9	4.4	4⅝
286T	30	...	...	...	4.4	9	4.4	4⅝
286T	40	30	20	15	5.4	9	5.2	4⅝
324T	40	...	...	...	5.4	10¼	5.2	5¼
324T	50	40	25	20	6.0	10¼	6.0	5¼
326T	50	...	...	...	6.0	10¼	6.0	5¼
326T	60	50	30	25	6.8	10¼	6.8	5¼
364T	60	...	40	30	6.8	11½	6.8	5⅞
364T	...	60	...	...	7.4	11½	7.4	5⅞
365T	...	...	50	40	8.2	11½	8.2	5⅞
365T	...	75	...	...	9.0	11½	8.6	5⅞
404T	...	...	60	...	9.0	14¼	8.0	7¼
404T	...	...	...	50	9.0	14¼	8.4	7¼
404T	...	100	...	...	10.0	14¼	8.6	7¼
405T	...	...	75	60	10.0	14¼	10.0	7¼
405T	...	100	...	...	10.0	14¼	8.6	7¼
405T	...	125	...	...	11.5	14¼	10.5	7¼

Table B Sheave Dimensions for V-belt Drive (Continued)

Frame	Horsepower at				V-belt Sheave (inches)			
					Conventional		Narrow	
	Synchronous Speed, Rpm				A, B, C, D, & E Sections		3V, 5V & 8V Sections	
	3600	1800	1200	900	Min. Pitch Dia.	Max. Width	Min. Pitch Dia.	Max. Width
444T	...	...	100	...	11.0	16¼	10.0	8½
444T	...	...	...	75	10.5	16¼	9.5	8½
444T	...	125	...	...	11.0	16¼	9.5	8½
444T	...	150	...	...	...	...	10.5	8½
445T	...	...	125	...	12.5	16¼	12.0	8½
445T	...	...	...	100	12.5	16¼	12.0	8½
445T	...	150	...	...	...	...	10.5	8½
445T	...	200	...	...	...	...	13.2	8½

c. Overhung Load Drive Data

For drives other than V-belt drives, determine the minimum pitch diameters by multiplying the V-belt minimum by the values shown in Table C.

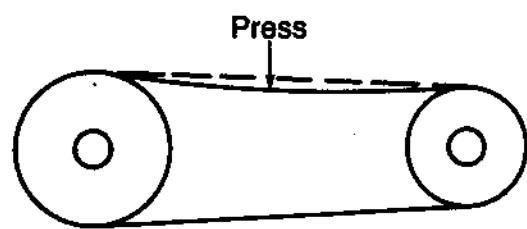
Table C

Drive Type	Multiplier	V-Belt Min. Dia. For
Flat belt (single ply only)	1.33	Conventional Belts
Timing belt	0.9	Super Belts (5V,8V)
Chain Sprocket	0.7	Super Belts
Spur Gear	0.75	Super Belts
Helical Gear	0.85	Super Belts

d. Belt Tension

Belt tension is checked as follows:

Press down on each individual belt. In general, a belt that can be deflected a distance equal to one half its own thickness for each 24 inches of unsupported length is properly tensioned. Refer to Figure 16.

**Fig. 16 – Checking Belt Tension.**

6. Vibration

Vibration may be caused by poor alignment, unbalance, resonant foundation, vibration of driven equipment, loose hold-down bolts, or other factors. Vibration is detrimental to all rotating apparatus and must be minimized. NEMA has established standards for maximum allowable vibration against which all motor manufacturing members test their motors. The user can be assured that new motors will meet these NEMA standards:

Table D – NEMA Vibration Standards

Speed rpm①	maximum amplitude in inches②
3500 and above	0.001
1700-3499	0.0015
less than 1700	0.002

① For a-c motors use the highest synchronous speed, for d-c motors use the highest rated speed.

② Amplitude as used here means total peak-to-peak displacement.

Figure 17 is a vibration severity chart for use as a guide in judging vibration as a warning of impending breakdown.

For more information on the causes and correction of motor vibration refer to *Westinghouse Electrical Maintenance Hints, Volume 2 Chapter 11*.

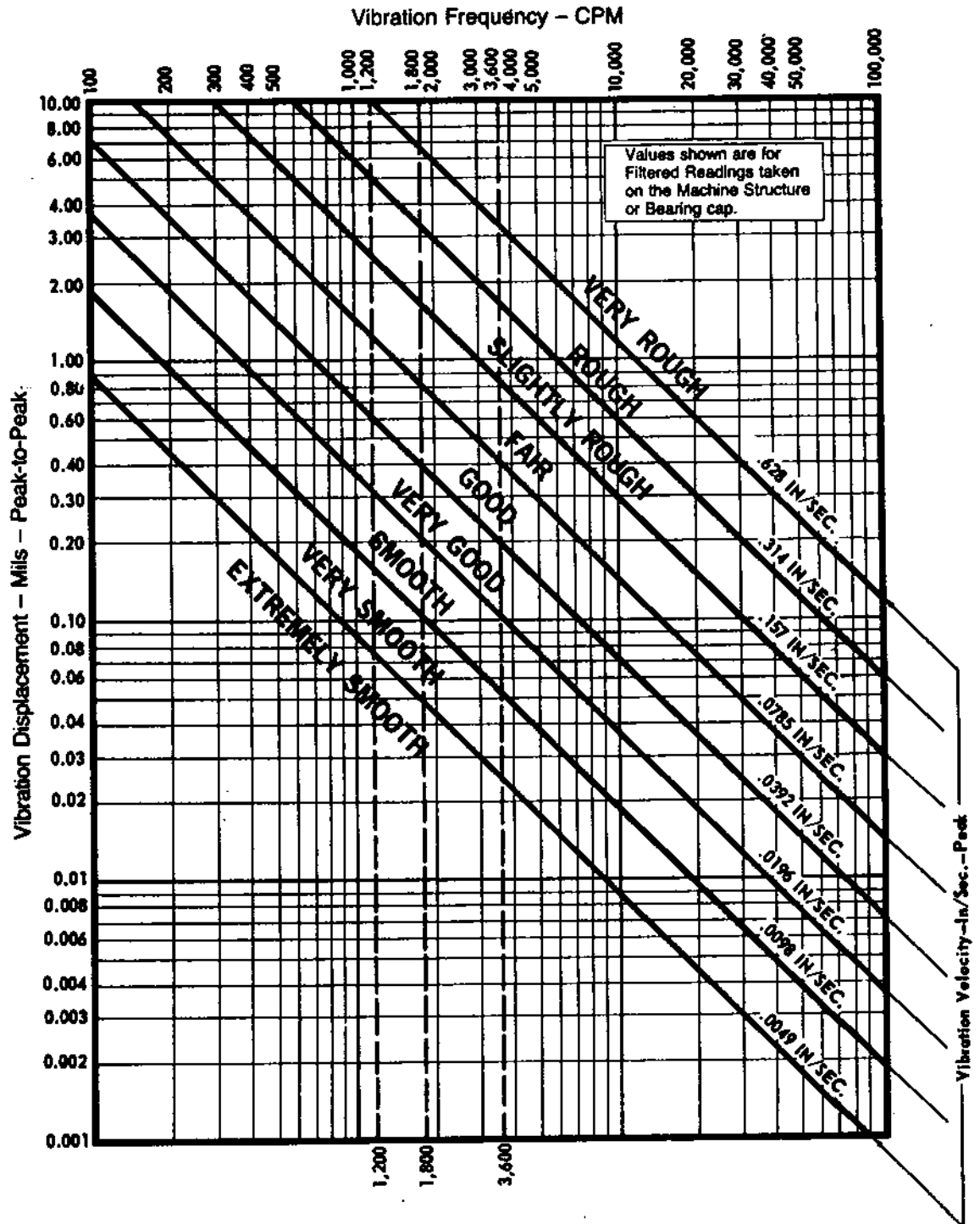
a. Measurement of Vibration

If vibration problems are encountered with installed motors it is first necessary to isolate the motor from its mounting to determine if the vibration is in the motor.

Since vibration is influenced by the mounting of the motor, it is desirable to test for vibration under actual installed operation conditions. From a practical standpoint however, it is necessary to measure vibration under specified, uniform test conditions which will result in reproducible tests and provide comparable measurements. To provide conditions for reproducible test, NEMA method 1-12.06 has been established. The measurement procedure is as follows:

1. Place the motor on an elastic mounting so proportioned that the up and down natural frequency shall be at least as low as $\frac{1}{4}$ of the operating or base speed of the motor. To accomplish this, it is required that the elastic mounting be deflected downward by at least the

For use as a GUIDE in judging vibration as a warning of impending trouble.



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Fig. 17 - Vibration Severity Chart

amounts shown by the following relationship due to the motor weight:

$$\text{deflection (inch)} \geq \frac{1}{2} \frac{386}{(\text{rps})^2} ; \text{ where } \text{rps} = \frac{\text{rpm}}{60}$$

When a flexible pad is used, the compression shown in the table below should in no case be more than $\frac{1}{2}$ the original thickness of the flexible pad; otherwise the supports may be so stiff as to distort vibration measurement.

Table E – Mounting Pad Compression

rpm	compression, inches
900	1
1800	$\frac{1}{4}$
3600	$\frac{1}{16}$
7200	$\frac{1}{64}$

Note: The required deflection is inversely proportional to the speed squared.

2. The end of the shaft shall have a full length key flush with the shaft diameter. An alternating-current motor shall be operated at rated voltage and nominal frequency without load.
3. Only reliable, accurate vibration measuring instruments will be used.
4. The amplitude of vibration shall be measured on the bearing housing, in both radial and axial directions referred to the shaft axis. See Figure 18. Care must be taken to assure that measurements truly represent vibration of the bearing housings and do not include any extraneous local vibrations.

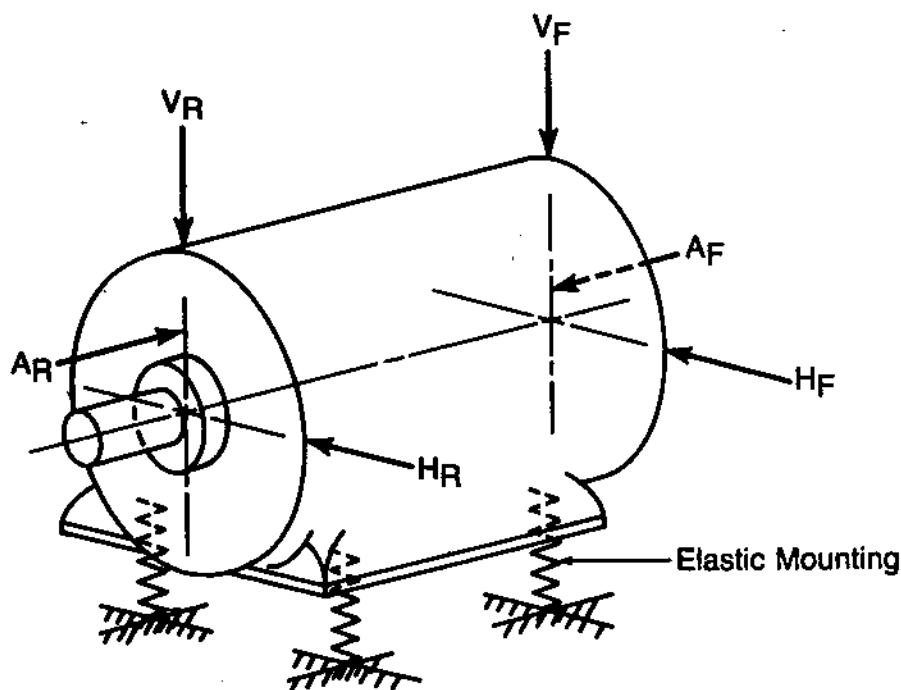


Fig. 18 – Motor Vibration Measurement

5. If vibration exceeds specified limits indicated in specifications, it is necessary to identify the source of the problem. The above method of measuring vibration is basically set up to check dynamic balance of the motor. There are other causes of vibration in the motor that are equally important.

a. The Cause of Vibration:

The cause of vibration is a force which is changing in either the direction or amount. The source can be identified by frequency and other characteristics of vibration.

b. The Vibration Analysis:

The vibration analysis consists of measuring the vibration and the characteristic of that vibration. It is required that at least the frequency, the amount, and the direction of the vibration be known in order to identify the source of force causing the vibration.

c. Recording Vibration:

To measure the vibration, place the pickup at points on a motor where the most information can be gained. The pickup is placed on the bearing housing as near to the shaft as possible.

- (1) Vertical and horizontal readings are taken with the pickup perpendicular to the shaft centerline (radial vibration).
- (2) Axial vibration readings are taken with the pickup parallel to the centerline of the shaft.

Note: The pickup measures the vibration occurring in the direction in which it is pointed.

- (3) Measure the displacement (mils or inches) and the velocity (inch/sec) of the vibration at the points indicated above.

Note: A check for any vibration on the motor should also be made after it has been stopped to assure that the vibration measured is not coming from another machine or source. If any peculiarities are noted, these should also be recorded.

d. Record the Data:

A good record of vibration readings will help avoid confusion and will provide a useful reference for future.

b. Motor Vibration Test Data**Motor****Frame Speed Hp Encl.****Test Instrument****Manufacturer Model****Latest Calibration Date****Tester's Name****Date of Test****Legend for Test Motor Sketch****Pick-up Point****Ball Bearing****Roller Bearing****Sleeve Bearing****Elastic Mounting****Clamped or Bolted Down****Test Motor Sketch**

Pick-up Position		Displacement (inches)	Velocity (inch/sec.)	Frequency (cpm)①	Remarks
Bearing	Point				
R E A R	H V A				
F R O N T	H V A				

① If frequency cannot be read directly due to instrument limitation, the General Machinery Vibration Severity Chart, Figure 17, should be used to determine frequency.

Table F -- Trouble Shooting Causes of Vibration

After the characteristics of the vibration have been determined, they can be compared with the characteristics of known sources of vibration. Some of the more frequently encountered causes of vibration are given below:

Vibration Amount and Direction	Description	Probable Cause	Action
Vibration Frequency $1 \times \text{Rpm of Shaft}$			
Greatest in vert. radial direction	Horiz. mtd. mtr. vert. displacement more than $1\frac{1}{2} \times$ horiz. both ends of mtr.	Elastic mtg. too stiff	Recheck & test mtg. Correct to spec. and retest.
Radial in all directions—steady	Radial displace approx. same all directions. Vibration persists with power off. Excess vib. on one end only.	Blower Unbalance or improper key used in balance or test.	Have rotor re-balanced. Rotor must be balanced with proper $\frac{1}{2}$ key and blower must be balanced with rotor.
	Radial displace approx. same in all directions may not be same amplitude at both ends. Vibration persists with power off.	Unbalanced rotor.	Have rotor rebalanced.
Radial—all directions. Small $<.0005''$ steady.	Similar to rotor unbalance. May occur with heavy rotors.	Eccentric inner race of ball or roller bearing re. shaft fit.	Assure rotor is supported on brg. fits during balance. Check fits of brg. runout or balance rotor on brgs.
Radial all directions	Vibration disappears when voltage reduced or power off.	Eccentric rotor (not necessarily unbalanced)	Bring rotor to specified TIR.
Radial one direction small $<.0005''$	Do not confuse with mtg. amplif. in one direction.	Squeezed or out of round bearing outer ring.	Check bracket bearing bore and bearing OD TIR.

Table F – Trouble Shooting of Vibration (Continued)

Vibration Amount and Direction	Description	Probable Cause	Action
Vibration Frequency $1 \times \text{Rpm}$ or $2 \times \text{Rpm}$ of Shaft			
Axial—high Some radial	May be noisy.	Off-square seated bearing on shaft or misalignment of i.e. brg. runner.	Check and correct.
	Radial vibration also high.	Bent shaft.	Check, correct, rebalance rotor
Vibration $2 \times \text{Rpm}$ Sometimes $3 \times \text{Rpm}$ of Shaft			
Unsteady	May be noisy.	Mechanical—rub, looseness, misalignment.	Locate and correct.
Variable Vibration Frequency			
Periodically pulsating or swinging.	Most common in 2-pole motors	Beat—two or more frequencies close together, frequency interference.	Consult design engineer.
Very High Frequency Vibration—Many Times Rpm			
Unsteady—small displacement but high velocity.	Rough vibration small displacement amplitude. Noisy.	Defective or damaged bearing (ball or roller) chips or dirt in bearings.	Replace bearings.

Note: There may be many other causes of vibration; i.e., structural resonance, but this can only be determined if the motor is installed in an actual application or if the conditions are known under which resonance is occurring. Other problems may involve winding design. Such cases may have to be analyzed by the manufacturer.

7. Flange Motors

Fits of motor flanges are accurately machined to mate with driven equipment. Mating surfaces must be free of dirt or burrs and solidly engaged. The assembly should turn freely without stressing shaft or bearings from misalignment or thrust.

8. *Electrical Connections – Procedure*

- a. Connect the motor to the proper power supply as indicated by the nameplate diagram.**

Warning: Do not make any connections to a motor until the power supply has been de-energized. Failure to heed this warning can cause severe personal injury or death, and damage to property.

- b. Install wiring, protective devices, and grounding in accordance with the National Electrical Code and local requirements.**
- c. Identify motor auxiliary devices such as space heaters or temperature sensors. Connect in proper circuits and insulate from motor power circuits.**

9. *Wound Rotor Motor Connections – Procedure*

- a. Connect cables from secondary control to brushholder assembly. Bring cables through squeeze connector on front bracket where provided.**
- b. Slip rings must be maintained in smooth, true condition. If necessary machine to restore proper surface for brushes.**
- c. Brushes must make good contact with slip rings along entire face of brush. If necessary dress brushes with fine sandpaper. Do not use lubricants.**
- d. Replacement brushes must be the same grade as the originals.**

Notice: Continuous light-load operation can develop threading (ring grooving), in which case a different grade of brush may be required. The motor manufacturer should be consulted in these instances.

D. *Start Up Procedure*

- 1. Disconnect load and start motor. Check direction of rotation.**

Caution: If rotation must be changed, allow the motor to stop completely. Interchange any two leads of a three phase motor. Reconnect a single phase motor per nameplate instructions. Fans on fan cooled motors that have directional rotation nameplates must be reversed on shaft if rotation is changed. Failure to follow this procedure can cause injury and damage to property.

2. **Connect load.** The motor should start quickly and run smoothly. If not, shut power off at once. Recheck the assembly including all connections before restarting. For single phase motors also examine capacitor wiring and mechanism for switching between starting and running.
3. **If excessive vibration is noted,** check for loose mounting bolts, too flexible motor support structure, or transmitted vibration from adjacent machinery. Periodic vibration checks should be made; foundations often settle.
4. **Operate under load for short period;** check operating current against nameplate.

E. Maintenance

Systematic inspection of equipment should be scheduled and records kept of the findings of these inspections. Examinations of these records will provide forewarnings of potential troubles. Periodically, at planned intervals such as plant shutdowns, the equipment should be completely dismantled and overhauled.

The three cardinal rules in maintaining electrical equipment are:

Keep it Dry

Keep it Tight

Keep it Friction-free

1. Cleaning

Dust, grit, oil and moisture are the great enemies of electrical equipment. Dust and grit can be removed by wiping with dry cloths, by brushing, by pick-up with a vacuum, or blowing off with compressed air.

Brushing and blowing can do as much damage as they correct. Both procedures can spread dirt and force it into inaccessible recesses. Care must always be taken to assure that any compressed air system used contains no moisture. Hose tips and nozzles should be non-metallic. Compressed air pressure should not exceed 50 psi.

Dust and grit will soak up oil and form a gum that is difficult to remove. Oil is particularly damaging in that it tends to attack insulating varnish. When a motor has become oil soaked it is in danger of burning out. Oil and grease covered machines should be thoroughly cleaned and a fresh coating of insulating varnish applied.

Warning: Do not operate a motor that is oil soaked or grease covered, it is in danger of burnout. Failure to heed this warning can cause severe personal injury and damage to property.

A soft, lint-free cloth soaked in trichloroethane solvent can clean most places. Difficult to reach places may require a soft brush or spray gun. Windings should be thoroughly dried after cleaning.

Warning: Avoid excessive contact with cleaning solvents and the breathing of their vapors. Some solvents are extremely toxic and readily absorbed into the system. Failure to heed this warning can cause severe personal injury or death.

2. Moisture

Electrical equipment operates best in a dry atmosphere. The effect of humidity on copper and iron is to cause oxidation which increases resistance and heating, and leads to eventual failure. High moisture levels can lead to direct short-circuiting and immediate failure. Other liquids such as oil can cause deterioration of insulating materials. Any moisture tends to increase dirt build-up which leads to overheating, short circuiting and failure.

Special enclosures are available for motors that must be operated in high moisture conditions, there are also space heaters offered to help lower moisture levels.

3. Tightness

Most electrical equipment operates with high speed movements which will eventually cause wear and imbalance of moving parts. This imbalance tends to create vibrations in equipment and to loosen vital connecting parts. Routine maintenance should always include the tightening of all connecting parts.

4. Lubrication – Ball Bearings

Unless a special grease is specified on the nameplate, one of the following or the equivalent should be used:

Chevron SRI-2 – Standard Oil of California

Premium RB – Texaco, Inc.

Unirex N2 – Exxon

Dolium R – Shell Oil Company

Rykon Premium – American Oil

a. Relubrication

When regreasing, stop the motor, remove inlet and outlet plugs, and add grease in accordance with the following table, use handgun only:

Table G – Grease Volume Application Table

Shaft Diameter in inches (At face of Bracket)	Amount of Grease to Add
¾ to 1¼	⅛ cu. in. or 0.1 oz.
1¼ to 1¾	¼ cu. in. or 0.2 oz.
1¾ to 2¾	¾ cu. in. or 0.6 oz.
2¾ to 3¾	2 cu. in. or 1.6 oz.

Notice: Overgreasing is a major cause of bearing and motor failure. Great care should be taken to prevent introduction of dirt and contaminants when adding grease to bearings.

Do not expect grease to appear at the outlet, but if it does, discontinue greasing at once. Run for about ten minutes before replacing outlet plug. Certain TEFC motors have a spring relief outlet fitting on the fan end; if the outlet plug is not accessible at surface of hood, it is the spring relief type and need not be removed when regreasing.

b. Frequency of Relubrication

The following table suggests relubrication intervals for motors on normal, steady running, light duty indoor loads in relatively clean atmosphere at 40°C (104°F) ambient temperature or less:

Note: For Motors Over 1800 rpm – Use ½ of tabled period.

For Severe Duty }
Dusty Locations } Use ⅓ of tabulated period.
High Ambient }

Table H – Lubrication Frequency

Type of Enclosure	Insulation	Frame Size					
		143 to 215T	254 to 326T	364 to 449T			
Open – DP	B	2 yrs.	18 mo.	1 yr.			
Enclosed – FC	B	18 mo.	1 yr.	9 mo.			
Open – DP	F						
Enclosed – NV	B	1 yr.	9 mo.	6 mo.			
Enclosed – FC	F						
Open – DP	H						
Enclosed – Lint	F	9 mo.	6 mo.	3 mo.			
Free – FC							
Enclosed – NV	F						
Enclosed – FC	H						
Enclosed – Lint	F						
Free – FC							

5. Lubrication – Sleeve Bearings

Before starting the motor, fill both reservoirs through the filler plug with best quality, clean motor oil. The oil should have a viscosity of from 180 to 200 SSU (equivalent to SAE No. 10). During operation, no oil should be added until it drops below the full level. Do not flood the bearing. At about 2-year intervals, dismantle and thoroughly wash out the bearing housing, using hot kerosene oil.

6. Replacing Ball Bearings

As ball bearings rotate the repeated stressing of bearings and races leads ultimately to fatigue of the metal and bearing failure. The higher the load the higher the stress, and the shorter the time until the bearing fails. Bearings are rated by their probability of fatigue failure.

Bearing manufacturer's testing of bearings discloses that bearings in a single group will have different life spans under the same load. For this reason bearings are rated for either minimum or average life.

Minimum bearing life is the period of time, based on continuous operation at designed load, after which 90 percent of the bearings will still be operating. Average bearing life is five times the minimum bearing life.

When removing or replacing a ball bearing there are several rules which should always be observed. Following these rules closely will prevent damage to bearings or motors and will result in longer bearing life.

When removing a bearing from a motor, always use an approved bearing puller, refer to Figure 19. Never open the protective cover on new bearings where the bearing will be exposed to dust or dirt. Always open a new bearing package in a clean place and do not remove bearing from the package until ready to install.

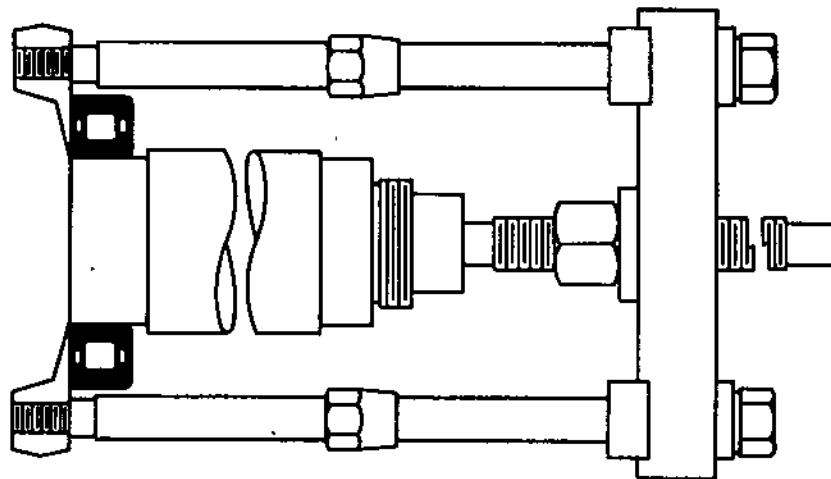


Fig. 19 – Use An Approved Bearing Puller

Never try to clean a new ball bearing. The slushing oil on new bearings should not be removed. Fill the bearing chamber only three-fourths full of clean grease. Do not pack the bearing full of grease as this will cause overheating.

Do not force the bearing on the shaft by pressing the outer race. Do not attempt to force a bearing on a badly worn shaft or a shaft which is too large.

A metal tube of a diameter that will fit over the motor shaft and press against the inner race of the bearing can be used to mount a replacement. The tube should be tapped or pressed, it should never be struck hard to force the bearing in place. Refer to Figure 20.

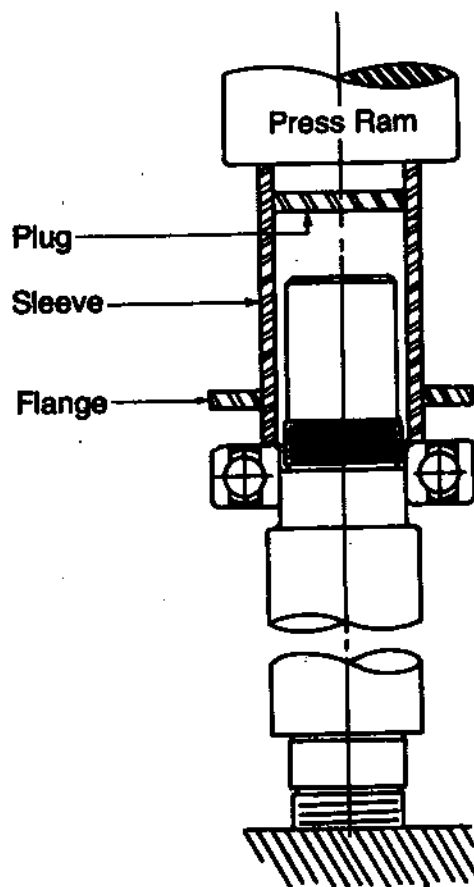


Fig. 20 – A Metal Tube Can Be Used to Install a Bearing

Another method of installing ball bearings is to heat the bearing in an oven or oil bath so that it will slide onto the shaft. Before heating, be sure that bearing inside diameter has been checked against shaft journal dimension to prevent too tight a fit after bearing cools. Difference of bore to journal should be .0004 tight to .0004 loose. Use a temperature of approximately 200°F. Too high a temperature will damage the bearing and too low a temperature will cause the bearing to seize the shaft.

7. Hazardous Duty Motors

These motors are constructed to comply with the U/L Label Service Procedure Manual. When reassembling a motor that has the Underwriters Label as Explosion Proof, it is imperative that the unit be re-inspected to assure the original fits and tolerances are maintained. Make sure that all plugs and hardware are securely fastened, and any parts replacements are accurate duplications of the originals.

8. Winding Inspection and Maintenance

Windings should be regularly inspected for accumulated dust and dirt, obvious insulation deterioration, and obstruction of ventilation.

a. Stator Windings

Stator troubles can usually be traced to such causes as worn bearings, moisture, overloading, operating single phase, and failing insulation.

A condition which frequently hastens winding failure is movement of the coils due to vibration. Insulation that has dried out it has lost its flexibility and the mechanical stresses caused by starting and plugging, and the normal stresses in operation under load can precipitate short circuits in coils and potential failure from coil to ground, this is usually at a point at which the coil leaves the slot. Periodic cleaning, varnishing and oven drying, performed so as to fill all air spaces caused by drying and shrinkage will maintain a solid winding and will also provide an effective seal against moisture.

b. Rotor Windings

The comments on stator windings also apply to the rotors of wound rotor motors but there are additional considerations due to it being a rotating element.

Most wound rotor motors have three-phase winding and are susceptible to single phase operation trouble. The first symptom of an open-rotor circuit is lack of torque with a slowing in speed. This condition usually produces a growling noise. There may also be a failure to start the load. The first place to look for an open secondary circuit is in the resistance bank or the control circuit external to the motor. Short-circuiting the rotor circuit at the slip rings and then operating the motor will usually determine whether the trouble is in the control circuit or in the rotor. The problem may be one of the stud connections to the slip rings.

If the rotor is wave wound with the windings made up of copper strap coils with clips connecting the top and bottom halves of the coil, the end connections should be inspected for signs of heating, which would be an indication of a partial open circuit. Faulty or improperly made end connections are a common source of open circuits in rotor windings.

A ground in a rotor circuit will not affect the performance of the motor unless there is a second ground. This condition might cause the equivalent of a short-circuit and would have the effect of unbalancing the rotor electrically. In addition to reduced torque there may also be excessive vibration and sparking and uneven wear of the collector rings.

Another method of checking for short-circuits in rotor windings is to raise the brushes off the sliprings and energize the stator. If the rotor winding is free from short-circuits there should be little or no tendency to rotate, even when disconnected from the load. If considerable torque is evidenced or there is a tendency to come up to speed, the rotor should be removed and the winding examined for fault. Some rotors having a wide tooth design may tend to rotate even when windings are in good condition.

Another check which can be made with the rotor in place and the stator energized, also with the brushes raised, is to measure the voltage across the rings to determine if they are in balance. Judgement is required to decide if any inequality in voltage is due to relative positions of the rotor and stator phases. Measurements should be made in several positions.

c. Squirrel Cage Rotors

Squirrel cage rotors generally require less maintenance than wound rotors. They may also give trouble due to open circuits or high resistance points in the rotor circuit. The symptoms of such conditions are a slowing under load and reduced starting torque. These symptoms are revealed by evidence of heating at the end ring connections, most noticeable when shutting down after operating under load.

In brazed rotors any fracture in the rotor bars will most likely be at the point of connection to the end ring or at the point where the bar leaves the laminations. Discolored bars are another evidence of excessive heating.

Brazing broken bars or replacing bars should be done only by trained, experienced technicians. Probably this work is best done in a properly equipped repair shop.

In die cast rotors cracks or imperfections may appear in the end rings. A faulty die-cast rotor can rarely be repaired and should be replaced.

d. The Air Gap

A periodic check of the air gap should be made with a feeler gauge at the shaft end of the motor. Normal wear can permit the rotor to rub the laminations.

On larger motors a record should be kept of these measurements. Four measurements taken approximately 90 degrees apart should be made. One of these points should be the load side, the part on the rotor periphery corresponding to the load side of the bearing. Comparison of these periodic checks will permit early detection of wear. Even a slight rub will generate heat sufficient to destroy the coil insulation.

F. Standards for Motor Insulation

In recent years the trend in motor construction has been to provide increased rating in a given size through the use of higher temperature insulation systems. An insulation system is a combination of insulation materials having a given hot-spot operating temperature. Maximum hot-spot temperatures for the various insulation systems are given in Table J. on page 2:7.46.

A particular thermal class system is a system utilizing materials having the same temperature index and operating at such temperature rises above stated ambient temperatures as the equipment standard specifies based on experience or accepted data. This system may contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy.

Table I – Medium and Large Motor Trouble Shooting Chart

This chart does not cover all possible problems. It lists only the more frequently encountered problems.

Trouble	Cause	What To Do
Motor fails to start	Blown fuses	Replace fuses at least 125 per cent of nameplate amperes
	Overload Trips	Check and reset overload in starter
	Improper current supply	Check to see that power supplied agrees with motor nameplate and load factor
	Improper line connections	Check connections with diagram supplied with motor
	Open circuit in winding or starting switch	Indicated by humming sound when switch is closed. Repulsion induction motors may spark at brushes. Check for loose wiring connections; also see if starting switch inside motor is closed
	Mechanical failure	Check to see if motor and drive turn freely. Check bearings and lubrication
	Short circuited stator	Indicated by blown fuses. Motor must be rewound
	Poor stator coil connection	Remove end bells, locate with test lamp
	Rotor defective	Look for broken bars or end rings
	Motor may be overloaded	Reduce load
Motor does not come up to speed	If 3 phase, one phase may be open	Check lines for open phase
	Broken rotor bars	Look for cracks near the rings. A new rotor may be required as repairs are usually temporary.
Motor takes too long to accelerate	Open primary circuit	Locate faults with testing device and repair.
	Excess loading	Reduce load
	Poor circuit	Check for high resistance
	Defective squirrel cage rotor	Replace with new rotor
	Applied voltage too low	Get power company to increase power tap.

**Table I – Medium and Large Motor Trouble Shooting Chart
(Continued)**

Trouble	Cause	What To Do
Wrong rotation	Wrong sequence of phases	Reverse connections at motor or at switchboard
Motor overheats while running under load	Overload	Reduce load
	Wrong blowers or air shields, may be clogged with dirt and prevent proper ventilation of motor.	Good ventilation is manifest when a continuous stream of air leaves the motor. If it does not after cleaning check manufacturer
	Motor may have one phase open	Check to make sure that all leads are well connected.
	Ground coil	Locate and repair
	Unbalanced terminal voltage	Check for faulty leads, connections and transformers
	Shorted stator coil	Repair and then check wattmeter reading
	Faulty connection	Indicated by high resistance
	High voltage	Check terminals of motor with a voltmeter.
Motor overheats while running under load	Low voltage	Check terminals of motor with a voltmeter
	Rotor rubs stator bore	If not poor machining, replace worn bearings.
Motor vibrates after corrections have been made	Motor misaligned	Realign
	Weak foundations	Strengthen base
	Coupling out of balance	Balance coupling
	Driven equipment unbalanced	Rebalance driven equipment
	Defective ball bearing	Replace bearing
	Bearings not in line	Line up properly
	Balancing weights shifted	Rebalance rotor
	Wound rotor coils replaced	Rebalance rotor

**Table I – Medium and Large Motor Trouble Shooting Chart
(Continued)**

Trouble	Cause	What To Do
Motor fails to start	Defective capacitor	Check for short circuit, grounded or open capacitor, replace if necessary.
	Worn or sticking brushes on repulsion induction motors	Check for wear and correct brush pressure. Clean commutator if dirty.
Motor stalls	Wrong application	Change type or size. Consult manufacturer.
	Overloaded motor	Reduce load.
	Low motor voltage	See that nameplate voltage is maintained.
	Open circuit	Fuses blown, check overload relay, stator and pushbuttons
	Incorrect control resistance of wound rotor.	Check control sequence. Replace broken resistors. Repair open circuits.
Motor runs and then dies down	Power failure	Check for loose connections to line, to fuses and to control.
Motor does not come up to speed	Not applied properly	Consult supplier for proper type
	Voltage too low at motor terminals because of line drop	Use higher voltage on transformer terminals or reduce load.
	If wound rotor, improper control operation of secondary resistance	Correct secondary control
	Starting load too high	Check load motor is supposed to carry at start.
	Polyphase motor running single phase	Check for open circuit
Motor vibrates after corrections have been made	Excessive end play	Adjust bearing or add washer

**Table I – Medium and Large Motor Trouble Shooting Chart
(Continued)**

Trouble	Cause	What To Do
Unbalanced line current on polyphase motors during normal operation	Unequal terminal volts	Check leads and connections
	Single phase operation	Check for open contacts
	Poor rotor contacts in control wound rotor resistance	Check control devices
	Brushes not in proper position on wound rotor	See that brushes are properly seated and shunts in good condition.
Scraping noise	Fan rubbing air shield	Remove interference
	Fan striking insulation	Clear fan
	Loose on bedplate	Tighten holding bolts
Noisy operation	Airgap not uniform	Check and correct bracket fits or bearing.
	Rotor unbalance	Rebalance
Hot bearings general	Bent or sprung shaft	Straighten or replace shaft
	Excessive belt pull	Decrease belt tension
	Pulleys too far away	Move pulley closer to motor bearing.
	Pulley dia. too small	Use larger pulleys
	Misalignment	Correct by realignment of drive.
Hot ball bearings	Insufficient grease	Maintain proper quantity of grease in bearing.
	Deterioration of grease or lubricant contaminated	Remove old grease, wash bearings thoroughly in kerosene and replace with new grease.
	Excess lubricant	Reduce quantity of grease bearing should not be more than ½ filled.
	Overloaded bearing	Check alignment, side and end thrust.
	Broken ball or rough races	Replace bearing, first clean housing thoroughly.

Table J – Insulation Hot Spot Temperatures

Thermal Class or Systems Class	Temperature Index (TI) or Maximum Hot-Spot Temperature, °C
90 (O)①	90
105 (A)	105
120 (E)②	120
130 (B)	130
155 (F)	155
180 (H)	180
200 (N)	200
220 (R)	220
240 (S)	240
Over 240 (C)	Over 240

① Obsolete

② European

Large Rotating Apparatus

Receiving and Storage 2:8.1
Pre-Erection Procedures 2:8.3
Foundations 2:8.5
Erection Procedures 2:8.7
Assembling Engine Type Rotors on Shafts 2:8.13
Exciters for Direct-Current Machines 2:8.15
Exciters for Synchronous Machines 2:8.16
Brushless Synchronous Machines 2:8.18
Insulation Maintenance of Large Rotating Apparatus 2:8.26
Visual Inspection 2:8.58
Dis-assembly Procedures 2:8.62
Routine Maintenance 2:8.63
Maintenance Records 2:8.64

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Large Rotating Apparatus

General

An effective preventive maintenance program can minimize service interruptions. A knowledge of those parts of motors and generators which need periodic adjustment, need regular inspection, or are most susceptible to malfunction, is essential. The ability to recognize and evaluate maintenance requirements in advance is necessary to a planned maintenance program.

Tests should be made only by experienced, trained personnel, preferably under the direction of the equipment manufacturer's engineering and service people.

A large plant may have many types and sizes of large rotating apparatus. Each of these machines will have been supplied with an instruction book. These instructions, specifically applicable to the unit, should be consulted and carefully followed.

8.1 Receiving and Storage

The size of a machine, the amount of bearing load in shipment, and the method of shipment will determine whether it will be shipped completely assembled or dis-assembled.

Prior to shipment, all machines are electrically and mechanically tested, then protected with heavy duty weather-resistant covering for shipment. Machines to be shipped overseas are also crated.

A. Receipt from Carrier

Immediately upon receipt, all wrappings and crates should be inspected for signs of damage. If damage is detected or suspected, unpack at once in the presence of a claim adjuster and report all damage to the delivering carrier and to the manufacturer.

B. Temporary Storage

Apparatus which cannot be installed immediately should be unpacked, examined, and stored indoors in an area which is clean and dry and where temperature variations are small and slow. It should not be stored

with the weather-proof sheeting covering it. The packaging for shipment is not adequate protection for outdoor storage, and equipment should not be stored outdoors, even for a short time.

1. *Protection In Storage*

Machines in storage must be protected from weather and from mechanical damage. Rain, snow, water or steam from leaking pipes, or condensation from atmosphere must be excluded. It is particularly important to keep the machine windings dry. Moisture lowers the insulation resistance and increases the likelihood of electrical failure. If the machine is moved from a cold to warm atmosphere it should be covered until it has reached room temperature to minimize condensation on the windings and other parts.

2. *Heating In Storage*

Care should be exercised to protect the windings from moisture any time the machine is not operating. Such protection will also act to prevent rusting of the core and corrosion of metal parts not covered with slushing compound.

If the machine is equipped with space heaters, the heaters should be energized whenever the storage area is cold and damp. Units not equipped with heaters may be kept adequately warm by operating one or more 100-150 watt incandescent lamps within the storage enclosure.

It is not advisable to pass low voltage direct current through the stator or rotor windings to keep the machine warm.

3. *Bearings In Storage*

When machines are received with bearings assembled, the bearing oil reservoirs should be filled to the indicated level with the proper lubricating oil. The rotor shaft should be rotated periodically a number of times to keep the journals lubricated and prevent rust. In a case where there are no oil rings, pour oil on the top of the shaft prior to rotating.

4. *Removal From Storage*

Before a machine which has been in storage for an extended period is started, it should be thoroughly inspected and cleaned. The insulation resistance should be measured. Low resistance readings may indicate concealed damage in the windings, or more likely, moisture absorbed into the windings requiring a special drying out procedure.

8.2 Pre-Erection Procedures

A. Location

Location must conform to all requirements of the National Board of Fire Underwriters and all local codes and regulations, and any Federal regulations that apply.

In addition, consideration should be given to the following:

Install the machine so it is well ventilated.

Install the machine so there is adequate working space around it for disassembly, inspection, cleaning, part replacement, and re-assembly.

The machine must be well ventilated so the hot discharge air will escape rather than re-circulate through the machine. Unless the room is large and well ventilated, natural convection ventilation will not be sufficient. If the machine is designed to take air from a pit, suitable ducts must be provided in the foundation.

B. Lifting and Handling

It is very possible, by rough handling or careless or improper use of bars or hooks, to do more damage to a machine before and during erection than would be done in years of service.

All lifting should be done with lifting bars, slings, or crane hooks. Various arrangements for handling equipment are used (i.e. holes, lugs, trunnions, etc.). The outline drawings should be consulted for detail of the lifting devices and any limitations thereof. The stator should never be lifted or supported by the core punchings or coils. Bedplate mounted assembled units should be lifted by slings attached in the openings in the bedplate. Care must be given to arrange the slings so the weight is evenly distributed and there is no distortion of the bedplate. Transition bases that adapt new equipment to existing foundations may not be designed to be used as a part of the lifting arrangement. The manufacturer's drawings and instructions should be consulted.

Care must be given to assure that the machine windings are not damaged in handling. Any impact on any part of the windings is likely to injure the insulation and result in a burned-out coil. The same care is required for the semiconductors and controls mounted with brushless motors and generators.

Notice: Certain rotors having direct connected exciters may not be designed to withstand a sling lift at the exciter outboard end. Before

such a lift location is used to thread the rotor into the stator bore, the manufacturer or manufacturer's instructions should be consulted. In some cases, a stub shaft or a steel pipe must be fitted on the drive shaft end to extend that end while fitting the rotor into the stator.

Lifting the stator and rotor should be done with the greatest possible care. The stator is provided with lifting lugs or holes into which crane hooks can be inserted. In lifting the rotor, it is preferable to use wire rope slings. When slings or chains are used, they should not be wrapped around the journals unless the journals are adequately protected. In no event should ropes or chains be allowed to exert pressure or stress on windings, controls, or semiconductor parts on brushless machines.

C. Shipping Braces

On bracket-bearing machines and some pedestal machines, a shipping brace on the shaft will be supplied. This brace should remain in place any time the unit is being moved. The brace holds the rotor in place and prevents damage from axial movement of the rotor. This brace should be retained for re-installation when the machine must be moved.

D. Preparation for Installation

Before beginning to erect the machine, the following points should be checked:

Inventory all parts at the site against the manufacturer's shipping list. Any missing or damaged part should be reported and reordered.

Locate foundation bench marks to permit establishing the centerline of the unit and the elevation of the foundation surface.

Check foundation against the outline drawings to assure that all pit areas, cable, conduit, bus, and ventilating ducts have been installed and in proper locations. Make sure dimensions permit correct assembly of the machine and its accessory equipment.

Check the size, location, and elevation of the foundation bolts against the outline drawing.

Provide a supply of leveling plates and shims to assure that the soleplate or bedplate will not be distorted when placed on the foundation. These plates should be approximately 1/4 inch by 4 inches and the length should allow them to extend about 2 inches beyond each flange of the bedplate or soleplate. Shims should be placed in the general location of

all load paths (i.e. at frame feet positions, pedestals, exciter supports, etc.).

A pair of tapered keys should be available for use on leveling plates for adjustments on large units.

8.3 Foundations

A rigid foundation is essential to minimize vibration and mis-alignment during operation. The foundation should be solid concrete with footers or piers deep enough to rest on a solid sub-base.

If it is necessary to support the motor on steel instead of concrete, the beams and girders should be braced and supported by columns so they are solid and rigid. A foundation design consulting engineer should design and supervise construction of this foundation.

The top of the concrete foundation should be roughened and cleaned before mounting bedplate or soleplates on it. A roughened surface assures a better bond with any grouting necessary.

A. Bedplate Elevations

Notice: Make sure the foundation is not too high. A foundation that is too low can be corrected by use of leveling plates, but a foundation of concrete that is too high can only be chipped away.

The pit beneath the machine, if required, should be deep enough to provide working space for connecting leads brought out at the bottom of the machine. The manufacturer's outline drawing will give a recommended minimum pit size. It will also specify the location of ducts.

B. Foundation Bolts

A wood template for location of foundation bolts should be made using the manufacturer's outline drawing for specifications. Figures 1 and 2 illustrate methods of anchoring foundation bolts and arrangement of bedplates and grout forms, and tubular bedplates, and leveling plates and shims.

C. Grouting the Bedplate or Soleplates

Grouting is done following alignment. Grout should be mixed to the formula provided by the architect engineer. Rails or soleplates are grouted to within a half inch of the top. The entire operation of mixing

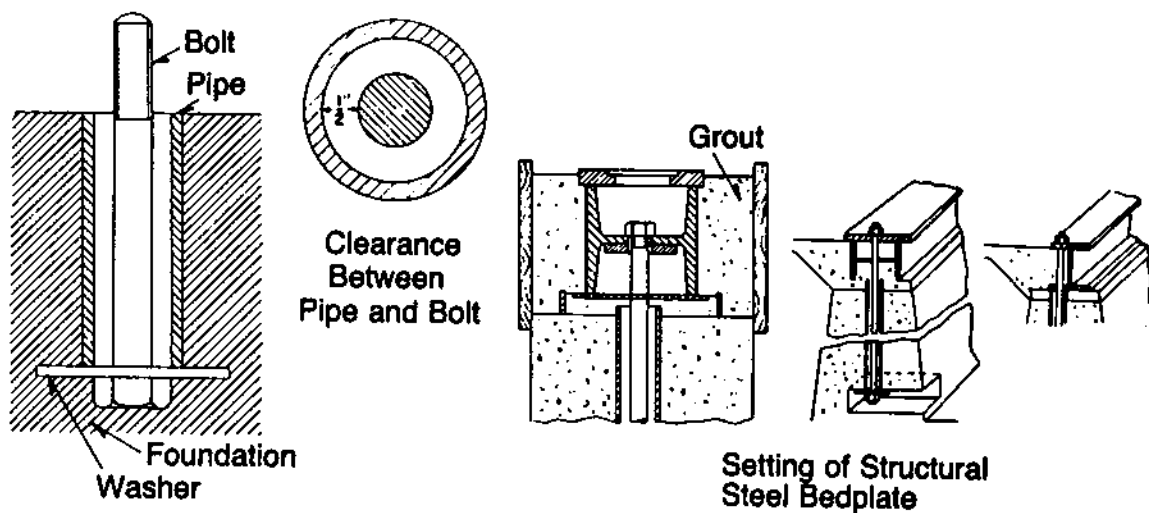
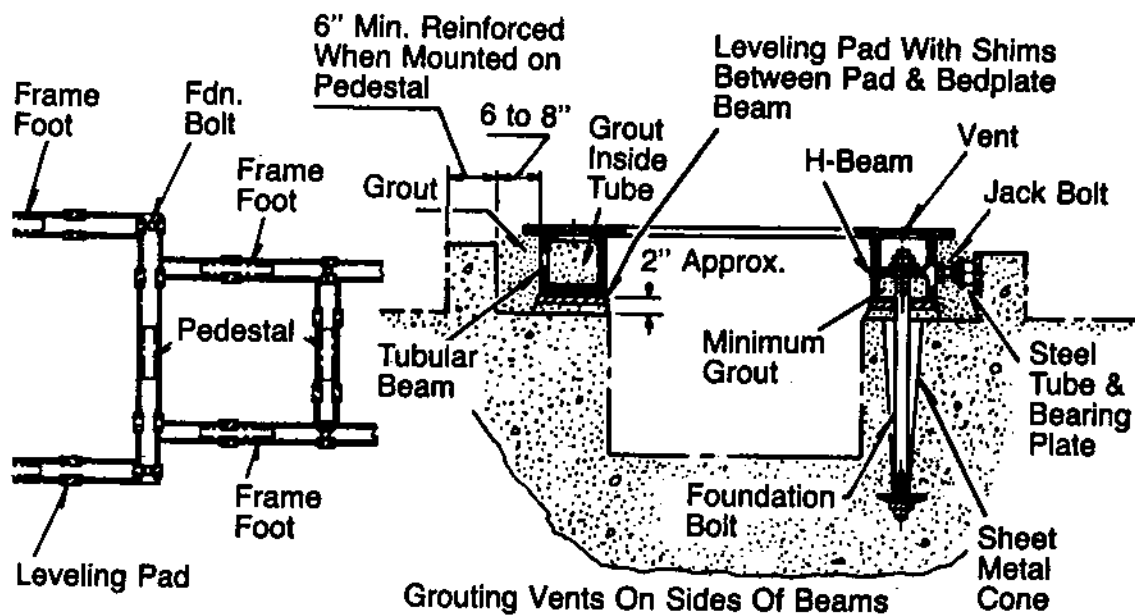


Fig. 1 - Method of Anchoring Foundation Bolts and Typical Arrangements of Bedplates and Grout Forms



Note: Foundation bolt for tubular beam similar to foundation bolt for H-beam. Jack-bolts when used may remain when grouting bedplate.

Fig. 2 - Method of Anchoring Foundation Bolts and Typical Arrangements of Tubular Bedplates, Leveling Plates, and Shims

and pouring the grout should be completed without interruption and as rapidly as possible. The grout should fill all spaces in the structural steel bedplates and should carry flush with the top of the bedplate so a solid tie between the bedplate and the roughened surface of the foundation is obtained. Ample curing time must be allowed before installing heavy rotors or stators. Covering with wet burlap and sprinkling occasionally with water will prevent too rapid drying and cracking. Use of rapid curing grout materials and those containing corrosive iron or other additives for re-inforcement is not recommended for this application.

8.4 Erection Procedures

In considering erection procedures, machines fall into two categories: those with bearings mounted in brackets attached to the machine frame; and those with independently mounted pedestal bearings.

Where detailed descriptions are given, they are written around current Westinghouse designs. Equipment made at other times and by other manufacturers may vary from these descriptions.

A. Two-Bracket-Bearing Machines

Two-bracket-bearing machines which are shipped assembled and are ready for erection by skidding or lifting on to the roughened foundation with the leveling plates in place.

Bracket-bearing motors furnished with soleplates or mounted on the bedplate of the driven equipment should be aligned by means of shims beneath the motor frame feet near the foundation bolts. Jackscrews are provided in the feet to facilitate inserting the shims. When alignment is correct, the jackscrews should be removed and the soleplates grouted to the foundation.

B. Cleaning

Warning: Avoid contact with or breathing vapors from cleaning solvents. These chemicals are highly toxic and readily absorbed into the system. Severe injury or death from poisoning or asphyxiation may result.

Machines shipped with shaft extensions and couplings pressed on are protected with a coating of slushing compound. This compound should be removed by washing with a petroleum solvent of an approved type.

The shaft journals are also protected with a slushing compound or R and O oil film however, it is soluble in the lubricating oil so need not be removed before operating the machine.

C. Couplings

If the machine half of the coupling was not factory mounted it should be attached to the shaft upon completion of cleaning. The coupling manufacturer's instructions should be followed in detail.

If the flexible coupling to be used is of the free float type, the coupling end-play should be limited to prevent damage to the machine bearing

due to axial loads not present when the machine was uncoupled. Both machine and coupling manufacturer's instructions should be consulted.

1. Preliminary alignment requires vertical adjustment, using the jack-screws, and axial adjustment before alignment of couplings. Hold-down bolts should be installed but not tightened. Shims should be installed and the jackscrews removed.

The unit should be connected to the mechanical load coupling accurately aligned. Misalignment will at times overload bearings and produce shaft stresses, vibration, and coupling wear.

Notice: All two-bearing motors should be flexibly coupled or belted to their mechanical loads. Flexible couplings should not be forced to accommodate excessive mis-alignments. Mis-alignments will produce undue wear and can cause vibration.

2. Final flexible coupling alignment is made with the use of a thickness gauge or dial indicator between coupling faces between the motor and generator or prime mover shafts. The distance between the flanges is checked at top and bottom and both sides with the shaft rotated in at least four positions. The measurements should not vary more than .002 inch, preferably .001 inch or less.

a. The vertical and lateral position of the machine can be approximated in each of the rotated positions by use of an accurate steel straight edge held on the edges of the flanges parallel to the shaft. Dial indicator gauges are required to give a more accurate reading.

b. The angular alignment should be checked by using a feeler gauge between hubs at four points 90 degrees apart. The machine should be positioned to obtain the best possible alignment and then the hub separation corrected.

c. The offset alignment can be checked by fastening an indicator bracket on one hub with the dial indicator button contacting the alignment surface of the opposite hub. The shaft with the hub to which the indicator is attached should be rotated and readings taken at four points 90 degrees apart. The machine position should be moved until all four readings are the same. The indicator should then be moved to the other hub and the procedure repeated. The angular alignment should then be re-checked.

After each corrective alignment, the hold-down bolts should be tightened and the alignment re-checked.

When the alignment is satisfactory with the foundation bolts drawn tight, make them captive with the locking devices when provided. Tack-welding the hold-down bolts in place is not recommended as it greatly complicates any future adjustment. The bedplate can be grouted after all alignments are made.

D. Belted Motor Alignment

The motor shaft must be aligned so it is parallel to the driven shaft. Belt grooves must be aligned axially. This is usually done with a straight edge across the end of the pulley sheaves.

Caution: Do not put excessive tension on drive belts. This causes a decrease in bearing life and may result in a broken motor shaft.

Belts are tightened by moving the motor on its slide rails. The slide rails are shown on the outline drawing provided by the motor manufacturer.

When alignment is completed and belt tension adjusted, the motor hold-down bolts should be securely tightened and made captive.

Notice: Dowels are used for alignment only and the use of dowel pins is recommended. Dowel pins are not intended to prevent motor shift if the hold-down bolts work loose. Hold-down bolts should be checked occasionally and kept tight.

The motor base should be doweled using the dowel pins, usually provided. The dowel holes nearest to the center of the motor should be used, one on each side of the base.

Holes should be drilled in the base, using the bedplate as a template. Holes should be reamed to fit the dowels.

E. Alignment of Shafts Between Coupled Machines

When solid couplings are used between coupled machines, the parallelism of the faces should be checked with thickness gauges. If the machine has a single shaft, or a single bearing section of a shaft (such as a control wheel shaft), the coupling should be opened just enough so the weight on the coupling end of the shaft is carried by the rabbet fits. Coupling alignment allowances are given in 2. *Couplings* above.

If the coupling being aligned is on a two-bearing machine, the coupling faces should be completely separated and the lateral and vertical alignment, and the angularity of both faces carefully checked and alignment adjusted. See 2. *Couplings*, above.

The pedestals are adjusted laterally, longitudinally, and vertically by placing shims under their bases and shifting them about. After each corrective adjustment, the pedestal bolts must be tightened and alignment re-checked.

Notice: The alignment of solid couplings must be more precise than flexible coupling alignment, solid coupling alignment should be true and parallel within .001 inch in all planes unless the assembly drawings specify otherwise.

F. Alignment of Shafts and Couplings on Three-Bearing Machines
For machines having three bearings with a solid coupling connecting the exciter shaft to the motor shaft, the alignment procedure is:

1. Assemble the motor rotor (as received, with exciter shaft bolted to motor shaft) in its stator with the motor shaft supported on its larger bearing only.
2. Align the motor flexible half coupling to the driven unit half coupling in accordance with the coupling manufacturer's instructions. Place required shims under the motor feet, or large bearing pedestal, and align.
3. Assemble the outboard, exciter small bearing, pedestal and pedestal support and place under the end of the exciter shaft.
4. Loosen the coupling bolts in the solid coupling which couples the exciter and motor shaft. This loosening permits aligning the coupling and allows the coupling rabbet fit to carry most of the load. The outboard bearing will also be carrying load.
5. Make alignment checks and adjustments as given under 2. *Couplings* above.
6. Remove protective tape from oil sight glasses and oil level gauges. Also remove protective covering from collector rings and brush inspection windows (conventional synchronous motors).
7. Fill bearing bracket oil reservoirs to proper level with quality machine oil. Refer to *Westinghouse Electrical Maintenance Hints, Volume 1, Chapter 9, Bearings*, for a more complete discussion of lubricants and lubricating systems.

For electrical connections, consult the motor manufacturer's connection drawings and instruction literature.

G. Aligning Pedestal Bearings and Single Bearing Motors

Larger machines are usually shipped dismantled. The extent of the dismantling depends on the size of the machine, method of transportation, and erection facilities. If the machine is dismantled, the parts or sub-assemblies will be match marked to facilitate assembly and complete assembly instructions will be given.

The following points in the re-assembly and erection of large machines should be given careful attention.

1. Alignment of Bedplates or Soleplates

The bedplate or soleplates should be positioned on the foundation and adjusted with wedges and shims until they are level, measured with an accurate spirit level. With accurate leveling of the bedplate or soleplates the machine, when mounted, will be in a sufficiently close alignment with shaft and coupling of any coupled apparatus to make any shifting of bedplate or soleplates unnecessary.

Reminder: Any corrections in elevation must be additive. Once the bedplate is mounted on the foundation and grouting completed, it cannot be lowered. It may be preferable in some instances to level and align the bedplate or soleplates with the machine in place, because of the deflection of the foundation under the weight of the machine. When the bedplate has been properly set, the foundation bolts should be drawn tight and alignment again checked.

2. Mounting on Bedplate or Soleplates

The method of mounting the stator, rotor, and pedestals in position will vary with the size of the machine. The stator should be lifted or skidded into an approximate position first. The rotor is then placed in the stator and allowed to rest inside the core. A fiber or cardboard pad is used to protect the punchings from damage. Finally the pedestals are slid into position under the journals. To do this the rotor and stator are blocked up or hoisted.

A spreading bar should be used when handling a rotor with a sling, to avoid damaging windings and controls. If the sling must be placed on journal surfaces, hardwood strips should be used as padding to prevent scratching the bearing surfaces. Slings should be used only within their load limits and felt padding should be used to protect the journal surfaces.

Rotors having direct connected exciters may be damaged if handled by a sling lift at the exciter outboard bearing where such construction is

encountered. Before such a lift location is used to thread the rotor into the stator core, the outline drawing should be consulted or the motor manufacturer consulted for specific lift instructions. In some instances a stub shaft or a steel pipe must be fitted on the drive shaft end to reinforce that section when lifting the rotor into the stator.

H. Axial Alignment and Air Gap Adjustment

When coupling alignment is completed, it is necessary to adjust the axial position of the stators of the machine and exciter. The pole tips on a synchronous machine must extend equal distances beyond the stator core at the two ends of the machine. The exciter rotor core should line up with the exciter stator core in the axial position.

The vertical positions of the machine and exciter stators should be adjusted to make the air gap uniform around the stator bore. This is done by using shims under the stator feet. The maximum and minimum air gap measurements should not vary by more than plus or minus 10 percent.

Warning: An unequal air gap can lead to unequal currents in the stator windings resulting in unequal heating. It will also cause an increase in the unbalanced magnetic pull between stator and rotor, increasing the possibility of the rotor pulling over and rubbing the stator iron, doing severe damage.

In making adjustments, the air gap should be measured from both ends of the machine and at various points around the rotor. Measuring gauges should extend to the center of the core.

On synchronous machines, when measuring air gap, the feeler gauge should be inserted between the poles on the rotor, then moved into the space between the pole face and the stator core. This procedure reduces the likelihood of reading a too small value for the air gap at a point near the end of the machine where a high punching is most likely to exist.

I. Adjustment of Air Gaps on D-C Motors and Generators

In measuring the air gaps on direct-current motors and generators, first measure the gaps under the two main poles located nearest the vertical centerline, from rear to front where possible. The maximum difference between these two gaps should not exceed .020 inch. Gap adjustment is made by shims under the frame feet.

Next measure the gaps on the two main poles nearest the horizontal centerline, from rear to front where possible. The maximum difference

between these two gaps should not be greater than .020 inch. Adjustment is made by shifting the frame horizontally. It is seldom necessary to shift bearing pedestals to obtain air gap symmetry or change elevation. If pedestals must be shifted, brush rigging changes will be required. Centering of the commutator in the brush rigging should be rechecked before start-up.

The final adjustment should give the best average centering for the armature in the main poles and the commutator in the brush rigging. Changes in individual pole air gaps and changes in individual brush arms should not be necessary since the machines are assembled and run at the factory.

To obtain satisfactory readings of the air gap, it may be necessary to remove varnish from both the stator and rotor punchings at the points where measurements are taken. Such spots should be re-varnished after measurements have been completed. .005" added to the measured value can account for normal varnish buildup.

When alignment is completed, the machine should be doweled to the base and the bedplate or soleplates grouted.

J. Re-alignment

When a machine has been dismantled for repair, satisfactory re-alignments should be obtained by returning it to the positions established by the dowel holes. The thickness of the shims used should be the same as those originally used. Re-checking of the coupling alignment and the air gaps is necessary after re-assembly. The level of the machine should be re-checked as foundations sometimes settle.

8.5 Assembling Engine Type Rotors on Shafts

A. Solid Rotors

The usual construction of the spiders of engine type rotors is solid, with neither the hub nor rim being split. When it is not desirable to ship the shaft to the factory for pressing into the rotor, it can be done in the field.

There are several ways to mount a solid rotor on a shaft:

The shaft can be pressed into the rotor by force.

The bore of the rotor can be expanded by heat.

The shaft can be shrunk by cooling to a low temperature. This method can be used effectively on hollow shafts. When outdoor temperatures are low, outdoor cooling can provide the necessary size reduction.

Since facilities are seldom available for pressing, and most shafts are solid, the usual procedure is to expand the rotor bore by heat.

Before fitting any kind of rotor on the shaft, all protective coats of oil, grease, or paint should be removed. If there is rust on the bearing journal, it must be removed. Rust may be removed with fine emery cloth, but the journal should then be polished with a fine oil stone. Any marks or scratches on the journal will cut the bearings and cause them to run hot. The journals should be thoroughly cleaned and any residual emery grit or polishing stone particles should be removed before assembly into bearings.

Methods of applying heat to the rotor will largely depend on the facilities available. It is important to raise the temperature gradually. Heat should be uniformly applied to avoid detrimental stresses in the rotor spider. Best results are usually obtained by enclosing the entire rotor in a temporary housing. (Occasionally it may be necessary to enclose only the hub.) When electric or steam heat is used, a tarpaulin will usually be satisfactory. Proper expansion can usually be obtained by heating the rotor to a temperature of 150C.

Notice: Steam heat is not recommended if the field coils are involved.

If poles and coils are mounted on the rotor, the enclosure should be made to cover only the rotor center. The rotor rim temperature should not exceed 100C for a Class A insulated rotor or 130C for a Class B rotor. Poles and coils should be kept outside the enclosure.

After the rotor has been located on the engine shaft, the entire mass should be allowed to cool gradually to avoid any serious contraction stresses.

B. Split Rotors

When the rotor cannot be pressed on the shaft of engine type machines at the factory, they may be designed with a split spider or a split hub. Brushless synchronous motors may be provided with a split hub and solid control wheel assembly.

On some larger split spiders, the rim is secured at the matched surfaces by dovetailed shrink links. The centerline of the two diametrically opposed poles corresponds to the splits in the spider rim. Usually 3 poles on each side need to be removed to assemble or remove the rotor from the shaft.

To remove shrink links they should be heated with a torch. 100-150C above the rim temperature will expand the links sufficiently to be lifted out. Tapped holes in the link are provided for lifting and handling. These holes can also be used to exert some pulling force.

The links are heat treated so reasonable care should be used in applying heat. The torch flame should be applied to the link evenly; first on the outside, then on the inside until the link can be removed. If blue spots appear on the surface of the metal it is an indication that the link has been overheated and the heat treatment properties have been destroyed. The damaged link should be replaced.

Care must be exercised to prevent the flame of the torch from striking the field coils. Protect the coils with a flameproof insulator cover, if necessary.

When assembling a spider, the key should first be placed in the shaft keyway. The two halves of the completely split spider may then be placed in position around the shaft.

The hub bolts of split hub rotors are first loosened to allow the hub to fit over the shaft. Tightening the bolts at the hub will bring the edges of the rim together around the shaft and the links can then be inserted after being heated to approximately 150C.

The collector rings on split rotors of conventional design are split. Although they are turned and ground true at the factory, they require care in assembly to assure they will run true.

Notice: Do not remove rings from the rotor; only loosen the bolts to open the splits. The splits can generally be re-aligned by light tapping with a rawhide hammer. If this re-alignment is not satisfactory the rings must be ground until they run true.

8.6 Exciters for Direct-Current Machines

Most commonly, a direct-current machine and its exciter are assembled on the same bedplate. When directly connected in a line-up of exciters, or as the main exciter for a motor-generator set on the same bedplate, the alignment and care of the exciter are just as important as the main motor or generator.

The exciter for a direct-current machine may be either a separate motor-generator set or a static power supply remotely located. This arrangement is typical of steel mill applications and other processes where the main machine is directly coupled to heavy equipment by extended shafts and universal couplings.

8.7 Exciters for Synchronous Machines

The exciters for synchronous machines are generally of two types, either brush-type or brushless. The brushless-type exciter is more commonly used on modern synchronous machines, both motors and generators, and the following discussion will be directed to this type exciter.

On slow-speed synchronous machines, the brushless exciter will normally be mounted inboard of the bearing while on high-speed machines it will be mounted over-hung on the shaft extension outboard of the opposite coupling-end bearing. The brushless exciter is basically a poly-phase a-c generator whose output is rectified to d-c by a solid state rectifier bridge that is mounted on the machine rotor. When the exciter is mounted outboard of the bearing, its output is fed to the main machine fields through conductors which pass axially through a hole in the shaft center. Output power from the exciter is controlled through the d-c excitation applied to the exciter fields in the exciter stator.

Many brushless exciters are of quill type construction where the armature is built on a hollow tube rather than a solid shaft. This quill is then assembled onto the main machine shaft in one of several ways. It may be pressed or shrunk onto fits on the shaft. In such an arrangement, it may or may not be keyed to the shaft. If unkeyed, it can be locked against a shoulder on the shaft by a bolted pressure plate arrangement on the outboard end to transmit the driving torque. Another similar arrangement uses a tapered fit between the shaft and quill, again with an outboard pressure plate arrangement. Before attempting to remove an exciter armature, the manufacturer's instruction book should be consulted for directions.

If any of the leads from the exciter rotor or the electrical joints in the leads must be disturbed from the factory assembly, care must be exercised in making the repairs. Joints should be double checked for proper tightness and reinsulating must be carefully performed. Leads must be securely restrained by lashing and clamping to prevent movement under centrifugal forces in operation. What appears secure at standstill may move sufficiently under rotation to cause trouble.

These exciters are built with stators similar to normal d-c machines with field poles and coils. Generally, the field coils will be random wound

Adjustable frequency (variable speed) machines are designed to operate over some specified speed range with motor and exciter input power using round magnet wire. The armatures are normally 3-phase, random wound of round magnet wire in semi-closed slots.

The air gap of brushless exciters is generally relatively small and it is important that it be carefully set. In general, at least 8 readings (4 each end) should be taken and any single measurement should not deviate from the average of all readings by more than 10%. It is important to recognize that thermal effects may cause the machine shaft to grow vertically in relation to the exciter stator and, in such cases, the cold settings of the air gaps in the top of the exciter may need to be made larger.

With electrical load on the exciter, unequal air gaps will increase the unbalanced magnetic pull between the rotor and stator and can result in the rotor "pulling over" and rubbing the stator bore resulting in iron damage.

When the stator frame has been properly located, the hold-down bolts should be tightened and double checked. Doweling the exciter stator feet to their support provides additional insurance against movement and air gap misadjustment.

A relatively new development in synchronous motors is the adjustable frequency (variable speed) machine. These machines, through the use of a static power supply that rectifies a-c power to d-c and then inverts the d-c to variable frequency a-c are capable of operating over a continuously variable speed range. The exciter is brushless and is basically a wound rotor induction motor which operates as a rotating transformer and is capable of supplying output power all the way down to and including standstill.

Excitation for the exciter in the form of variable voltage power is supplied from a part of the same power supply as described above for the motor. The exciter output is rectified to d-c and provides excitation for the motor fields. Some adjustable frequency synchronous motors are designed for across-the-line starting at full voltage while others are only designed for starting synchronously with the power source from standstill. The latter are sometimes referred to as "soft-start" machines.

The exciter stators are generally 3-phase lap wound with random wound coils of round magnet wire. The rotors are also 3-phase, lap wound with round wire random coils. The exciters will generally have relatively small air gaps and the precautions listed above for the air gap setting for fixed speed exciters will apply.

8.8 Brushless Synchronous Motors

A. Synchronous Generators

Brushless synchronous generators receive their field excitation from brushless exciters that are mounted directly onto the machine shaft. The output of the exciter is in turn controlled by the d-c excitation provided to its stator fields by some type of voltage regulator, either automatic or manual. The output of the exciter is rectified to direct current by a rotating, full-wave rectifier. Unlike the brushless exciters for synchronous motors, those for generators have increased capability to supply higher output under rapidly varying load conditions and, for a given nominal rating, are generally larger physically. See Figure 3.

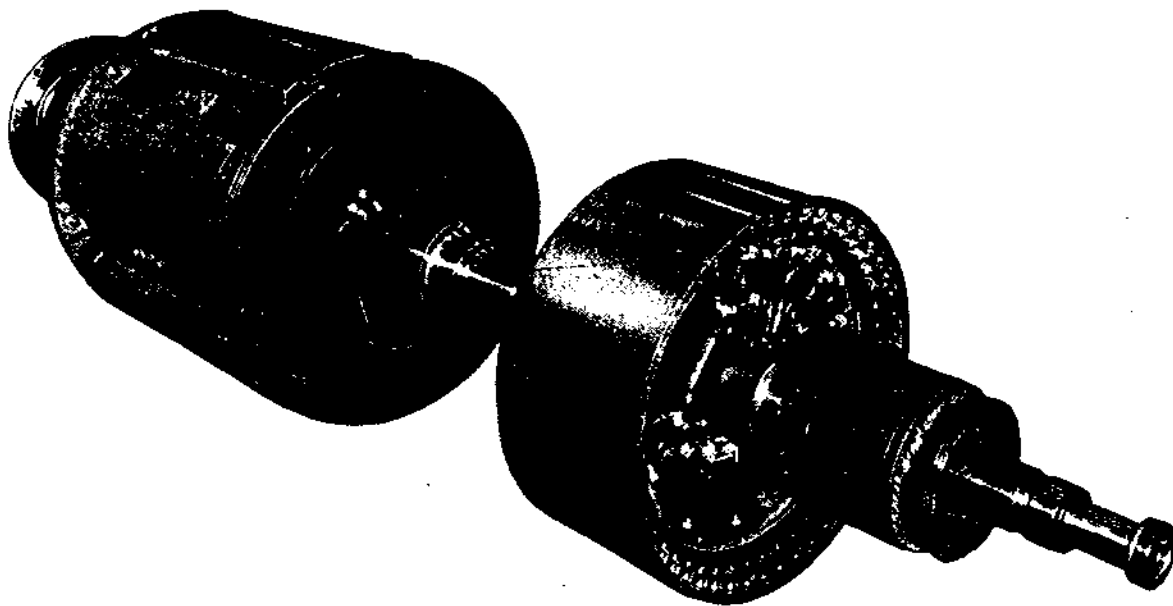


Fig. 3 – High Speed Synchronous Rotor with Brushless Controls

The solid-state diodes used in the rectifier circuits are sometimes provided with series fuses with visible indicators that signal a “blown” fuse. The mounting into which the diodes are fitted also serves as a heat sink for dissipating the heat generated by the diode. It is very important to consult the manufacturer’s instruction book when replacing a defective diode for any special precautions regarding type and installation procedure. Loose mounting, improper contact and non-use of heat conducting compound (if required) between diode and heat sink and loose electrical joints can lead to additional problems.

B. Synchronous Motors

Synchronous motors are generally of two types: Fixed speed machines are designed to operate on input power of a fixed nominal frequency, generally 60 Hz.

being supplied by a "black-box" static power supply. Motors designed to start across-the-line at full voltage are referred to as "line start", and those designed only to start synchronously from standstill, are referred to as "soft start" machines. "Line start" machines can, in general, be soft started but "soft-start" machines can never be line started unless specifically permitted by the manufacturer. The difference in capabilities of the two types of machine is basic to their design.

1. *Fixed speed synchronous motors* have a brushless excitation system that performs the following functions:

Provides d-c power for motor field excitation from an a-c exciter and rectifier.

Provides a starting resistor that is in series with the motor field during start up and is removed when d-c excitation is applied at "pull-in".

Provides the functional solid state controls that disconnect the starting resistor and apply d-c excitation at the proper rotor speed and angle relative to the stator. This control also will perform the same function should the rotor "pull-in" to synchronism by reluctance (without motor field excitation being applied).

Figure 4 is a typical diagram for a brushless control scheme for a fixed speed machine and the following is a brief description of the functioning of the various components. Specific details for a particular machine should be available from the manufacturer's instruction book.

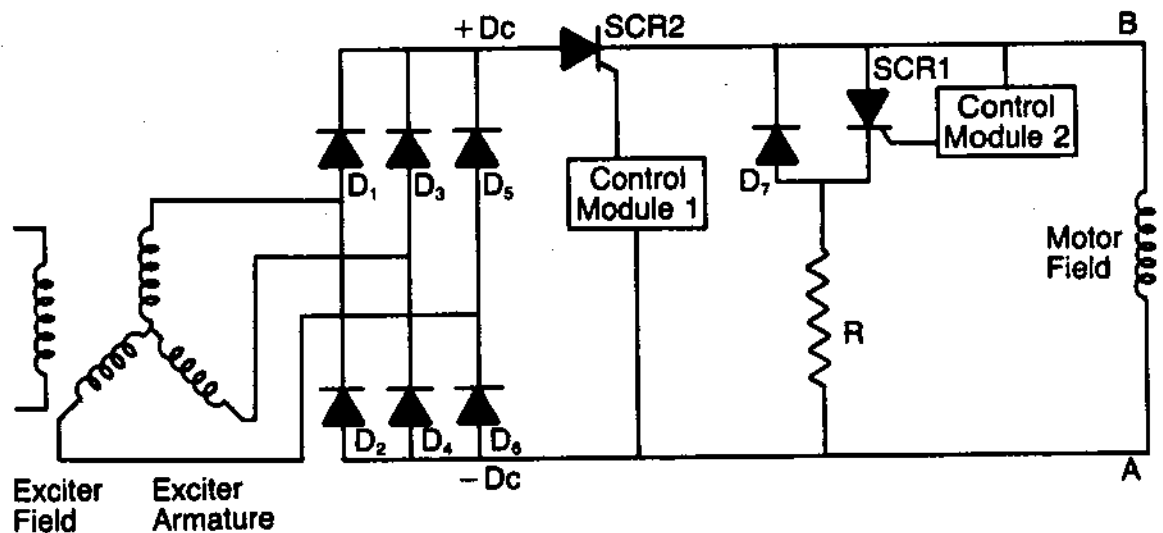


Fig. 4 – Typical Brushless Synchronous Motor Control System. The Basic Control System for All Brushless Motors

When the motor control circuit breaker is closed for start up, a-c excitation is applied to the fields of the brushless exciter; however, no exciter output is produced until the motor begins to rotate. The exciter output (which is a-c) is rectified to d-c by the full-wave bridge composed of diodes D1-D6. D-c power is available but is not supplied to the motor field during start up because SCR2 is not triggered by Control Module 1.

As the motor accelerates from standstill, a varying frequency voltage is induced in the motor field coils (between A & B) by the rotating magnetic field created by the stator winding. This alternating voltage is sensed by Control Module 2 which triggers SCR1. With diode D7 always conducting in the other direction, the starting resistor R is effectively connected in series with the field and the alternating current induced in the field has a complete circuit.

As the motor approaches synchronous speed, the frequency of the induced voltage decreases and, at the optimum speed for pulling into synchronism, the proper frequency is sensed by Control Module 1 and SCR2 is triggered, allowing field current to flow in the motor field, and the motor pulls into synchronism. Module 2 senses no alternating voltage being induced in the motor field and SCR1 is no longer triggered which disconnects the starting resistor. If the driven load on the motor is sufficiently low that the motor pulls into step on reluctance torque (magnetic attraction between the iron field poles and the rotating magnetic field of the stator), Control Module 1 will sense that there is no alternating voltage from the motor field and will trigger SCR2 initiating the same sequence described above.

Should the motor fall out of synchronism because of overload, input power interruption, loss of exciter excitation, etc., the Control Modules will sense the alternating voltage induced in the motor fields under such circumstances and the exciter output will be disconnected from and the starting resistor connected across the motor field. This puts the motor back into the starting mode; however, standard motor protection schemes will normally shut the motor down.

2. *The brushless control scheme for an adjustable frequency synchronous motor with line start capability is essentially the same as described above for the fixed speed machine. When such a machine starts from zero speed synchronously with the power supply, excitation power is available immediately from the exciter since the input to the exciter is a-c and the exciter merely acts as a transformer. The Control Modules sense no alternating voltage from the motor fields (they are in synchronism with the rotating stator magnetic field) and thus exciter output current flows in the motor field and the starting resistor is not connected.*

For the adjustable frequency motor that is only capable of so-called "soft" starting, the brushless control system is somewhat different. Since the motor never operates out of synchronism with its incoming power, except under abnormal conditions where it has either pulled out of step due to overload or fallen out of step due to loss of input power, the control modules need only be capable of removing excitation (via SCR2) and inserting the starting resistor (via SCR1) to protect the motor fields while it is being shut down. The post-synchronization feature that operates if the motor synchronizes on reluctance torque is not required.

3. Brushless Control Assembly Component Parts

The diodes and their associated heat sinks used in the rectifier assembly are matched for proper functioning. Modifications and substitutions should not be made without consulting the motor manufacturer. The diodes are selected for both current and voltage rating and the heat sinks (and diode arrangement) are selected to provide proper heat dissipation and thus operating temperature of the diodes. See Figure 5 for a schematic diagram of a three phase rectifier bridge.

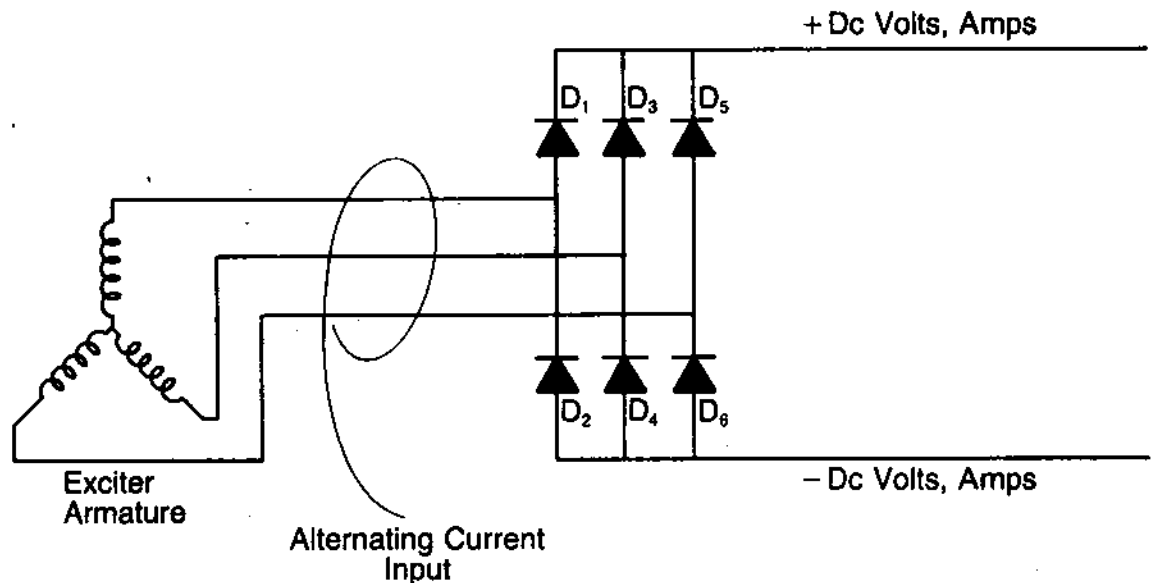


Fig. 5 – Rectifier Assembly – Brushless Synchronous Generator – Use of Diodes to Convert Alternating to Direct-Current

The thyristors and their heat sinks are also matched for proper heat dissipation and cooling. The thyristors are properly sized for current and voltage ratings with characteristics that match the capabilities of the control modules and, again, modifications and substitutions should not be made without consultation with the motor manufacturer. Figures 6 and 7 illustrate three and two diode per heat sink arrangements.

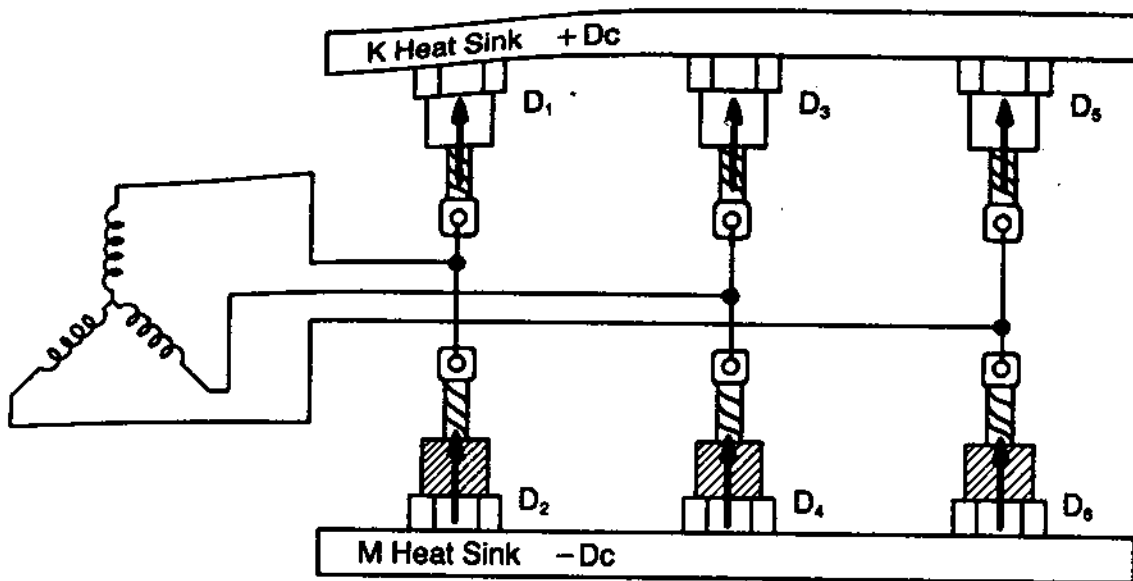


Fig. 6 - Three Diodes per Heat Sink

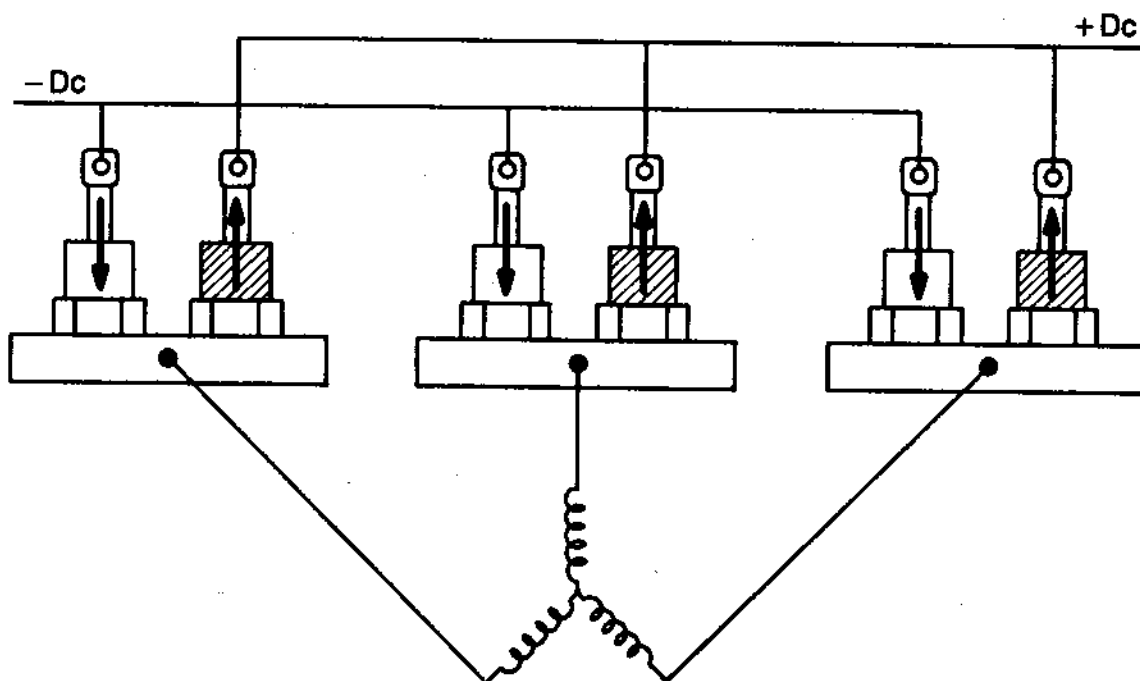


Fig. 7 - Two Diodes per Heat Sink

The starting resistor provides a path for the current that is induced in the motor field circuit during both start up and shut down. Without such a path (field open circuited), the voltages induced in the fields could rise sufficiently high to cause break downs of the turn-to-turn insulation in the coils. The total resistance value of the resistor is selected to limit the induced voltage to a safe value. The resistance value also influences

both the pull-in torque and the torque pulsations of the motor during start up. Therefore, the resistance value of the starting resistor should not be changed without consultation with the motor manufacturer.

Several different types of resistors are used. A commonly used type is composed of several ordinary metal sheath type heaters connected electrically to obtain the desired total resistance and current rating. These heaters (resistors) can be individually replaced; however, substitutions should not be made that will effect either the total resistance or overall current capabilities since these will effect the motor starting performance and temperature rise of the resistors when they are in use.

It is very important that this type of resistor be replaced exactly as it was originally mounted using any spacers, insulators, etc. The nuts on mounting bolts should be just snug and locked with a thread cement such as Lock-tite. If the nuts are too tight, the resistor cannot expand as it heats. The electrical terminal connections are very important since a loose connection could result in an open circuit and possible damage to the motor field coils. They should be checked for proper tightness before the initial start up of the motor. If individual resistors are replaced, the terminals should be locked with a thread cement after they are properly tightened.

The servicing of the control module(s) should follow the specific procedures given in the manufacturer's instruction book. If a module has an adjustable setting, it should not be changed indiscriminately. A replacement module should exactly duplicate the original unless a substitute has been recommended by the manufacturer.

When it becomes necessary to replace any of the power semiconductors, certain precautions must be observed. If the devices have threaded studs for mounting, heat is dissipated from the base of the device through both the thread connection and the contact surface on the base of the device and the contact face on the heat sink. To enhance this heat flow, a heat conducting silicone compound should be applied to the threads and device base before insertion into the heat sink. Torque values used in installing stud type devices should carefully follow the manufacturer's recommendations. If the semiconductor is of the "Hocky-puck" type (without threaded base and pigtail lead), it will be provided with a special mounting and clamping device. The manufacturer's instructions for successfully replacing such a device must be carefully followed.

Figures 8 and 9 diagram a three module and two module brushless motor control.

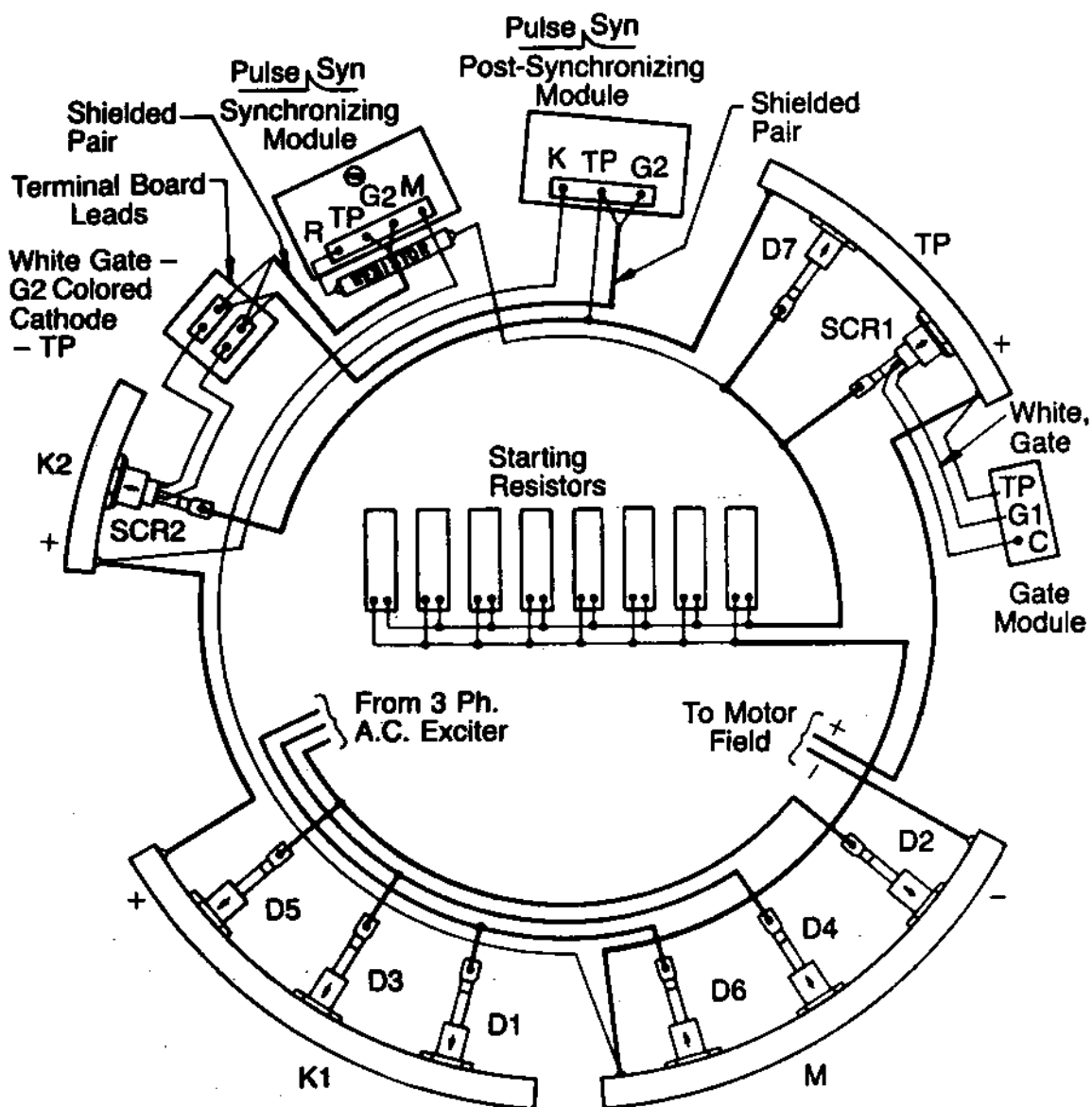


Fig. 8 - Brushless Motor Control Schematic Diagram - Three Module Design

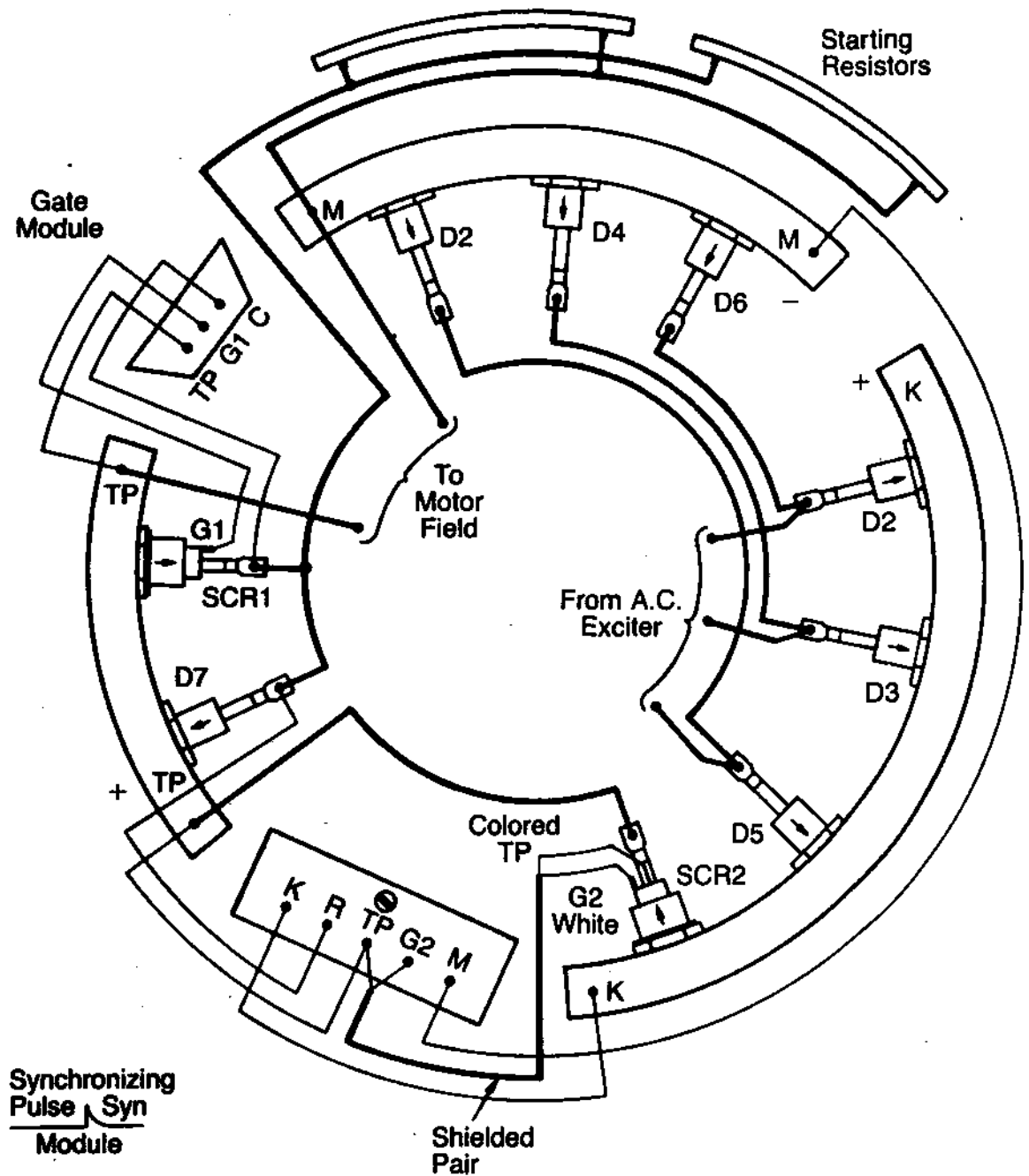


Fig. 9 - Brushless Motor Control Schematic Diagram - Two Module Design

8.9 Insulation Maintenance of Large Rotating Apparatus

Warning: Do not allow insulation tests to be made by any but qualified, experienced personnel. The hazards involved in testing and the potential dangers resulting from improper testing could cause risk to life and serious damage to property.

Any adequate preventive maintenance program must include periodic evaluation of the insulation system by test and visual inspection.

Visual inspection is necessary to detect mechanical damage caused by loose parts or foreign objects, evidences of wear or deterioration from thermal, electrical or magnetic stresses, and vibration. Adequate evaluation of an insulation system requires an inspection and test program based on a number of complimentary tests and visual inspection methods.

Regular inspections involving complete disassembly of the unit and removal of the rotor to permit close examination of possible areas of difficulty, are recommended.

The frequency of major inspections will depend on many factors, chiefly system demand and machine availability. For turbine generators, it is recommended that the rotor be removed after the first year of service and a thorough inspection and tests made. Successive major inspections should be made at intervals of two to five years. A recommended practice is to make major inspections and tests on the generator at three year intervals timed to coincide with turbine outages. Generator inspection and maintenance work can usually be made within the time required for a turbine overhaul.

A detailed examination of the generator windings should be made immediately after it has been subjected to a heavy fault condition, (a three-phase or line-to-neutral short circuit), or a severe out-of-phase synchronization. The mechanical forces acting on the end of the windings during fault conditions can stress the windings and their bracing to many times normal. Usually in faults of this type, it is only necessary to provide complete access to the end-windings, the rotor need not be removed.

Severe faults can also generate excessive torques in the shaft and coupling. These components are designed to withstand the forces of a three-phase short circuit at the generator terminals, but the torque on the coupling can approach 25 times normal from synchronizing out of phase. These forces can result in distortion of the coupling keys or bending of the shaft. An inspection of these parts is mandatory following a major fault.

There is no single test which gives an overall evaluation of insulation condition in a machine. There are a number of tests which help to evaluate specific properties of insulating components. In applying any test in a comprehensive maintenance program, the following criteria should be considered.

The tests applied must be capable of detecting insulation weakness. Application of tests at a too low level is misleading; the results tend to create an unjustified confidence. For any test to be valid it must stress the insulation at more than service potential.

Tests should have a direct reference to service experience. If any one property of the insulation system is questionable, tests designed to reveal any weakness in that property should be performed.

A. Factors Affecting Insulation Life

The preventive maintenance program should be designed to detect the affects and provide data on the deteriorating influences to which insulation systems are subjected.

Thermal aging from cumulative time-temperature effects.

Overheating from overload, high ambient temperature, ventilation restrictions or other causes.

Excessive moisture, oil, or grease.

Chemical fumes or airborne contaminants.

Contamination by conducting materials.

Overvoltage from switching or lightning surges.

Mechanical damage from short circuit or high inrush forces, physical shock, or vibration.

Mechanical damage from overspeed.

Mechanical damage from loose parts or foreign material.

Ionization effects.

B. Insulation Systems

An appreciation of the many components of a large motor or generator insulation system is a great help in planning a preventive maintenance program.

The insulation components described here are based on current Westinghouse designs. Insulation systems of motors or generators built at other times or by other manufacturers may vary in detail. The manufacturer's instructions should always be consulted.

1. Stator Windings

Insulation is usually full Class B withstand, transposed group, turn, and ground wall insulation as shown in Figure 10.

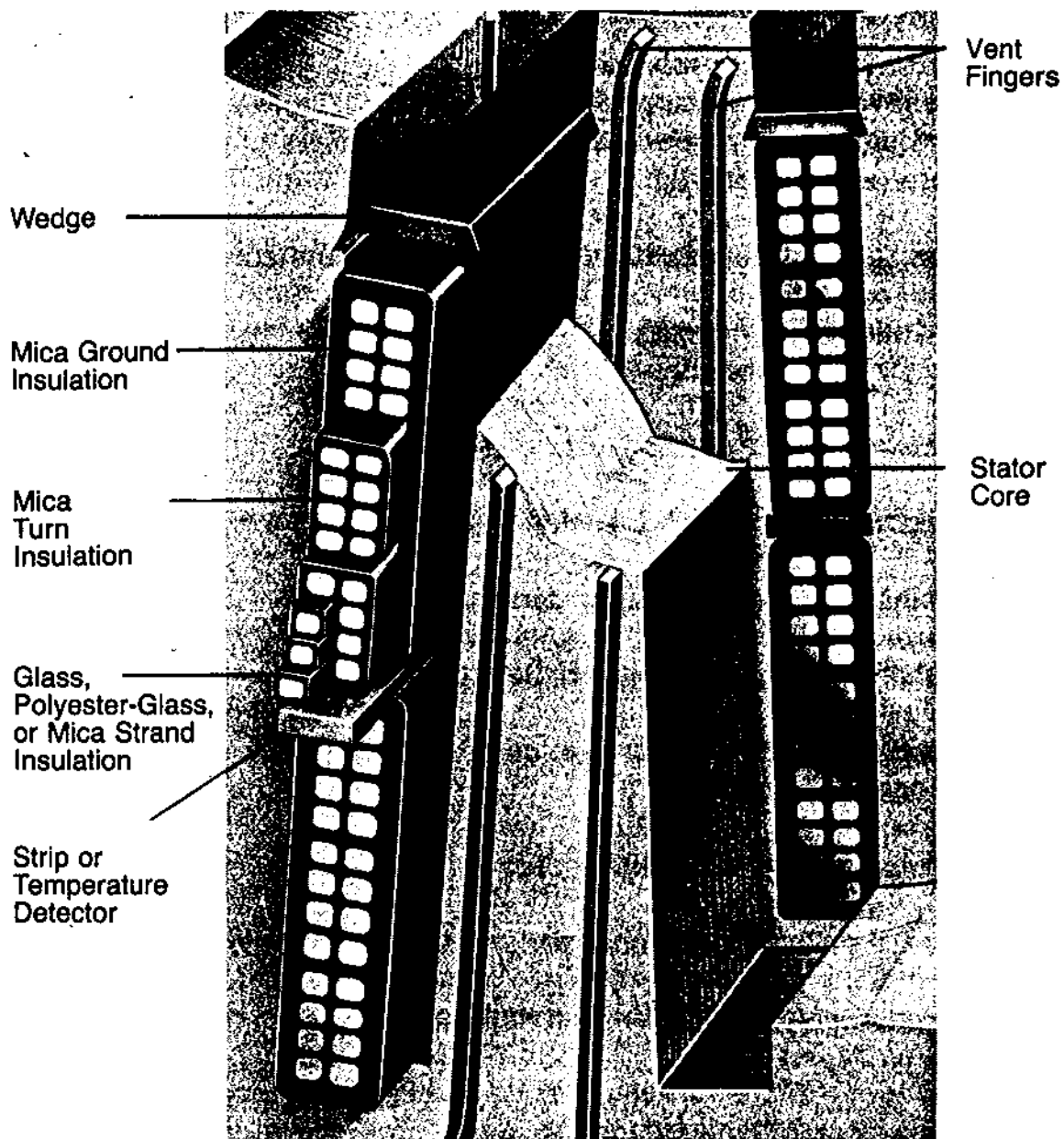


Fig. 10 - Typical Multi-Turn Coil with Turn Insulation

- a.** Strands are insulated with continuous glass film or polyester glass fibers.
- b.** Transposed groups are usually dependent on the strand covering for their dielectric barrier, except at the end connections where mica is used in various forms.
- c.** Turn insulation on groups of strands forming a single turn (or conductor) is usually mica tape. Most large turbine generators have single conductor coils.
- d.** Ground insulation takes several forms depending on operating voltage.

Older, obsolescent, and obsolete systems use such materials as mica splittings in the form of wrappers and tapes using organic binders and varnish or asphalt binders and impregnants.

Modern systems use mica splittings in the form of wrappers and tapes with glass fibers and synthetic solventless heat reactive resins. These resins are vacuum-pressure impregnated into the insulation system and heat cured, resulting in an insulation that has excellent mechanical properties and maximum resistance to moisture and chemicals.

- e.** Coil surfaces on high voltage (generally above 7 kV operating voltage) coils are treated with a low resistance conducting varnish to adequately ground the coil within the slot, to reduce surface voltage build-up and thus eliminate slot discharge. The portions of the coils just outside the iron are treated with a high resistance coating to prevent corona formation.
- f.** Winding support insulation which includes coil braces and supports, winding spacing blocks of various types, slot wedges and slot fillers are made of various types of high pressure glass fiber laminates. Conforming materials are synthetic resin saturated glass and polyester moldings and felts.
- g.** Stator insulated through-bolts are insulated from ground through their entire length with a multiple layer of treated fish paper bonded with shellac. All end hardware is insulated by high pressure laminate washers and mica bushings on more recently built units, to improve creepage distances. Refer to Figure 11. (Used on older apparatus.)
- h.** Stator Core Insulation. The individual laminations making up the stator core are insulated from each other by a surface coating of such materials as varnish, water glass, and inorganic substances [such as

monoaluminum phosphate (alkophos)] depending on the age of the machine.

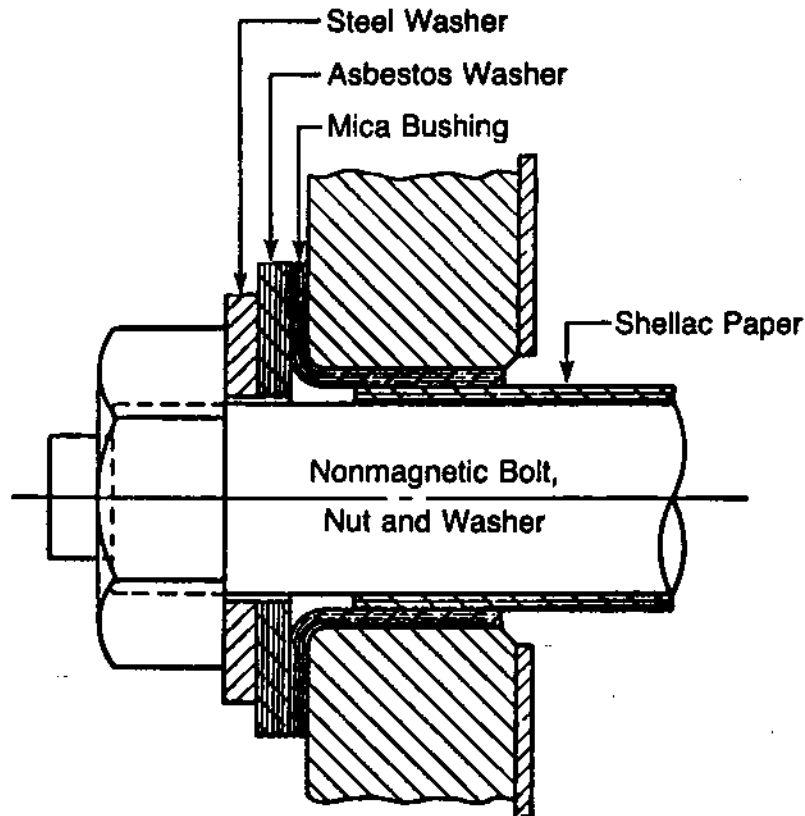


Fig. 11 – Typical Insulated Thru-Bolt and Details

2. Rotor Insulation

a. Rotating salient pole field coils are insulated from the pole by either mica splitting or resin bonded glass composite materials. Wire wound coils are wound of either glass or polyester and glass fiber insulated wire and are bonded with a thermo-setting resin. Strap wound coils are insulated between turns with synthetic fiber laminates bonded with a thermo-setting resin.

b. Collector lead and ring insulation is generally made from high pressure laminates.

C. Electrical Testing of Insulation

Warning: Do not make electrical insulation tests on motors or generators unless they have been electrically isolated and will remain so during the testing. Failure to do so before testing begins can result in serious injury or death by electric shock, and damage to property.

Electrical tests should discover existing weaknesses or faults in the insulation system and give some indication of the expected service life expectancy and reliability.

The following tests and testing principles should be considered in planning a diagnostic test program.

1. Insulation Tests at Low Voltage

The simplest and most easily made insulation resistance test is the megohmmeter measurement. This is a low voltage, direct-current measurement of leakage relative to surface contamination and moisture content of insulation. It is important to understand the limitations of these tests.

Megohmmeter tests will not usually reveal complete but clean, dry ruptures in the ground wall insulation.

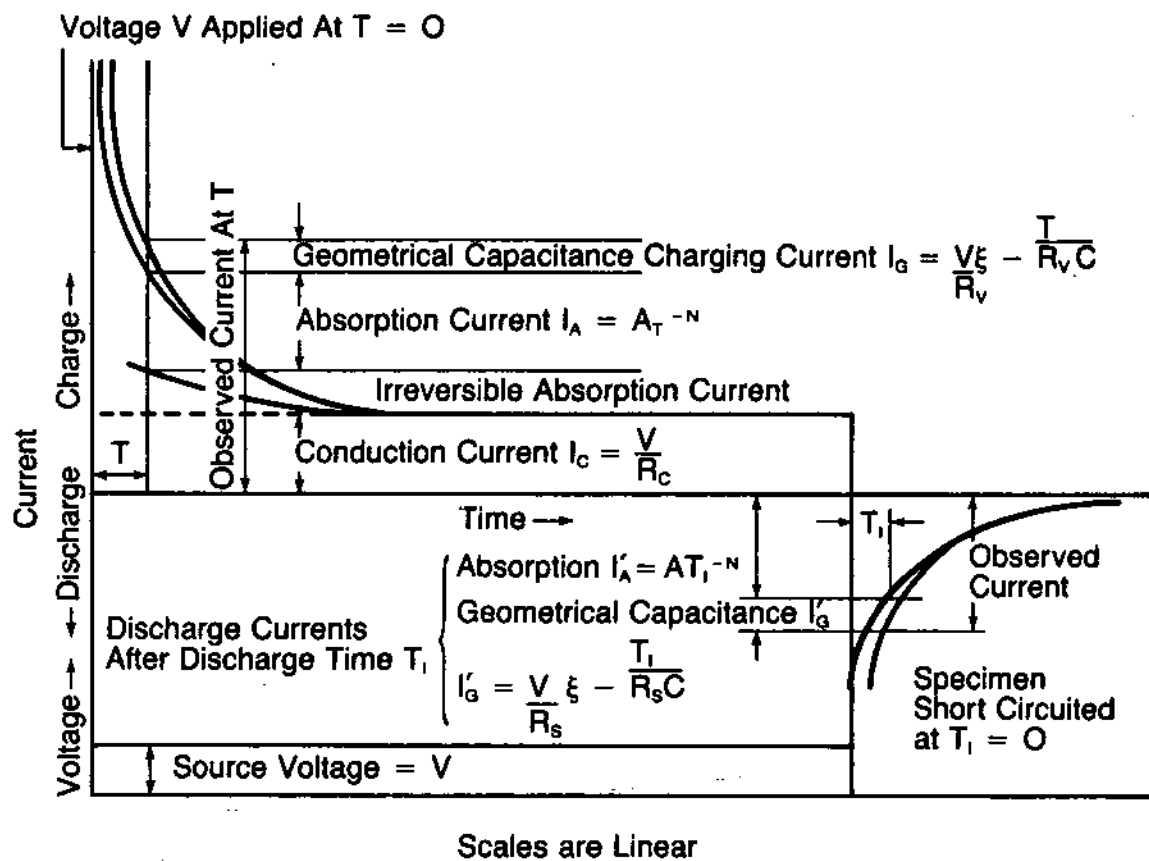
When applied to high voltage insulating systems, megohmmeter tests do not offer any proof of the physical integrity of insulation or its ability to withstand high voltage tests or even service potential.

Megohmmeter measurements are commonly made to determine insulation condition with regard to contamination before overvoltage tests are made. When testing a stator winding, it is preferable to test one phase at a time, to ground with the other two phases grounded as this procedure allows a comparison between phases and also tests the insulation between phases and between phase and ground.

2. Dielectric Absorption Testing

Dielectric absorption tests are a measurement of insulation resistance against time. The time period will usually be until resistance stabilizes, or as much as ten minutes.

Insulation leakage is not constant. It starts at a relatively high value and decreases until it reaches a stable value. This stable value is called the conduction component, and is established by the direct-current resistivity of the material. On an energized system, the difference between the total leakage and the constant steady state value (conduction component) is due to a phenomenon called dielectric absorption, See Figure 12. Any major insulation system should have occasional dielectric absorption tests made under comparable conditions of cleanliness, moisture and temperature.



$\xi = 2.718$ V = Voltage N = Storage Coefficient
 R_v = Resistance of Voltage Source A = Constant = DCV
 R_s = Resistance of Short Circuit D = A Constant Which is Characteristic of the Insulation
 R_c = Leakage Resistance
C = Specimen's Geometric Capacitance

Fig. 12 – A Dielectric Absorption Stability Curve

Dielectric absorption tests, as described in IEEE No. 43, are more significant than one-minute insulation resistance tests, (particularly on higher voltage windings) because the slope of the time-resistance characteristic gives further information about the condition of the insulation with respect to moisture and contamination. This slope is expressed as the ratio of ten to one-minute insulation resistance, and is called the polarization index. The ratio which is non-dimensional, aids in making comparisons between insulations of machines of different size. It also allows comparison of measurements on the same machine taken at different times.

Dielectric absorption measurements can be made at voltages as low as 500 volts, but higher voltages are recommended, particularly on high voltage stator windings.

A polarization index of 2.0 or more is normal for asphalt, bitumen, and varnish impregnated windings. Modern impregnated insulation systems

will produce higher index values. This index value applies only to a stator winding and could be considerably different if the measurements were made with parts external to the windings such as leads, cables, or protective equipment included in the test circuit.

A polarization index of less than 1.0 indicates time-dependent leakage. The cause should be investigated and corrected before the machine is either tested or returned to service.

An abnormally high polarization index, in the order of 5 or more, on insulation that has been in service 20 years or more, could be an indication that the insulation is intact but brittle and dried out.

Typical polarization index curves are shown in Figure 13.

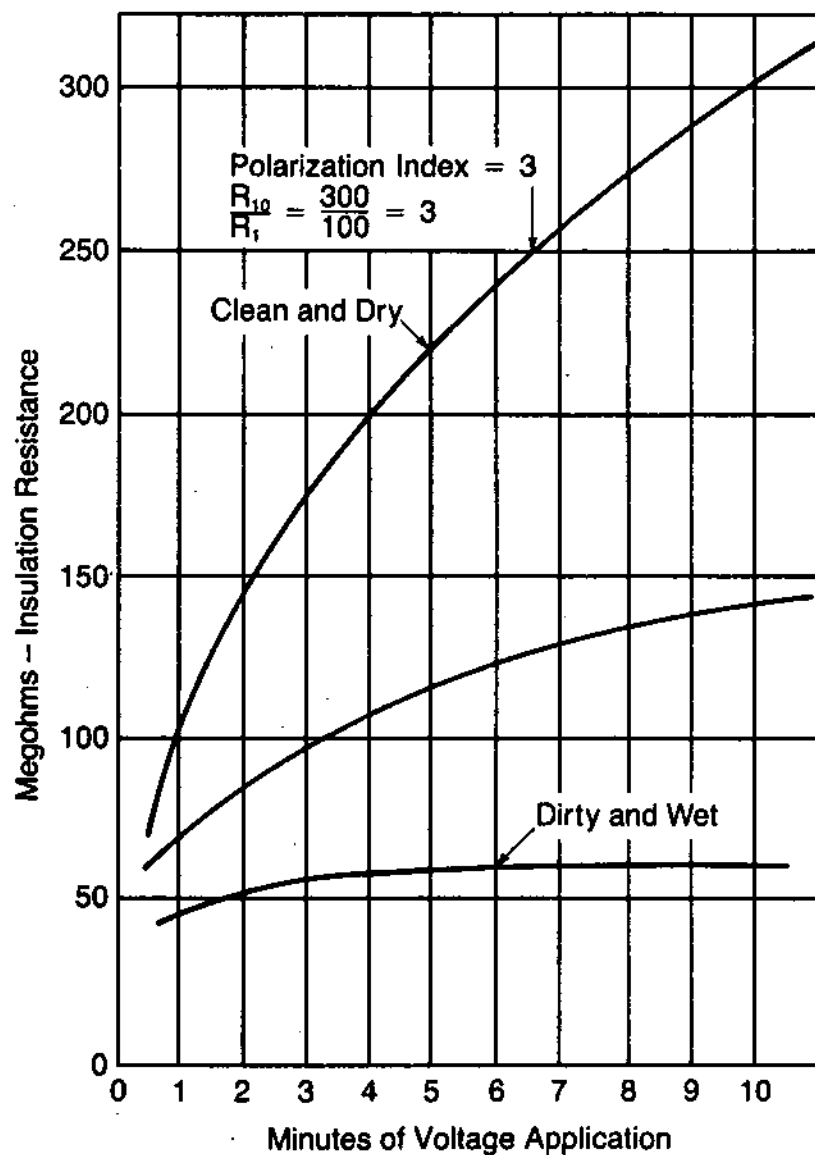


Fig. 13 - A Polarization Index Graph

3. Over-potential Tests

Low voltage insulation resistance and dielectric absorption tests do not produce electrical stresses of sufficient magnitude to expose faults which might lead to in-service failure. Power factor (or tangent delta) measurements which are an effective tool used by the manufacturer in insulation development and quality control, are not effective in assessing either the condition of insulation or its suitability for continued operation. Electric strength has been demonstrated to be the most effective criterion for determining the condition of an insulation system which has been subjected to long use and aging conditions.

The following curves have been selected to demonstrate the need for overpotential testing the electrical strength of an in-service insulation system. These curves show that while following the trend of tangent delta measurements permits comparison between different insulation systems, their limits during aging tests are less clearly defined than they are by overpotential tests.

Figure 14 shows comparisons of electric strength as a function of aging. The curves give performance of two older insulation systems at 120C and more modern systems at higher temperatures.

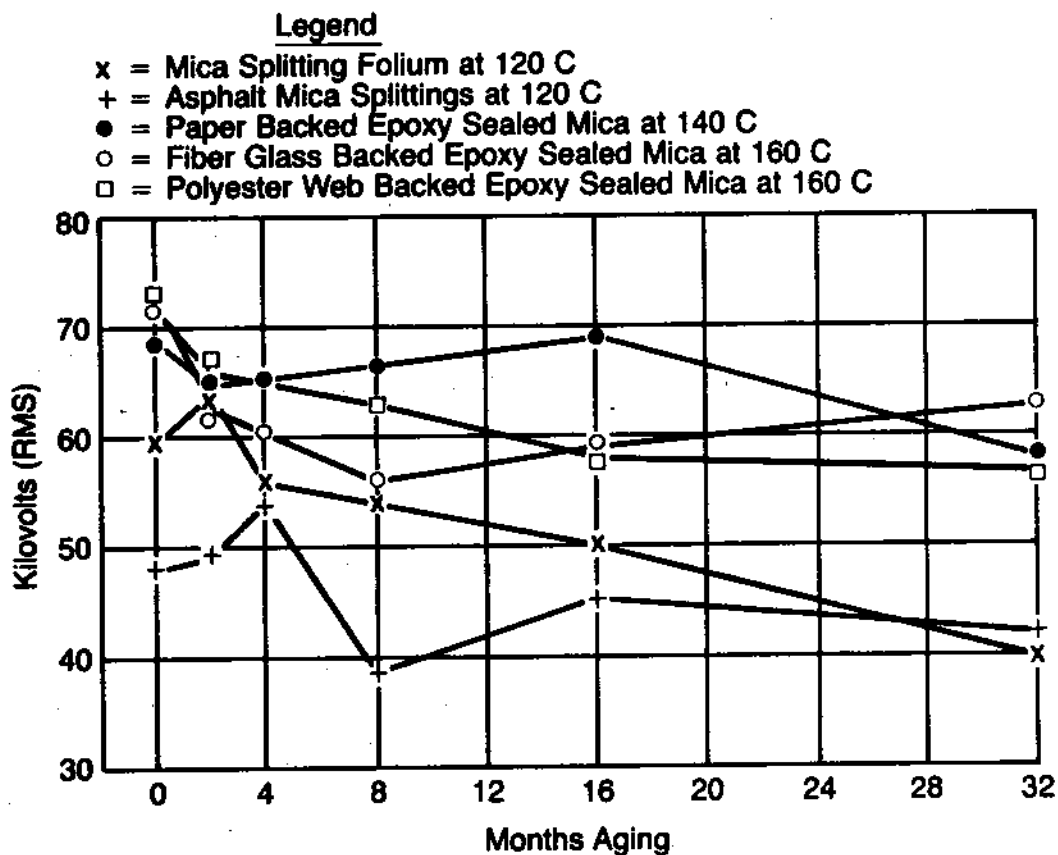


Fig. 14 - Graphic Presentation of Electric Strength as a Function of Thermal Aging

Figure 15 is a similar comparison at higher temperatures. The curves reveal that the newer systems have better electric strength and better aging characteristics.

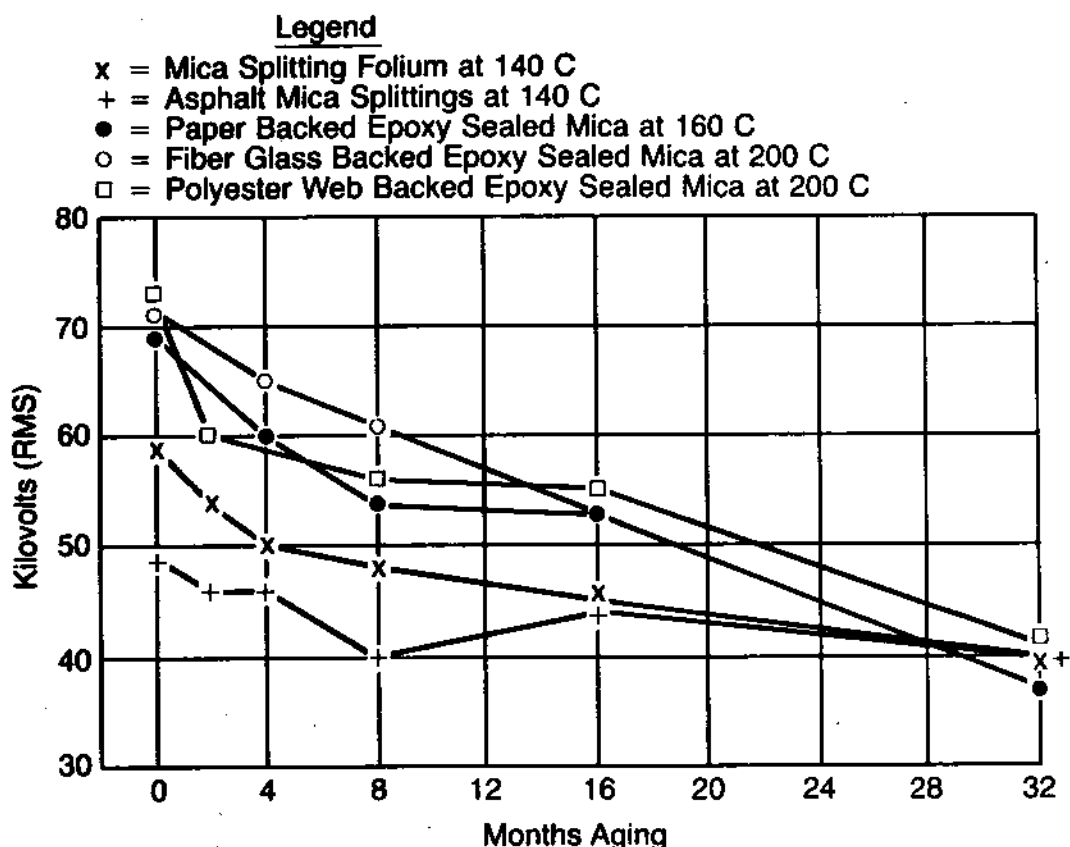


Fig. 15 – Curve Showing Electric Strength as a Function of Thermal Aging

Figures 16 and 17 show the changes in tangent delta plotted against months of aging for the same systems and at the same temperatures. These tests were made at voltages of 2 kV to 30 kV.

In Figure 16 the paper backed epoxy system at 140C appears comparable with the micafolium and asphalt bonded systems at 120C. The other synthetic resin systems show greater stability at higher temperatures. An interesting phenomenon is demonstrated, the delta tangent delta passes through a peak as a function of aging and then begins to decline.

Figure 17 shows further change in tangent delta at the 2kV to 30 kV test range as a function of aging.

Over-potential tests may be performed using either alternating voltage or direct potential. The testing program illustrated in Figures 14 and 15 is not practical in a field maintenance program, but the behavior of the insulation system during repeated maintenance over-potential tests is equally revealing. The measurements necessary for this evaluation can be made during the direct-current tests.

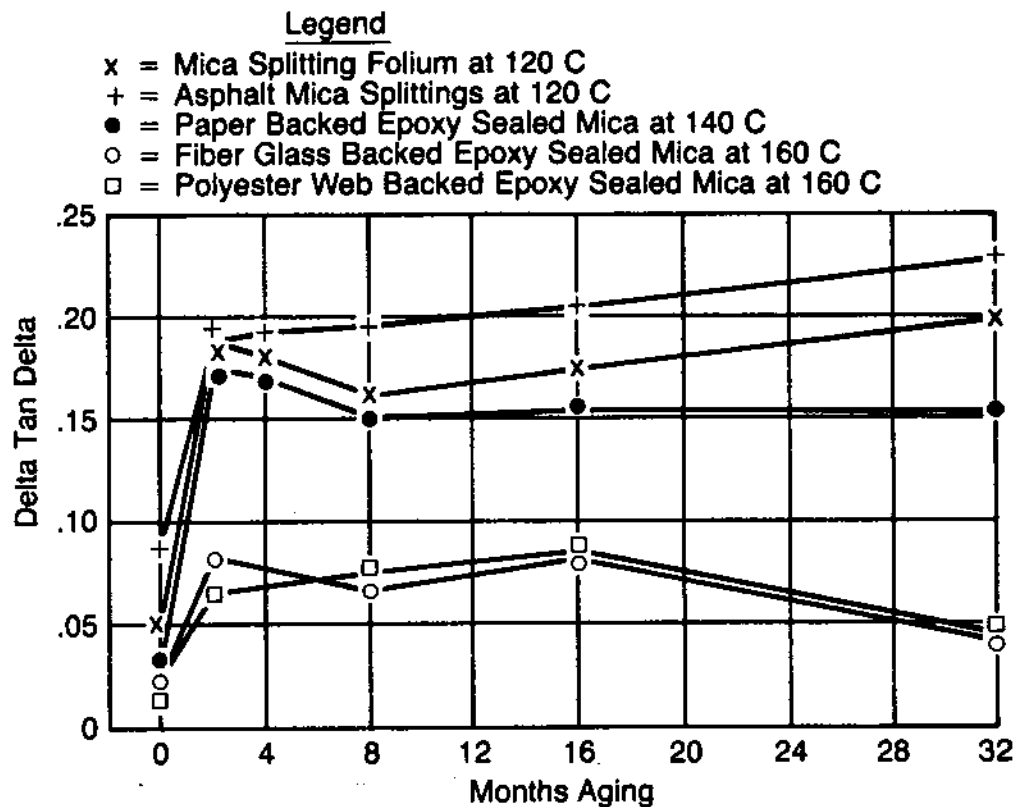


Fig. 16 – Change in Tangent Delta at 2 to 30 kV Test Range as a Function of Thermal Aging

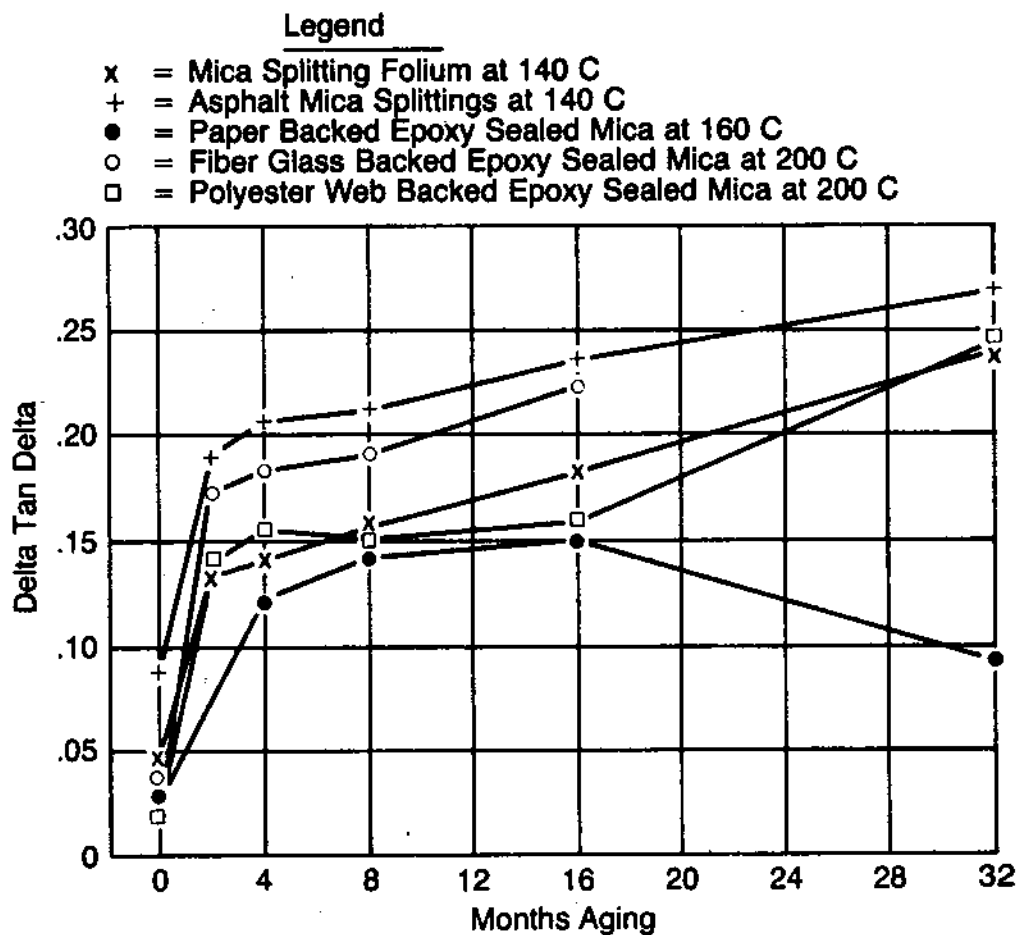


Fig. 17 – Further Change in Tangent Delta (from Fig. 16) at 2 to 30 kV Test Range as a Function of Thermal Aging

The level of over-potential which should be applied depends on such factors as the type of machine, the degree of exposure to over voltages, and the level of serviceability required. The selected test level should be sufficiently searching to reveal any weakness, (present or potential,) which might lead to insulation failure. For machines expected to give a high level of service reliability, the maximum recommended value is:

$E_{\text{Test}} = \text{Direct-current test potential}$

$$E_{\text{Test}} = 1.3 \times E \times 1.7$$

Where E is the voltage rating of the machine under test.

There are other advantages in direct-current testing:

Direct-current voltages are less damaging when a test failure occurs than are alternating-current voltages for equivalent results.

Imminent failure can often be predicted during d-c testing and the test stopped before serious damage occurs.

Time of voltage application is less critical with direct current.

Equipment required for d-c testing is smaller and lighter than equivalent a-c equipment.

Controlled Overvoltage Test

Many d-c test methods have evolved, most of which have some particular merit.

In these tests the increase in the direct voltage is controlled. Measured currents are continuously observed for abnormalities with the objective of stopping the test before breakdown occurs. These tests are also known as direct-current leakage tests or step voltage tests.

There are drawbacks in using these tests:

A breakdown may occur without prior indication by current measurement.

There is some controversy in the interpretation of the test result, it being a matter of judgement and experience.

Of the various test methods, the following are most often used:

For a detailed discussion of recommended precautions, practices and procedures of the two test methods summarized below, reference should be made to IEEE Std. 95, latest issue.

(1) Uniform Rate of Rise Method

The recommended maximum d-c test voltage should be 1.25–1.50 times the rated machine a-c voltage times 1.7. An initial voltage of approximately one-third of the maximum d-c test voltage is applied for 10 minutes to obtain a polarization index.

If a satisfactory polarization index is obtained, the test is continued by increasing the test voltage by not more than 3% of the final test voltage each minute. The voltage setting should be made in the first 10 seconds of each interval with allowance for voltage rise due to regulation of the test set. The voltage should not be further adjusted during the one minute interval because errors are thus introduced. The current and voltage for each time interval are read and recorded at the *end* of the interval.

The data should be plotted immediately after being taken at each step. For a winding indicated as being in good condition, a plot of current vs test voltage will usually produce a smooth curve with rising characteristics. Refer to Figure 18. When there is *no* abrupt change from a smooth curve, a break down is probably *not* eminent and the testing can be continued. For a detailed discussion of deviations from a smooth curve and possible interpretation, IEEE Std. 95 should be consulted.

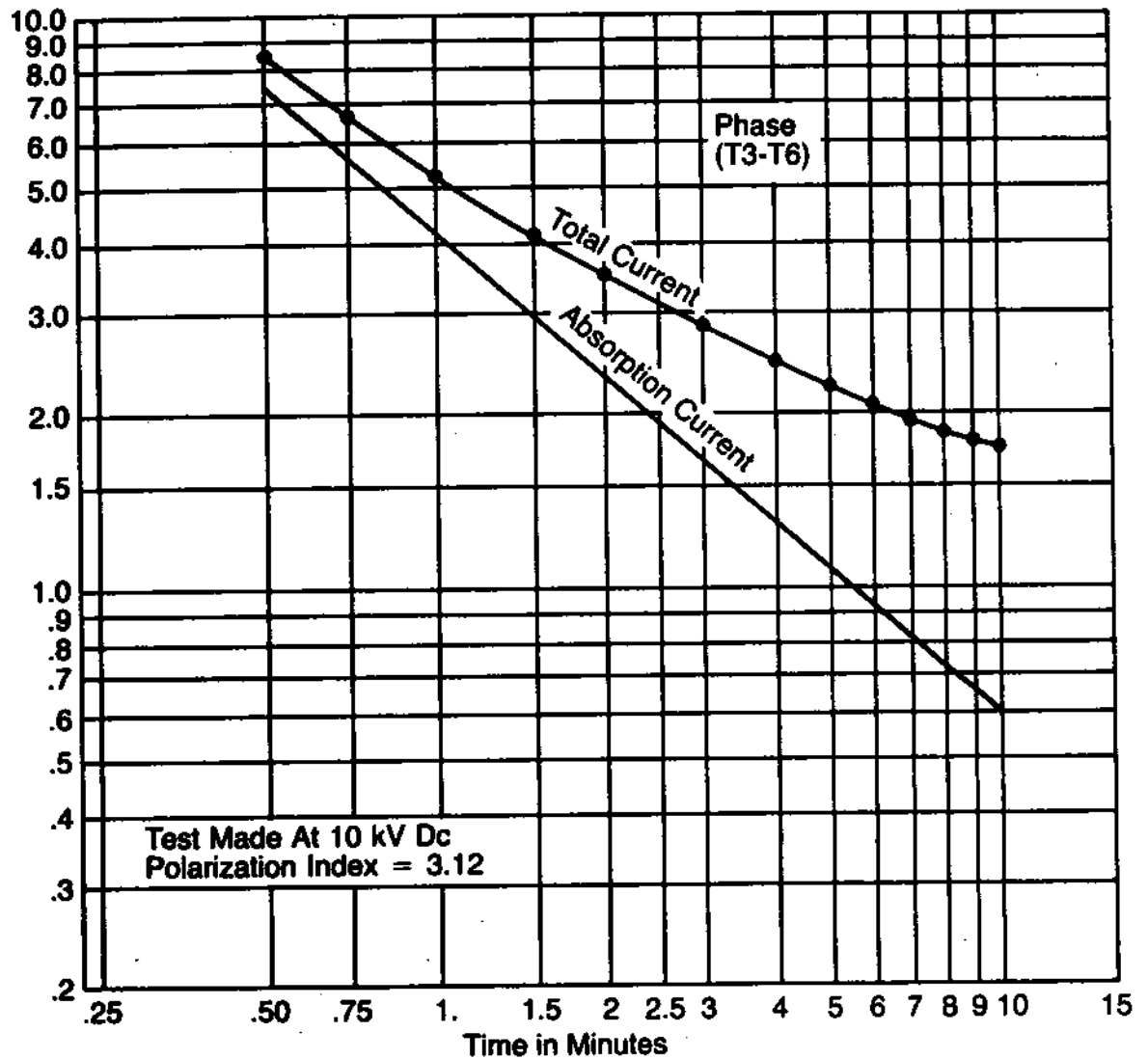
(2) Graded Time Method

In this method, an attempt is made to separate the absorption current component from the total leakage and thus obtain the true leakage. On each step, the test potential is maintained for a pre-determined time interval which is dependent upon certain current values obtained during the first ten minutes of test voltage application. These time intervals allow almost complete absorption and the final current is very nearly true leakage. If *complete* absorption were actually reached, the total testing time would be prohibitively long.

a. The recommended maximum d-c test voltage is again determined as in Ia., above.

b. An initial voltage value that is approximately one-third of the maximum d-c test voltage is applied. Current readings are made at 0.5, 0.75, 1.0, 1.5 and 2.0 minutes and each minute thereafter to 10 minutes. These values are plotted on log-log coordinate graph paper (Figure 18). When the 8th minute reading is taken, a smooth curve is drawn through

Microamperes



Leakage - Voltage Test Calculations

Read Values of Microamperes at 3.16, 1.0 and 10.0 Minutes From Above Curve

$$\begin{aligned}
 i_{3.16} &= \underline{2.7} \\
 i_{1.0} &= \underline{5.3} \\
 i_{10.0} &= \underline{1.7} \\
 i_{1.0} \times i_{10.0} &= \underline{9.0} \\
 (i_{3.16})^2 &= \underline{7.3} \\
 A &= (i_{1.0} \times i_{10.0}) - (i_{3.16})^2 = \underline{1.7} = A \\
 \frac{i_{1.0} + i_{10.0}}{2(i_{3.16})} &= \underline{7.0} \\
 B &= (i_{1.0} + i_{10.0}) - (2 i_{3.16}) = \underline{1.6} = B
 \end{aligned}$$

Conduction Component $\frac{A}{B} = \frac{1.7}{1.6} = \underline{1.1}$

$$\begin{aligned}
 i_{1.0} &= \underline{5.3} \\
 \frac{A}{B} &= \underline{1.1} \\
 i_{a1.0} &= (i_{1.0}) - \left(\frac{A}{B}\right) = \underline{4.2} = \text{Absorption Current At One Minute}
 \end{aligned}$$

$$\begin{aligned}
 i_{10.0} &= \underline{1.7} \\
 \frac{A}{B} &= \underline{1.1} \\
 i_{a10.0} &= (i_{10.0}) - \left(\frac{A}{B}\right) = \underline{.6} = \text{Absorption Current At Ten Minutes}
 \end{aligned}$$

$$\frac{i_{a1.0}}{i_{a10.0}} = \frac{4.2}{.6} = \underline{7.0} = \text{Absorption Ratio}$$

S. O. _____ Serial _____ Customer _____ Plant _____ Unit _____
 Phase _____ Wdg. Temp. _____ Rel. Hum. _____ Engr. _____ Date _____

Fig. 18 - Typical Graph and Test Data Reference Sheet

the (most) preceding points, extrapolating the curve to 10 minutes without delay. This allows two minutes additional time for making the following computations.

c. Three current values are read from the smooth curve at 1.0, 3.16 and 10 minutes for calculating the conduction current component of the measured currents by the following equation:

$$C = \frac{A}{B} = \frac{(1.0 \times 10.0) - (3.16)^2}{(1.0 + 10.0) - 2(3.16)}$$

When C is subtracted from the total current values at 1.0 and 10.0 minutes, the absorption current values are found:

$$N = \frac{i_{a1.0}}{i_{a10.0}} = \frac{\text{absorption current at 1 min.}}{\text{absorption current at 10 min.}}$$

As soon as "N" is determined, the succeeding time periods to be maintained between changes in test voltage can be determined from Figure 19.

At the end of 10 minutes the initial test voltage must be *immediately* raised 20%. The voltage setting should be made in the first 10 seconds of each time interval with allowance for voltage rise due to regulation of the test set. The voltage should not be further adjusted during the time interval due to errors thus introduced. For the test results to be valid, the voltage increases must occur promptly at the time intervals determined from Figure 19. Figure 20 shows total leakage current against voltage.

d. Current and voltage values are read at the end of each interval immediately prior to raising the test voltage to the next value. These values are plotted as in Figure 20. The comments made in Id. above will also apply here in the interpretation of the results obtained.

For a detailed discussion of these two test methods refer to the current issue of *IEEE Std. 95*.

Moisture in insulation usually produces a continuous upward curvature and internal void ionization produces minor breaks in the slope of the curve. A sharp break in the curve is usually an indication of an abnormality; it is a signal to stop the test before failure occurs.

Some failures can and do occur without warning, and very high leakages do not always lead to failure. The ultimate evaluation is that the winding either withstood the overpotential test or it did not.

Table A1
Elapsed Time at the Conclusion of Each Voltage Step

Voltage Percent of First Step	Absorption Ratio <i>N</i>							
	2		3		4		5	
	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)
100	10		10		10		10	
120	13	14	13	27	13	36	13	44
140	15	56	16	21	16	39	16	53
160	18	17	18	55	19	21	19	42
180	20	24	21	12	21	47	22	14
200	22	19	23	18	24	1	24	34
220	24	4	25	14	26	4	26	43
240	25	42	27	1	27	59	28	45
260	27	12	28	41	29	47	30	38
280	28	37	30	15	31	28	32	25
300	29	57	31	44	33	3	34	7
320	31	12	33	8	34	34	35	43
340	32	23	34	27	36	0	37	14
360	33	31	35	43	37	22	38	41
380	34	35	36	55	38	40	40	5
400	35	36	38	4	39	55	41	25
420	36	35	39	10	41	7	42	42
440	37	31	40	14	42	17	43	56
460	38	25	41	15	43	23	45	8
480	39	17	42	14	44	28	46	17
500	40	8	43	11	45	30	47	23
520	40	56	44	6	46	30	48	28
540	41	42	44	58	47	29	49	31
560	42	28	45	50	48	25	50	31
580	43	11	46	40	49	20	51	30
600	43	54	47	28	50	13	52	28
620	44	35	48	15	51	4	53	24
640	45	15	49	1	51	54	54	18
660	45	53	49	45	52	44	55	11
680	46	31	50	28	53	32	56	3
700	47	8	51	10	54	18	56	53
720	47	43	51	51	55	4	57	42
740	48	18	52	32	55	48	58	30
760	48	52	53	11	56	32	59	18
780	49	25	53	49	57	14	60	3
800	49	58	54	26	57	55	60	48
820	50	29	55	3	58	36	61	33
840	51	0	55	38	59	16	62	16
860	51	30	56	13	59	55	62	58
880	52	0	56	40	60	33	63	40
900	52	29	57	21	61	10	64	20
920	52	57	57	54	61	46	65	0
940	53	25	58	26	62	23	65	39
960	53	53	58	58	62	58	66	18
980	54	20	59	29	63	32	66	56

NOTES:

(1) Time at end of first step: 10 min.

(2) Voltage increment: 20 percent of first step.

Fig. 19 – Time-step Absorption Reference Table from IEEE Std 95-1977 Large Rotating Machinery with High Direct Voltage

Table A1 (continued)
Elapsed Time at the Conclusion of Each Voltage Step

Voltage Percent of First Step	Absorption Ratio <i>N</i>							
	6		7		8		9	
	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)
100	10		10		10		10	
120	13	49	13	54	13	58	14	2
140	17	4	17	14	17	22	17	30
160	19	59	20	13	20	25	20	36
180	22	37	22	56	23	12	23	26
200	25	2	25	25	25	46	26	4
220	27	17	27	45	28	9	28	31
240	29	23	29	55	30	24	30	49
260	31	21	31	58	32	30	32	59
280	33	13	33	54	34	30	35	2
300	34	59	35	44	36	24	36	59
320	36	40	37	29	38	12	38	51
340	38	16	39	9	39	56	40	38
360	39	48	40	45	41	35	42	20
380	41	16	42	17	43	11	43	58
400	42	40	43	45	44	42	45	33
420	44	2	45	10	46	11	47	5
440	45	20	46	32	47	36	48	33
460	46	35	47	51	48	58	49	58
480	47	48	49	8	50	18	51	21
500	48	59	50	22	51	35	52	41
520	50	8	51	34	52	51	53	59
540	51	14	52	44	54	3	55	15
560	52	19	53	52	55	14	56	28
580	53	21	54	58	56	23	57	40
600	54	22	56	2	57	30	58	50
620	55	22	57	5	58	36	59	58
640	56	19	58	6	59	40	61	4
660	57	16	59	5	60	42	62	9
680	58	11	60	3	61	43	63	13
700	59	5	61	0	62	43	64	15
720	59	58	61	56	63	41	65	16
740	60	49	62	50	64	38	66	15
760	61	39	63	43	65	34	67	13
780	62	28	64	35	66	25	68	10
800	63	17	65	26	67	22	69	6
820	64	4	66	16	68	14	70	1
840	64	50	67	6	69	6	70	55
860	65	35	67	54	69	57	71	48
880	66	20	68	41	70	47	72	40
900	67	6	69	27	71	35	73	31
920	67	46	70	13	72	23	74	22
940	68	29	70	58	73	10	75	11
960	69	10	71	41	73	57	75	59
980	69	50	72	24	74	42	76	46

NOTES:

- (1) Time at end of first step: 10 min.
- (2) Voltage increment: 20 percent of first step.

Table A1 (continued)
Elapsed Time at the Conclusion of Each Voltage Step

Voltage Percent of First Step	Absorption Ratio <i>N</i>							
	10		11		12		13	
	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)
100	10		10		10		10	
120	14	5	14	8	14	10	14	13
140	17	36	17	42	17	47	17	52
160	20	46	20	54	21	2	21	9
180	23	39	23	51	24	1	24	11
200	26	20	26	34	26	48	27	0
220	28	50	29	7	29	23	29	38
240	31	11	31	31	31	50	32	7
260	33	24	33	47	34	8	34	28
280	35	30	35	56	36	20	36	42
300	37	31	37	59	38	26	38	50
320	39	25	39	57	40	26	40	52
340	41	15	41	49	42	21	42	49
360	43	0	43	37	44	11	44	42
380	44	42	45	21	45	57	46	31
400	46	19	47	1	47	40	48	16
420	47	53	48	38	49	19	49	57
440	49	24	50	11	50	55	51	35
460	50	52	51	42	52	28	53	10
480	52	18	53	10	53	58	54	42
500	53	41	54	35	55	25	56	11
520	55	1	55	58	56	50	57	39
540	56	19	57	18	58	13	59	4
560	57	35	58	37	59	34	60	26
580	58	50	59	53	60	52	61	47
600	60	2	61	8	62	9	63	6
620	61	12	62	21	63	24	64	23
640	62	21	63	32	64	37	65	38
660	63	29	64	41	65	49	66	51
680	64	35	65	50	66	59	68	3
700	65	39	66	56	68	7	69	14
720	66	42	68	1	69	15	70	23
740	67	44	69	5	70	20	71	30
760	68	44	70	8	71	25	72	37
780	69	43	71	9	72	28	73	42
800	70	42	72	9	73	30	74	46
820	71	39	73	8	74	32	75	49
840	72	35	74	7	75	32	76	51
860	73	30	75	4	76	30	77	51
880	74	24	76	0	77	28	78	51
900	75	17	76	55	78	25	79	50
920	76	10	77	49	79	21	80	47
940	77	1	78	42	80	17	81	44
960	77	52	79	35	81	11	82	40
980	78	41	80	26	82	4	83	35

NOTES:

- (1) Time at end of first step: 10 min.
- (2) Voltage increment: 20 percent of first step.

Table A1 (continued)
Elapsed Time at the Conclusion of Each Voltage Step

Voltage Percent of First Step	Absorption Ratio <i>N</i>							
	14		15		16		20	
	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)	(Min.)	(Sec.)
100	10		10		10		10	
120	14	15	14	17	14	19	14	25
140	17	56	18	0	18	4	18	17
160	21	16	21	22	21	28	21	48
180	24	20	24	29	24	36	25	3
200	27	11	27	22	27	32	28	5
220	29	52	30	4	30	16	30	57
240	32	23	32	38	32	51	33	39
260	34	46	35	3	35	19	36	13
280	37	2	37	21	37	39	38	41
300	39	12	39	33	39	53	41	1
320	41	17	41	40	42	2	43	17
340	43	16	43	41	44	5	45	27
360	45	11	45	38	46	4	47	32
380	47	2	47	31	47	58	49	33
400	48	49	49	20	49	49	51	30
420	50	32	51	5	51	36	53	24
440	52	12	52	47	53	20	55	14
460	53	49	54	26	55	1	57	1
480	55	23	56	2	56	38	58	45
500	56	55	57	36	58	14	60	27
520	58	24	59	6	59	46	62	6
540	59	51	60	35	61	17	63	42
560	61	15	62	1	62	45	65	16
580	62	38	63	26	64	11	66	48
600	63	59	64	48	65	35	68	18
620	65	17	66	9	66	57	69	46
640	66	34	67	27	68	17	71	13
660	67	50	68	44	69	36	72	37
680	69	3	70	0	70	53	74	0
700	70	16	71	14	72	9	75	21
720	71	27	72	26	73	23	76	41
740	72	36	73	38	74	36	77	59
760	73	44	74	47	75	47	79	16
780	74	51	75	56	76	57	80	32
800	75	57	77	3	78	6	81	46
820	77	1	78	9	79	14	82	59
840	78	5	79	14	80	20	84	11
860	79	7	80	18	81	26	85	22
880	80	8	81	21	92	30	86	32
900	81	9	82	23	83	33	87	41
920	82	8	83	24	84	36	88	49
940	83	7	84	24	85	37	89	55
960	84	4	85	23	86	38	91	1
980	85	1	86	21	87	37	92	5

NOTES:

- (1) Time at end of first step: 10 min.
- (2) Voltage increment: 20 percent of first step.

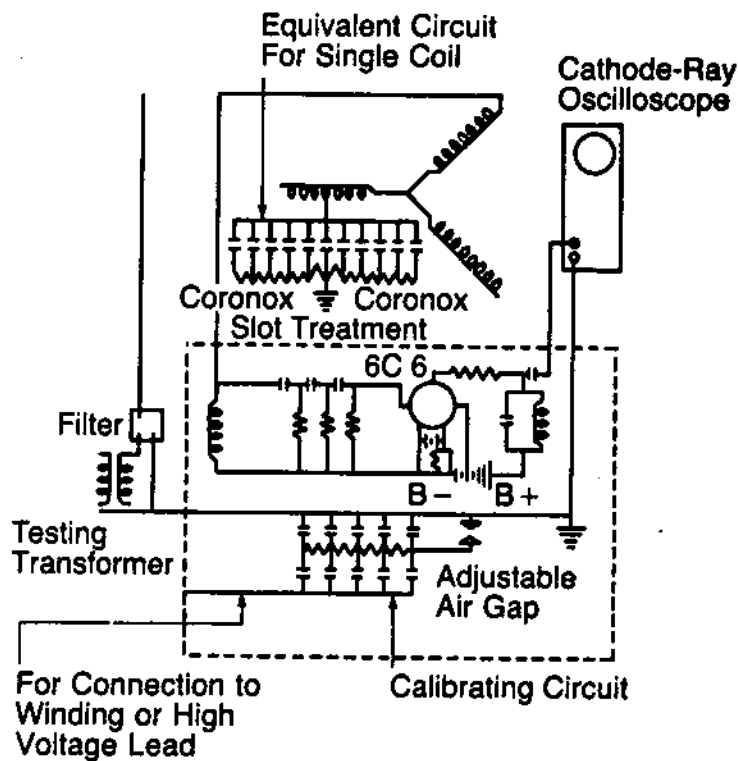


Fig. 21 - Slot Discharge Test Circuit Schematic

D. Conductor Insulation Tests

The chance of failure of the insulation between conductors of a motor or generator varies with the design and conditions of service.

1. Coil Design

Most a-c motors and generators for industrial applications of 300 hp and above have stator coils which consist of one or more rectangular copper strands which are combined to form a conductor. The conductor is formed into a coil consisting of one or more conductors shaped into straight portions each of which fits into a slot one pole pitch or less apart, and diamond shaped end winding portions connecting the straight portions. The leads are brought out across the loops at the extreme front of the coil. Figure 22 shows a typical stator coil for a synchronous or induction motor.

2. Electric Strength of Conductor Insulation

There are three general types of insulation used between electrically stressed parts of a motor. One or a combination may be used.

1. A solid dielectric barrier
2. Gaseous insulation provided by suitable physical spacing.

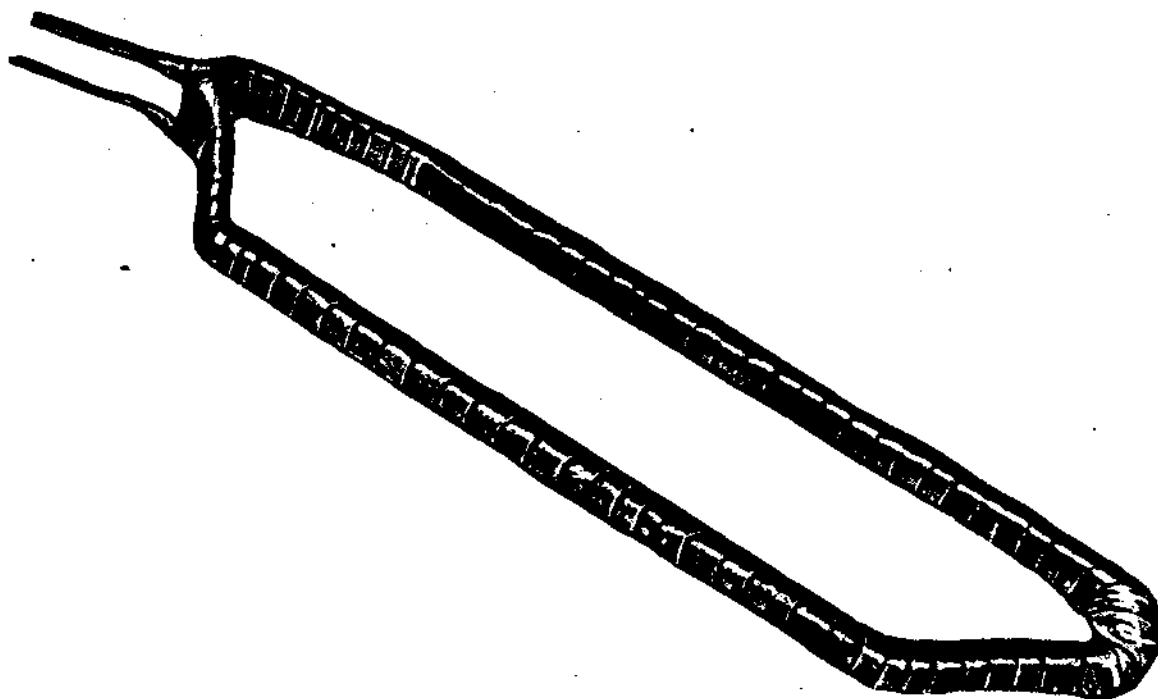


Fig. 22 – Typical Stator Coil for a Synchronous Induction Machine

3. Creepage over insulation surfaces.

Where conductor insulation is in the form of a fibrous wire covering, either with or without adhesive, it is considered to be type 2, the porous fibrous insulation providing only physical separation between the conductors.

Mica tape conductor insulation is predominately a combination of types 1 and 3 where the mica splittings form a solid dielectric barrier but creepage surfaces exist along the mica platelets. The use of fibrous insulation is much more common than mica tape on motor coils. Many more recent machines use mica tape insulated wire.

3. Conductor Insulation Test Levels

Tests designed to confirm the adequacy of insulation between conductors must be many times the normal operating volts per turn which rarely exceed 20 to 30 volts.

A test of 300 volts rms per turn indicates a spacing adequacy of only 0.0005 inch. For spacing normally expected to be 0.010 inch or greater, the 300 volt test and possibility of spacing so small, is little assurance against marginal conditions. Thermal effects, vibration, and coil deflection resulting from starting inrush or other conditions experienced in normal operation could cause changes in the space greater than a 300 volt test assures.

During the process of manufacture, coils are tested at voltages well above the minimum sparking potential. A 500 volt rms per turn test for coils with fibrous wire insulation is a representative value for manufacturer's tests. Exact test levels vary with design.

Maintenance tests on conductor insulation should be related to the value of a new coil test rather than operating volts per turn of the motor.-

Notice: Test voltages which are equivalent to $\frac{1}{2}$ to $\frac{2}{3}$ of new coil test values are generally sufficient to provide assurance of the adequate insulation.

4. Testing Procedures, Factory or Shop

To stress the insulation between turns in a coil or winding, voltage must be impressed across its terminals. If this voltage is at power frequency, the resulting current will far exceed the thermal capacity of the conductors and the power requirements would be prohibitively high. For these reasons, it is necessary to apply a high frequency or a surge of sufficient steepness to produce the desired stresses. The two most commonly used methods of testing coils use either high frequency or steep surge.

a. Rotating Spark Gap High Frequency Test

A schematic diagram of the rotating spark gap high frequency oscillator used for testing coils and windings is shown in Figure 23. In this device, the coil under test is in parallel with a condenser charged from a power source, and in series with an adjustable rotating spark gap. A sphere gap is connected across the coil under test to measure the voltage across it. In making the test the spark gap spacing is gradually increased

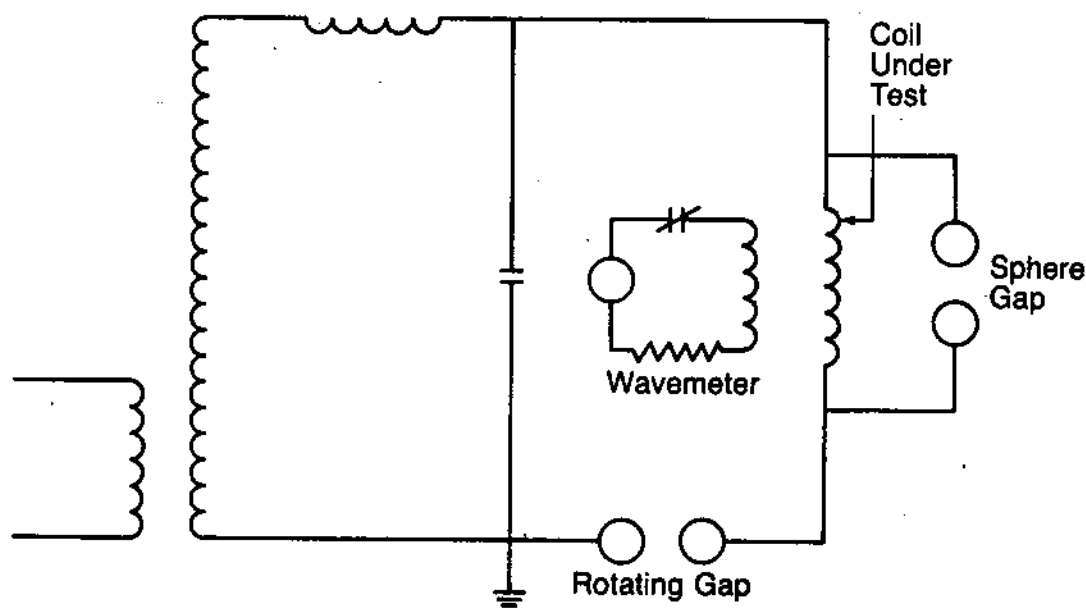


Fig. 23 - Simplified Circuit of Rotating Spark Gap Type High Frequency Test Set

from a low value until the desired voltage is obtained across the coil under test. There is sufficient inductance in the source so the voltage across the coil is due to the transient oscillation resulting from the discharge of the condenser through the inductance of the coil being tested. The frequency of the resulting wave train of oscillations depends on the capacitance value of the condenser and the inductance of the coil under test. Coils are usually tested at frequencies of approximately 100 kilohertz turn-to-turn. When a short circuit occurs in a coil, the amplitude of the voltage for a given spark gap setting is reduced and the frequency of the oscillation is increased. A wave meter, sensitive to frequency shift as well as amplitude reduction, is used to detect short circuits. The purpose of the rotating gaps is to minimize erosion of the electrodes due to the discharge current.

This type of tester has a high frequency output and is therefore effective in locating short circuits. There are no practical limitations in the magnitude of high frequency voltages obtainable for testing.

There is a major disadvantage, important at low voltages. For small gap settings, the gap breakdown becomes increasingly difficult to maintain at a uniform level. At very low voltages the applied test voltages may be subject to appreciable variation.

b. Surge Comparison Tests

Figure 24 is a schematic diagram of a surge comparison test set up. A capacitor is charged with a direct-current voltage by a rectifier. The

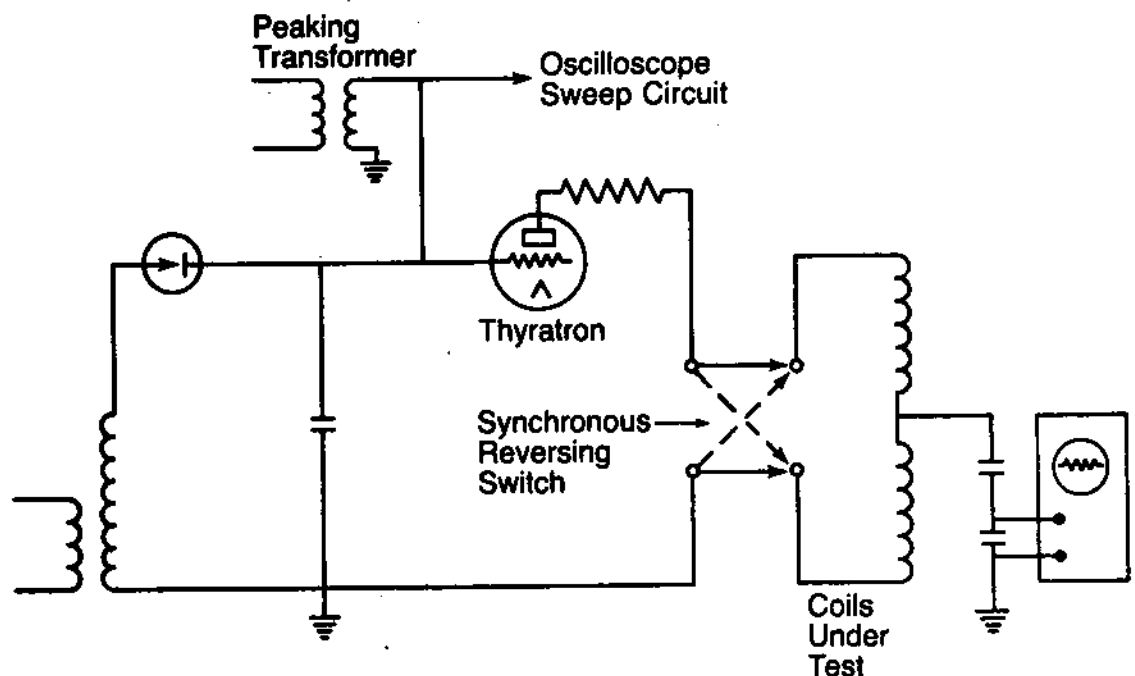


Fig. 24 - Simplified Diagram of a Surge Comparison Test Circuit

capacitor is discharged by the firing of a thyatron through the current limiting resistance and two similar coils which are in series. A commutating device alternately applies a surge to one end of the combination with the other end grounded and vice versa. An oscilloscope, through a voltage divider, displays the resulting surge alternately across each coil. Because the coating on the oscilloscope screen tends to retain an image, both traces are visible on the screen at the same time. When the coils are identical, the traces superimpose. When a short circuit exists, the traces differ. The extent of the difference depends on the number of turns in the coil, and the number of turns short circuited.

A peaking transformer initiates the firing of the thyatron as well as the sweep circuit of the oscilloscope.

The surge comparison test has a lower energy and total voltage output with a maximum of forty kilovolts peak, but with a more controllable voltage output than the spark gap oscillator. It is particularly useful on lower voltage machines.

Notice: Neither high frequency nor surge comparison tests are suitable for testing in the field. With a number of coils in series the magnitude of the high frequency or surge voltages is limited by the maximum voltage which may be applied to the ground insulation without exceeding the specified test voltage.

The equipment is also limited but this limitation can be overcome on completed windings only by applying an induced surge test one coil at a time as illustrated and diagramed in Figures 25 and 26.

c. Induced Surge Voltage Test

For field maintenance testing of windings, the induced surge voltage test can be used. In this test, a surge coil is placed over a coil in the winding, see Figure 25, and surge coil is connected to a surge generator, refer to Figure 26. Close magnetic coupling between the surge coil and the winding coil under test is obtained through use of the U shaped laminated iron cores which encircle the surge coil and span the core teeth on either side of the coil under test as shown in Figure 25. With good coupling, the volts per turn in the coil under test is almost the same as in the surge coil. An oscilloscope, with a voltage divider, will display the resulting surge voltage in the winding.

In addition to the voltage induced in the stator coil under the surge coil, voltage is also induced in the two other coils having one side in the same slots. These coils may be either in the same phase or different, depending on the winding arrangements. The surge pattern will repeat for successive slots in a winding. The voltage existing across the wind-

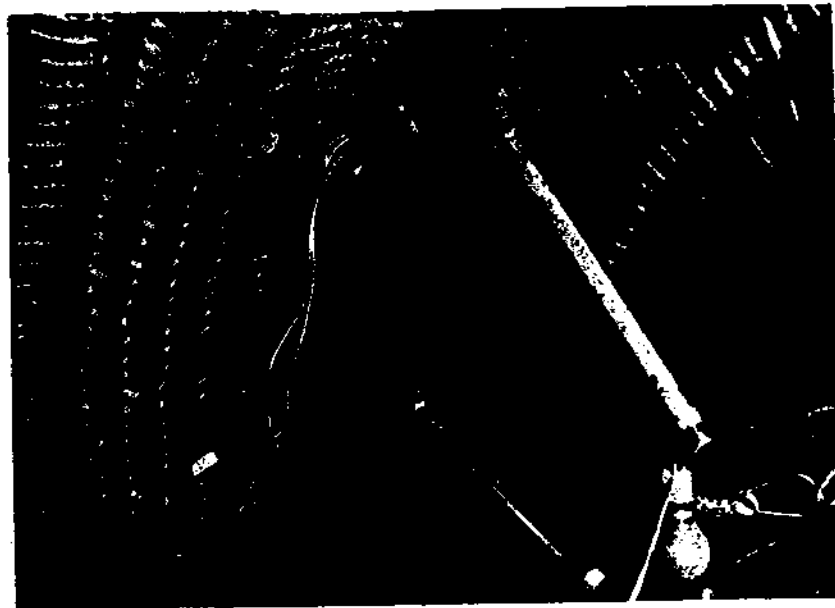


Fig. 25 – Induced Surge Voltage Winding Test Set Up

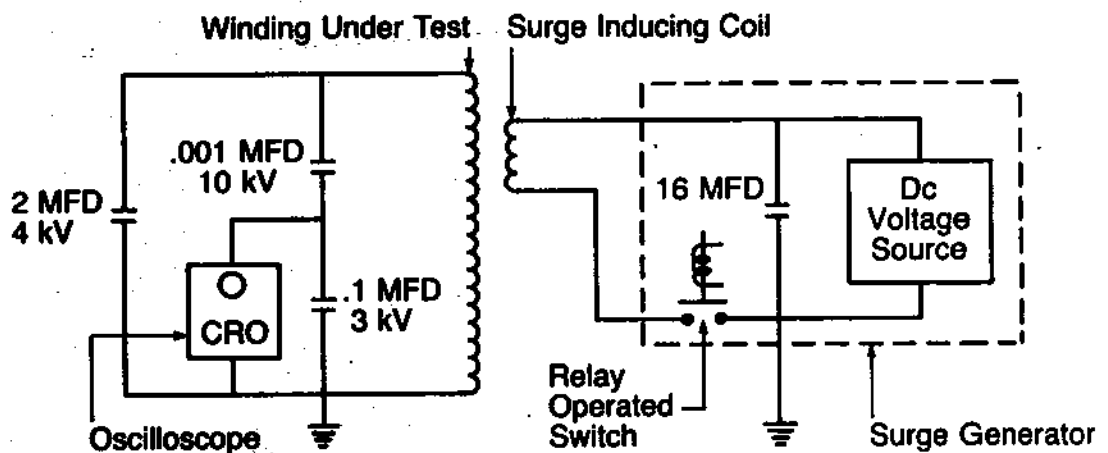


Fig. 26 – Induced Surge Test Method Schematic

ing will vary in a repetitive pattern as surge voltage is induced successively from coil to coil in the winding.

A short circuit in a coil under test markedly affects the voltage at the winding terminals and the indication is very definite. In making the test several levels of test voltage should be applied to each coil. This will give an indication of the voltage level at which failure occurs and more positively identifies the shorted coils. Figures 27 and 28 illustrate oscillograms of coils under induced surge voltage test.

Figure 29 shows the results of an induced surge voltage test on an 800 hp, 2400 volt synchronous motor. The coil numbers in boxes are those with indications of short circuits. Figure 30 shows the test being performed on a repaired motor.

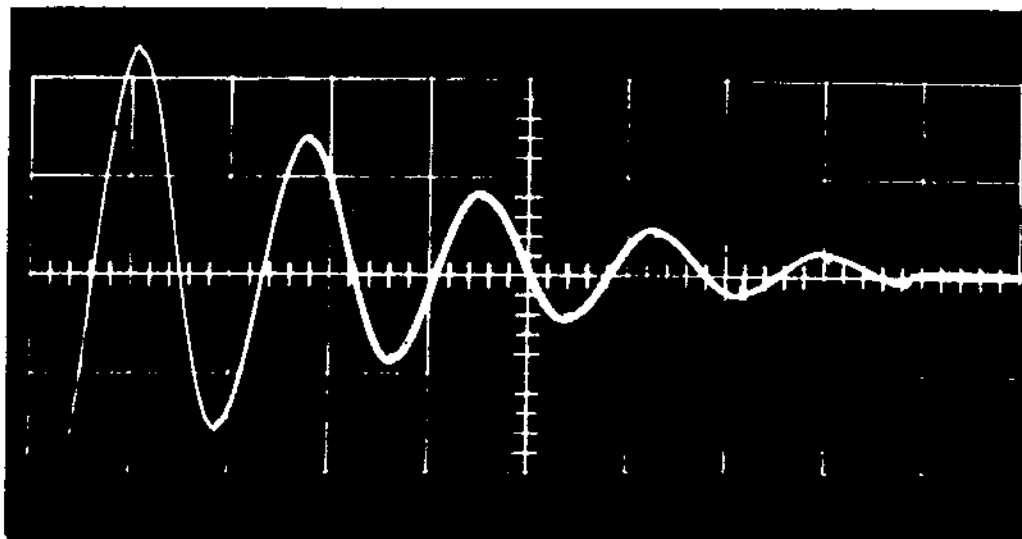


Fig. 27 – Typical Wave Form from a Good Coil Under Induced Surge Voltage Test

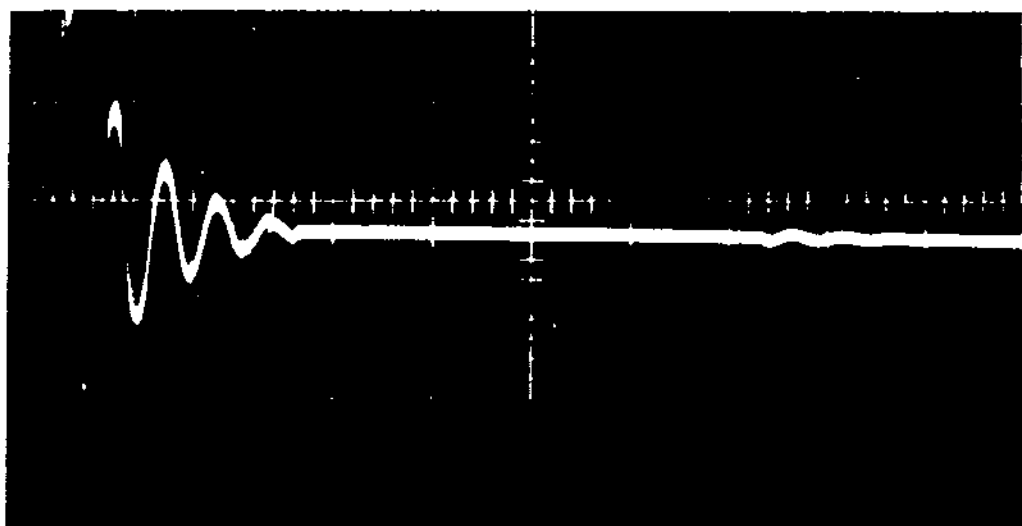


Fig. 28 – Wave Form of a Coil Under Induced Surge Voltage Test Having Shorted Turns

This test has been used in both shop and field and represents the most practical, portable method for making effective tests on conductor insulation of machines. Rotor removal is required for this test.

5. *Summary of Standard Testing*

Overall reliability of insulation of modern motors and generators is very high but the very high losses that result in industrial processes being shut down, make reassurances such as insulation testing economically sound.

Suitably searching tests can be made at regularly scheduled maintenance periods. Experience indicates that a considerable portion of failures are initiated by conductor insulation failure.

**Induced Surge Test
Stator of 800 Hp, 2400 Volt Synchronous Motor**

Phase	Coil	1400V	2800V	Coil	1400V	2800V	Coil	700V	1400V	2800V	Coil	700V	1400V	2800V	Coil	700V	1400V	2800V
B	1	1.1	2.2	37	1.3	2.6	73	1.0	1.9	1.3	145	.5	1.0	2.2	181	.6	1.2	2.4
B	2	1.5	3.1	38	1.6	3.2	74	1.1	2.6	1.5	146	.6	1.5	3.0	182	.6	1.4	2.8
B	3	1.0	2.0	39	1.6	3.0	75	1.0	2.5	1.6	147	.6	1.4	2.8	183	.5	1.1	2.2
A	4	1.4	2.7	40	1.0	2.4	76	1.5	2.8	.8	148	.6	1.4	2.8	184	.6	1.2	2.4
A	5	1.4	2.8	41	1.0	2.5	77	1.4	2.8	.8	149	.6	1.4	2.8	185	.6	1.2	2.4
C	6	1.2	2.7	42	1.6	3.0	78	1.0	2.5	1.5	150	.6	1.3	2.6	186	.6	1.3	2.6
C	7	1.1	2.1	43	1.6	3.2	79	1.2	2.8	1.6	151	.6	1.4	2.8	187	.7	1.4	2.8
C	8	1.2	2.4	44	1.3	2.6	80	.8	2.1	1.4	152	.6	1.3	2.6	188	Coil Cut Out		
B	9	1.5	2.9	45	1.2	2.6	81	1.1	2.5	1.0	153	.6	1.3	2.6	189	.6	1.2	2.4
B	10	1.4	2.9	46	1.0	2.3	82	1.2	2.6	1.0	154	.6	1.4	2.8	190	.4	.5	.6
A	11	1.2	2.5	47	1.5	2.9	83	1.1	2.5	1.3	155	.6	1.2	2.6	191	.6	1.2	2.4
A	12	1.2	2.7	48	1.6	3.0	84	1.2	2.6	1.6	156	.6	1.2	2.6	192	.7	1.4	2.8
C	13	1.3	2.6	49	1.0	2.3	85	1.0	2.3	.9	157	.6	1.2	2.4	193	.5	1.1	2.3
C	14	1.6	3.2	50	1.2	2.7	86	1.3	2.9	1.0	158	.7	1.5	3.0	194	.7	1.4	2.8
C	15	1.6	3.1	51	1.1	2.6	87	1.3	2.8	1.0	159	.7	1.5	3.0	195	.6	1.4	2.8
B	16	1.1	2.5	52	1.4	2.8	88	.9	2.2	1.6	160	.6	1.2	2.4	196	.6	1.2	2.4
B	17	.9	1.8	53	1.4	2.8	89	1.2	2.6	1.6	161	.6	1.2	2.5	197	.5	1.0	2.0
A	18	1.4	2.9	54	1.1	2.5	90	1.2	2.6	.9	162	.7	1.4	2.8	198	.6	1.2	2.4
A	19	1.5	3.0	55	1.1	2.7	91	1.3	2.9	1.0	163	.7	1.5	3.0	199	.6	1.3	2.8
A	20	1.4	2.7	56	.9	2.1	92	1.1	2.4	.5	164	.6	1.3	2.6	200	.5	.9	1.8
C	21	1.2	2.6	57	1.6	3.0	93	1.2	2.6	1.5	165	.6	1.2	2.4	201	.6	1.3	2.6
C	22	1.1	2.6	58	1.6	3.0	94	1.2	2.6	1.4	166	.6	1.2	2.4	202	.7	1.4	2.8
B	23	1.4	2.6	59	1.0	2.5	95	1.2	2.4	1.2	167	.6	1.3	2.6	203	.6	1.3	2.6
B	24	.5	.6	60	1.0	2.5	96	1.3	2.7	1.0	168	.6	1.3	2.8	204	.7	1.4	2.8
A	25	.9	2.0	61	1.4	2.8	97	.8	1.9	1.3	169	.5	1.1	2.2	205	.5	.9	1.8
A	26	1.3	2.8	62	1.7	3.3	98	1.3	2.8	1.7	170	.7	1.4	2.8	206	.6	1.3	2.6
A	27	1.2	2.6	63	1.6	3.0	99	.9	2.0	1.5	171	.6	1.2	2.4	207	.4	.5	.6
C	28	1.5	2.8	64	1.0	2.5	100	1.3	2.6	1.0	172	.6	1.3	2.6	208	.6	1.2	2.4
C	29	1.5	3.0	65	1.0	2.4	101	1.3	2.8	1.1	173	.6	1.3	2.6	209	.5	.9	1.9
B	30	1.1	2.5	66	1.6	3.2	102	1.1	2.5	1.5	174	.6	1.3	2.6	210	.7	1.4	2.8
B	31	1.1	2.0	67	1.7	3.3	103	1.3	2.8	1.7	175	.7	1.4	2.8	211	.7	1.5	3.0
B	32	1.0	2.2	68	1.3	2.6	104	1.0	2.4	1.5	176	.6	1.2	2.5	212	.4	.5	.6
A	33	1.5	3.0	69	1.0	2.4	105	1.3	2.5	1.2	177	.6	1.3	2.6	213	.6	1.3	2.6
A	34	1.5	2.9	70	1.0	2.4	106	.5	.6	1.2	178	.6	1.3	2.6	214	.6	1.3	1.6
C	35	1.0	1.1	71	1.5	2.8	107	.9	1.8	1.4	179	.6	1.2	2.4	215	.7	1.3	2.6
C	36	1.2	2.5	72	1.5	3.0	108	1.1	2.5	1.5	180	.6	1.3	2.6	216	.4	.5	.6

① Figures in these columns are the amplitude of the first peak of the surge observed on the oscilloscope. The voltage indicated at the top of the column is the surge induced in the coil under test.

Fig. 29 — Results of an Induced Surge Test on an 800 Hp, 2400 Volt Synchronous Machine

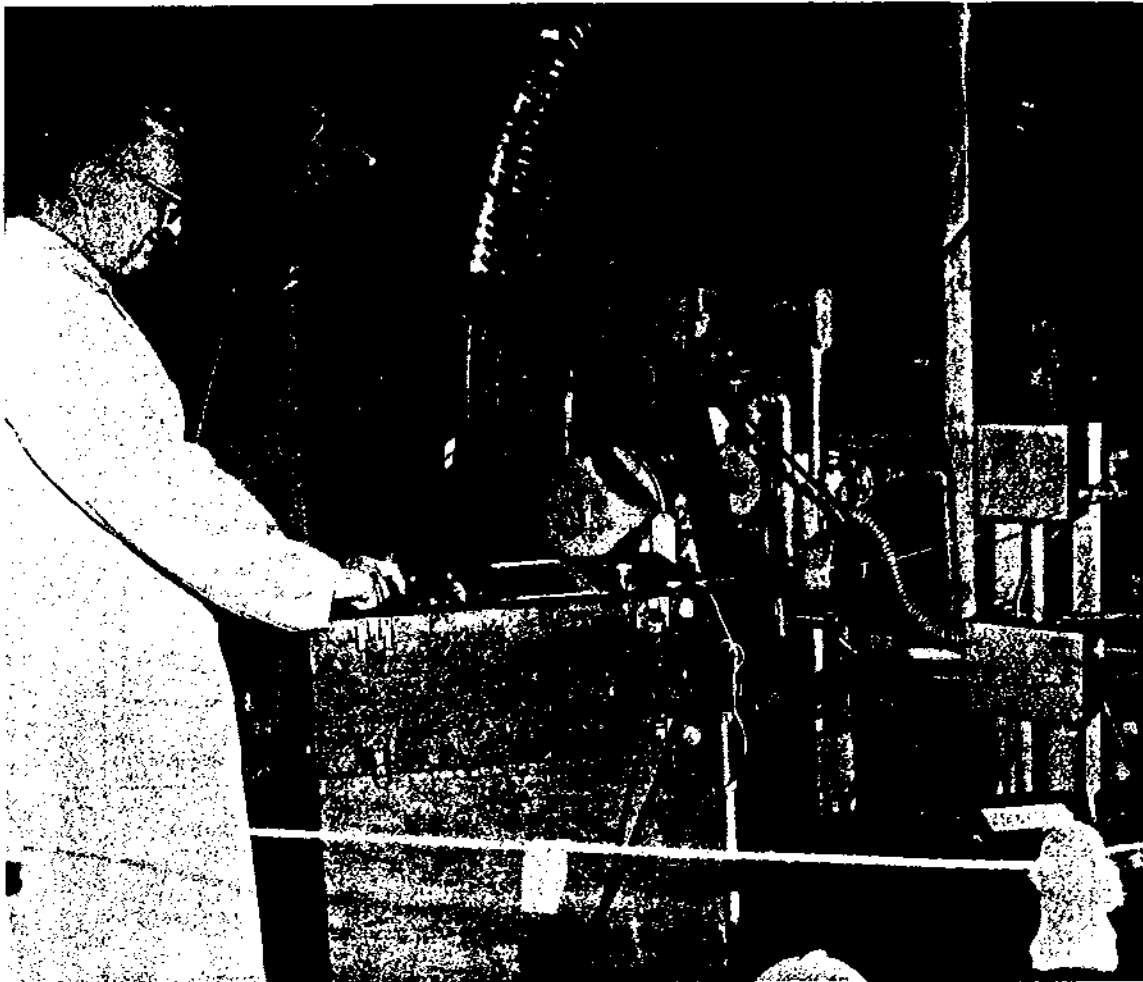


Fig. 30 – Surge Test Equipment In Use on a Repaired Motor

Comprehensive insulation tests should be conducted anytime a motor or generator is dis-assembled for cleaning and overhaul.

6. Other Tests

Other tests that should form a part of a maintenance program for large motors and generators are:

Insulation resistance tests on insulated stator core through-bolts, embedded winding temperature detectors, rotor and exciter windings.

Impedance tests on rotor windings. These test procedures are covered in specific detail in IEEE Std. 56-1977.

Notice: During static rotor testing with the rotor outside of the stator, care must be taken that the field poles are not in close proximity to any outside iron parts since the magnetic coupling with such stray parts can effect the test results. If the rotor is resting on a reinforced concrete floor such coupling can occur with the reinforcing rods or mesh within the concrete.

If a rotor has brushless excitation, the manufacturer's instructions should be reviewed carefully before making impedance tests.

Resistance measurements on rotor and stator windings and temperature detectors.

Cylindrical rotor short circuits between turns can often be detected by application of a potential of 120 volts, 60 hertz, to the collector rings. Flux distribution over the rotor body surface is detected by a special test coil connected to a galvanometer. The test coil is arranged to span adjacent rotor teeth. It is usually placed on the part of the rotor body close to the coil retaining rings. The magnitude and sign of the voltage in the coil for each pair of teeth is plotted. The flux pattern shows a significant change in magnitude and sign when a short circuit exists.

When an a-c voltage is applied to collector rings the induced voltage in the test coil can be read on a vector meter. An iron-cored coil is used on the rotor body or an air-cored coil may be used in the end windings.

Special tests are required on hollow conductor generators. These include resistance measurements between adjacent cooling tubes, between cooling tubes and winding copper, and air pressure tests to detect obstructions in cooling tubes.

Stator Core Interlaminar Insulation Test

When mechanical damage has short circuited core laminations, repair is recommended to restore the interlaminar insulation. Such repairs, involving insertion of mica splittings, grinding, and acid etching, require much time and are usually difficult. It is desirable to determine the need for and effectiveness of such repairs before undertaking the work. This can be done with a loop test.

In the performance of a loop test the actual volts per turn in the stator winding, and thus the core density, should be reproduced by the test loops where possible, a 5 per cent over-voltage is preferable when possible. Hot spots should be searched out by hand as soon as the power has been switched on and the thermocouples placed on any doubtful areas. The test should be continued for three to four hours (until temperatures stabilize) unless severe overheating occurs.

As a general rule, hot spots of 12 C or more above the average steady state readings require attention. Any damaged areas with lower tempera-

ture differences can safely be left untouched, providing it has been definitely established that the correct flux density has been attained on the test.

For a calculation of the ampere-turns required for the loop test, several machine constants are required and they should be obtained from the manufacturer. These constants are:

1. Stator voltage
2. Total number of stator slots
3. Number of turns per coil and
Number of coils per slot
4. Number of parallels in winding
5. Number of phases
6. Coil pitch
7. Number of poles
8. Outside diameter of core
9. Inside diameter of core (bore diameter)
10. Slot depth
11. Core density at rated voltage.

The ampere-turns required to magnetize the core at rated density can be taken from the following table:

Core Density Kilolines Per Sq. In.	Ampere-turns Per Inch of Core Mean Periphery
85	9
90	18
95	37
106	145

The mean periphery of the core is calculated:

$$\text{core mean periphery} = \left[\frac{\text{Core O.D.} + (\text{Core I.D.} + 2 \times \text{Slot Depth})}{2} \right] \pi$$

A search coil should also be placed around the core and the volts per turn checked. If any discrepancy exists between the measured ampere-turns and the search coil voltage, the latter should be used.

The search coil voltage is calculated:

$$\text{search coil voltage/turn} = \frac{\text{phase voltage}}{2 \times K_d \times K_p \times \text{turns per phase in series}}$$

$$\text{phase voltage} = \frac{\text{Line Voltage}}{\sqrt{3}} \text{ for star connected winding}$$

Distribution factor, $K_d = 0.955$ for 3 phase star or delta winding

Chord factor, $K_p = \text{Sine} \left(\frac{y}{mq} \times 90^\circ \right)$ where $y =$ coil pitch
 $m =$ no. of phases
 $q =$ slots per phase per pole

Turns per phase in series $= \frac{QN_s}{2 \text{ cm}},$

where $Q =$ no. of stator slots
 $N_s =$ no. of turns per slot
 $c =$ no. of parallels
 $m =$ no. of phases

While most of this information can be obtained from examination of the machine, the core density must be obtained from the manufacturer. Core density varies usually from 60 to 100 kilolines per square inch. If a test must be made before information from the manufacturer is available, 85 kilolines can be taken as an average value, but subject to later verification.

An alternate method of approximating the search coil voltage per turn is:

search coil voltage per turn $= \frac{4.44f B_c A_c}{10^5}$

where $f =$ frequency
 $B_c =$ core density
 $A_c =$ area of core

Area of core $A_c = (L_c - L_v) 0.95 \frac{(\text{core O.D.} - [\text{core I.D.} + 2 \text{ hs}])}{2}$

where O.D. = outside diameter of core
I.D. = inside diameter of core
hs = depth of slot
 $L_c =$ length of core
 $L_v =$ total length of vents

Determination of the number of turns and the cable capacity depends on the voltage supply available:

$$\text{No. of turns} = \frac{\text{voltage supply available}}{\text{search coil voltage}}$$

$$\text{Amperes required} = \frac{\text{total ampere turns}}{\text{No. of turns}}$$

For this short time duty, the following cable sizes are normally adequate:

Size AWG	Maximum Current Capacity. (short time rating)
10	60
8	80
6	105
4	135
2	160
0	189

It is recommended that the test turns be equally distributed around the core if this is convenient and kept as close to the laminations as possible.

When the search coil is energized, any hot spots due to short circuited laminations will be apparent in a few minutes.

Warning: Exercise extreme care in entering the core of a large machine with the exciting coil energized because voltage is induced between core ends producing risk of serious injury and damage due to electric shock.

8.10 Visual Inspection

Effectiveness of visual inspection is dependent on knowing where to look and what to look for. Some of the areas for inspection are indicated under 8.9, A. *Factors Affecting Insulation Life*.

Items which should be included in any visual inspection program are:

A. Stator Inspection

1. *Deterioration of coil insulation* due to thermal aging. Examination may reveal general puffiness and swelling into ventilation ducts.

A lack of firmness of the insulation indicates a loss of bond and a separation of insulation layers, from each other or from the coil conductors.

2. *An examination should be made for coil tape separation.* This is most likely to occur on long stator coils having asphaltic type bonds. Particular attention should be given to the areas immediately adjacent to the ends of the slots.

Where considerable cracking is found, it is recommended that the wedges at the ends of the slots be removed, as dangerous cracks may also have developed just within the slots. Consideration should be given to repair even if the defective coils have withstood overpotential tests.

3. *Inspection should be made for contamination* of coil and connection surfaces by substances which adversely affect insulation strength. Most commonly these are carbon dust, oil, and moisture.

4. *Abrasion or Contamination of Coil* and connection surfaces from airborne particles moving at high speed, or from chemicals. These effects are generally encountered in air cooled machines.

5. *Tightness of coil bracing* should be verified. This includes checking wedges and filler strips in stator slots and the various components of end winding bracing for looseness or movement. The end winding bracing structure should be kept as tight as possible. While a two or three mils movement between bracing members and the stator coil can be tolerated for resistance to short circuit forces, clearances of this order in larger machines can allow vibrations capable of abrading insulation.

6. *The parallel ring connection support structure* should be checked for tightness. Even slight looseness can lead to serious problems due to wear.

7. *Examination should be made for damage from corona or slot discharge.* This is less common in newer machines. It is often confused with light colored dust due to powdering of laminations and glass lashings on loose bracing members.

Corona damage on hydrogen cooled machines is most often minor. Stalactite and stalagmite build-ups may appear between top and bottom coil sides where they are connected in different phase groups, but this is usually confined to the surface paint.

It is self-limiting in a hydrogen atmosphere since it depends on oxides in the paint for propagation.

8. *Eroding effects of foreign substances* embedded in or lodged against insulation surfaces can be particularly damaging, as are magnetic particles which vibrate with the magnetic field in the machine.

9. *The stator core requires detailed examination.* The bore surface should be checked for looseness.

Laminations should be checked for evidences of burning which can lead to interlaminar short circuits.

Building bolts and through bolts should be examined for looseness. Bolt looseness, or weld breaks at the back of the core can usually be detected by the presence of iron oxide (rust).

Core looseness to the extent that breaking of parts seems likely, or where the noise level is excessive, should be reported to the machine manufacturer for recommended corrective measures.

10. *Bushings should be examined for leakage* or cracked porcelain. They should be cleaned to avoid extraneous leakage paths before making any direct-current overpotential tests.

B. Rotor Inspection

1. *The end windings* under the retaining rings should be examined for cleanliness, tightness of bracing, and possible coil movement.

Where end windings are dirty and have low insulation resistance, it may be necessary to clean them with a suitable solvent. This is particularly true of older air-cooled machines.

Warning: Avoid contact with solvent or breathing solvent vapors. These substances are highly toxic and readily absorbed into the system. Overexposure can result in serious illness or death from asphyxiation.

Cleaning should be done with care to prevent the solvent from carrying the dirt into inaccessible places. It is recommended that the rotor be tilted and one small area at a time be washed. Lower portions of the windings should be covered with fiber sheets so the contaminated solvent will run off. After cleaning, the windings can be dried by circulating a current of about 25 percent of full load through them.

2. *The rotor body* should be checked for loose or cracked wedges.

Balance weights should be tightly in place.

3. *Examination should be made for evidence of heating or current flow at the fit between the retaining rings and the rotor body.*
4. *The collector rings should be inspected for movement or breakage.*
5. *Journals and bearings should be examined for excessive wear, grooving, or circulating current effects. Bearing currents can be damaging. The voltage is measured between the shaft and ground at the collector end. Voltages are normally in the order of 0.2 to 10 volts. Refer to *Westinghouse Electrical Maintenance Hints, Volume 1, Chapter 9* for more complete information on bearings.*

C. Salient Pole Rotor Inspection

1. Inspect the damper winding and all of its interpole connections. The bars in the pole face slots should show no signs of any predominant movement toward one end of the pole. The bars must be sufficiently loose in the slots to allow for axial movement due to thermal expansion but not so loose that they can vibrate, since such vibration can lead to mechanical abrasion and/or fatigue of the bars.

The damper bars should be carefully examined for cracks or breaks. Often these can be detected by heating discoloration of the adjacent pole laminations caused by current in the bar by-passing the damaged area by flowing through the laminations. Such failures must be repaired as they will lead to larger problems.

2. The damper winding end connecting segments and the connections between poles should be examined for cracks and breaks. If the connections between poles are bolted, they should be checked for tightness and signs of heating. If heating has occurred, the affected joint should be opened, inspected and the contact surfaces cleaned of any corrosion.

3. Coil bracing between the field coils should be checked for mechanical integrity. Looseness can result in both mechanical and electrical problems. Contamination such as dirt, oil, moisture, carbon, etc. on the surfaces and parts of such bracing can provide creepage paths both between coils and between coil and ground. If cleaning is attempted, it must be done carefully so as not to move the contaminants into inaccessible areas from which they cannot be removed.

4. Field coil insulation parts such as top and bottom insulating washers should be carefully inspected for cracks and broken edges that could reduce creepage distance from the coil to the pole. Such damaged parts should be replaced with parts made of material with equal or greater temperature rating.

5. Connections between field coils and between field coils and collector rings should be carefully inspected for such things as loose joints, joints showing signs of heating, deteriorated insulation or mechanical supports, etc. In making any repairs, it should be recognized that parts will be subject to centrifugal forces and windage in operation. Parts must be adequately supported and all insulating tapes must be securely applied and anchored.

6. Pole attachments to the spider, whether bolts, dovetails, "T" tails, or other, should be carefully checked for tightness.

7. Collector rings should be checked for ring tightness (movement), condition of hub insulation and ring surface condition such as grooves, "hard" spots, out of roundness, etc. If the hub insulation has deteriorated, cleaning and repair must be done carefully to prevent entrapping dirt under the new insulation. The finish surface of any new hub insulation should be very smooth to reduce the adherence of dirt. If there is excessive carbon dust or ring grooving, the grade of brush should be investigated. "Hard" spots and out-of-roundness should be corrected by machining.

D. Brush Rigging Inspection

1. *Brush rigging should be examined for evidence of flashover.*

2. *Brush boxes should be checked before dis-assembly for clearance from the collector rings or commutator surface. These clearances should agree with the manufacturer's recommendation.*

Refer to *Westinghouse Electrical Maintenance Hints, Volume 2, Chapter 14, Commutator Care and Maintenance* for more detailed information.

Brushes should be free riding and there should be minimal carbon build-up.

3. *All brushes should be inspected for excessive edge chipping, grooving, or double facing.*

Brush shunt connections should be checked for broken strands and tightness.

8.11 Dis-assembly Procedures

Dismantling is almost a reversal of the assembly procedures given in the manufacturer's instruction book.

Particular attention should be given to:

1. *Mechanical alignment* of the generator or motor should be checked after breaking the coupling, to determine if re-alignment is necessary.
2. *After removal*, end brackets should be cleaned and made ready for re-assembly. All gaskets should be available before re-assembly begins.
3. *Gland seal rings* should be examined for excessive wear and replacement rings ordered immediately if needed.
4. *Bearing seats* should be inspected to assure that self-aligning bearings ride properly.
5. *The bearing bore* should be measured for excessive wear. Normal clearance is 2 mils per inch of diameter.
6. *Labyrinth bearing seals* should be checked for excessive clearance, especially if oil leakage is a problem.
7. *Bearings* should be inspected for loose or cracked babbitt and for signs of bearing currents. This check should be made as soon as possible to provide adequate time if re-babbitting is required. Reflectoscope tests may be made, if warranted.
8. *After re-assembly*, when the unit is returned to service, vibration checks should be made at each bearing. If vibration exceeds 1.5-2 mils, re-balancing is recommended.

Warning: Do not operate machines with excessive vibration, serious damage can result.

8.12 Routine Maintenance

Warning: Do not undertake maintenance work on an energized motor or generator. Make sure it is de-energized and will remain so during the work period. Failure to heed this warning can cause severe injury or death and damage to property.

Brush holder and collector ring assembly should be part of any routine maintenance, and replacement of brushes should be made when needed. During periodic brush changes, inspections should be made for surface condition, free movement in the holders, and edge chipping. Chipping can be caused if the brush boxes are more than $\frac{1}{8}$ inch from the commutator collector ring. Brush holders should also be checked for carbon

build-up and correct spring tension. Examination should be made for signs of looseness, flashover, or excessive heating.

Close examination of the collector rings should be made for any scoring, pitting, or unusual marks. Rings should be clean with no evidence of heating. The recommended care and maintenance of collector rings and brushes is covered in *Westinghouse Electrical Maintenance Hints, Volume 2, Chapter 14, Commutator Care and Maintenance*.

A check should always be made for accidental oil leakage. If found, it should be cleaned out immediately. This is especially important in generators with hollow conductors.

Water detector drain valves should be checked frequently.

Coolers when used, should be cleaned frequently. The manufacturer's instructions should be consulted for procedure and the amount of load which may be carried with part of the coolers out of service.

Air filters in the collector ventilating system must be kept clean.

8.13 Maintenance Records

Maintenance records are essential to an effective maintenance program. They should be completed in detail by the people making the inspection and doing the maintenance work. These records are what makes preventive maintenance possible. They provide the experience record that makes it possible to anticipate maintenance problems and prevent breakdown.

Parallel Operation of Direct-Current Generators and Direct-Current Motors

- Basic Requirements for Parallel Operation 2:9.1
- Paralleling Adjacent Machines 2:9.2
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- Series and Parallel Operation of D-C Motors 2:9.17

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Parallel Operation of Direct-Current Generators and Direct-Current Motors

Parallel Operation of D-C Generators

This treatment of the paralleling of direct-current machines is designed to give a basic knowledge of how it is accomplished and what to look for if paralleling problems are experienced. While this discussion limits itself to the low output range, the higher range machines respond to the same techniques.

9.1 Basic Requirements for Parallel Operation

A. The first requirement to obtain parallel operation is that each of the generators must run at a constant speed with any constant load. An extreme example of generators difficult to operate in parallel is generators driven by a single-cylinder, single-acting, low speed engine having a flywheel so small that the speed fluctuates periodically. When the speed increases, the generator voltage increases. This increases the load on that particular generator and decreases the load on other parallel generators. When the speed drops, the generator voltage and load drops and the load on the other parallel generators increases. The unstable generator will then cause the load to surge back and forth between machines.

Generators driven by turbines or by electric motors do not have this characteristic and can be paralleled with greater ease. Generators driven by reciprocating engines, steam, gas, diesel, or gasoline engines may present paralleling problems; but if the speed fluctuations are small and of high frequency, most generators will parallel satisfactorily. In all further discussion it will be assumed that each generator is driven at a speed that is constant when a given load is applied. Of course, decrease in speed of a generator due to increase of load also affects parallel operation by causing the voltage to decrease as the load increases. This will be allowed for, in all cases, by using the volt-ampere curve obtained by driving the generator by the proper motive power, rather than by driving it at a constant speed.

B. The second requisite to parallel operation is that each of the generators to be paralleled must tend to transfer its load to the other

machines. If this second necessary condition were always fulfilled the great majority of the paralleling troubles would be eliminated.

Each of the generators to be paralleled must be so designed and adjusted that, as the current between the points of paralleling and through its armature increases, its voltages (as read at the points of paralleling) must decrease materially. For this discussion, the points of paralleling will be defined as: the point at which the current flowing through the armature of a particular generator divides from the rest of the load current. In most, but not all cases, the points of paralleling are the points where the armature leads connect onto the equalizer line, or bus. If the required drooping volt-ampere characteristic is not present, a fair division of load may be obtained for a short time because an unstable condition is set up. Since load division will ultimately change even though the total load does not, one generator could eventually carry all the load and might even drive the other generator as a motor.

C. The third factor to obtain satisfactory parallel operation is the relative shape of the saturation curves of the generators being paralleled. To understand the possible division of load between units, the "no load" saturation curve of each should be plotted on a common graph, plotting armature terminal voltage against per cent field current. Use 100% as being the necessary field current to obtain rated voltage from each generator. When the curves are plotted, and they appear to have the same general shape, it will be possible to make other required adjustments and get satisfactory division of load. If the units do not have similar shaped saturation curves, steps should be taken to alter the main poles of the generators having less saturation. This should not be done without obtaining recommendations from the manufacturer.

If these three conditions are met, each generator will carry (without shifting) such loads as it is adjusted to carry. Ordinarily, only one adjustment is made on a shunt generator and that is by adjusting the shunt field. This is usually a permanent adjustment. Strengthening the series field of a generator has little effect on the division of load at light loads but makes that generator take a larger share of the load at the heavy loads.

9.2 Paralleling Adjacent Machines

Parallel operating systems normally fall into one of two classes. The most common one is where the generators to be paralleled are closely grouped, as in a power plant. In this case, the resistance of leads, buses, and equalizers is negligible. The second class is where the generators are widely separated and the resistance of the line connecting them appreciably affects the division of load. The resistance of any size of

equalizer that is necessary becomes so great as to make it impractical and causes it to be omitted. This is very common in mine railway systems and on installations where the load division is affected by changes in load at the point of paralleling.

The point of paralleling is the point of load division, in a paralleling circuit, at which the load current of a unit divides from the rest of the load on the system. When generators are to be operated in parallel, it is common to have an individual load carried by the unit most likely to be kept on the line. Often, two or more generators are paralleled for added load. Frequently the distribution center for the total load to be divided results in load conditions that are not equally divided by distance between armatures. The generators are subjected to shifts from one point to the other. When a constant output and division of load is required, adjustments are necessary as the load shifts.

On closely paralleled machines all the generators on the system must impress the same voltage at the points of paralleling. If volt-ampere curves are drawn for each generator at the proper excitation, including both shunt and series ampere turns, then on any curve the current and voltage values found at the point of paralleling must be the output that generator is delivering, and the sum of such currents for all generators must equal the load current. The separate generator currents, the load current, and the voltage all readjust themselves until these conditions prevail, since no other conditions are stable.

9.3 Shunt Generators

Typical curves of two shunt-wound generators are shown in Figure 1. Curve A is for a 50 kW, 250 volt generator with its shunt field adjusted to give rated voltage and current. Curve B is a similar curve for a 100 kW, 250 volt generator. It is evident that when two machines adjusted in this manner are paralleled through leads of negligible resistance and a total load of 600 amperes is applied, each machine will carry its rated load at 250 volts. However, with a load of 300 amps, generator A would carry 125 amps at 281 volts and generator B would carry 175 amps at 281 volts. If the field rheostat of generator A is changed until the new Curve A₁ is produced when 300 amps total load is applied, each generator will carry half of its rated current. Then, when 600 amps total load is applied, one generator will carry more and one less than its rated current. Generator A will be carrying 175 amps at 244 volts and generator B, 425 amps at 244 volts.

If the two generators, adjusted to give curves A and B, Figure 1, are paralleled and carry a total load of 600 amps, each generator is carrying its rated current. Then, if due to a momentary change of speed the

smaller generator carries 250 amps, its voltage will drop to 225 volts. The voltage of the other machine will rise momentarily and the generator with the higher voltage will take on increased load and, the generator with the lower voltage will drop part of its load. This redistribution of load raises the voltage of the generator with the lower voltage, and decreases that of the other generator. Finally each generator will carry its rated current due to load balancing.

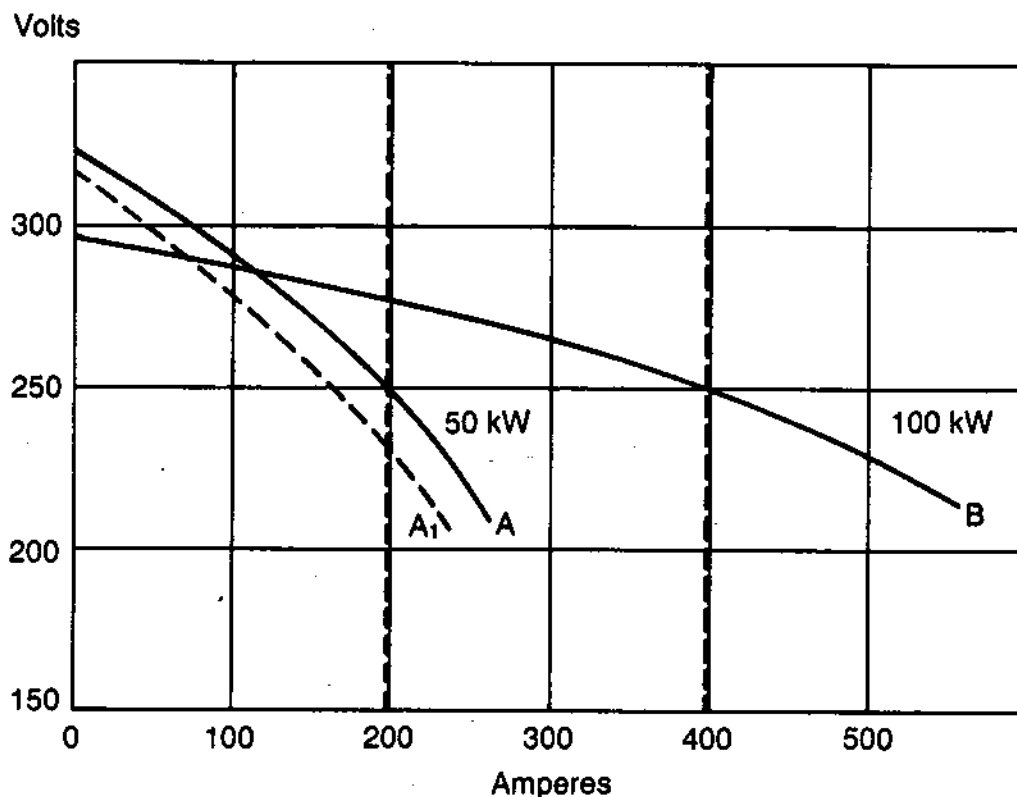


Fig. 1 – Typical Regulation Curves of Two Wound-Shunt Generators

If the generators had the characteristics as shown in Figure 2, instead of Figure 1, and the load momentarily becomes 250 amps on generator A and 350 amps on generator B; the difference of voltage between the two generators would be 7 volts instead of 33 as in the preceding case. It is obvious that the generators producing the greatest corrective voltage i.e., those of Figure 1 would be the first to redistribute their load properly and be most stable. In the case of the generators represented by Figure 2, a slight change in generator characteristics has extremely great effect on the division of load. A small change in the resistance of the field due to its heating up might change the one generator's curve from A to A₁. Under this condition the load would shift until generator B carried almost all of the load.

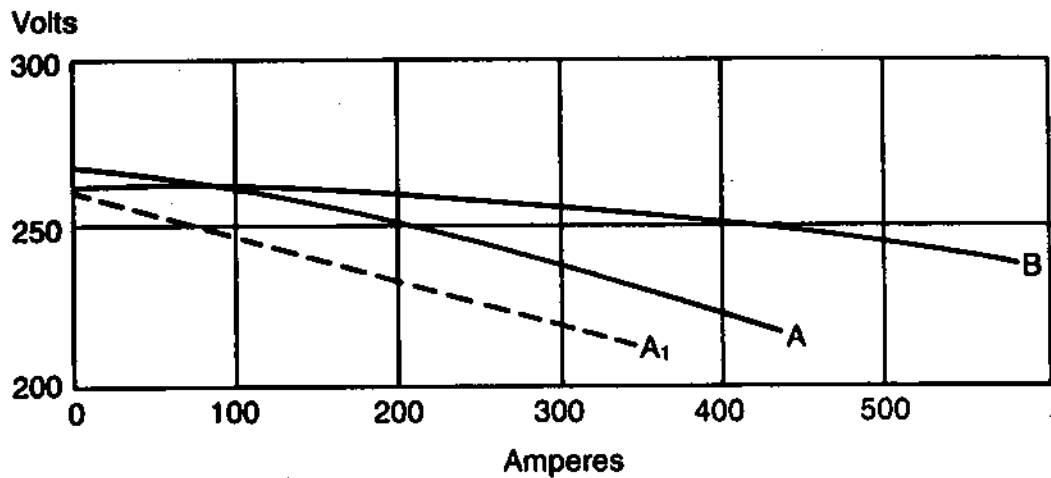


Fig. 2 – Less Drooping Curves of Shunt Generators

From this information the following conclusions may be drawn when two shunt-wound generators are paralleled by means of leads of negligible resistance:

1. If each generator has a regulation curve that is decidedly drooping, the generators may be satisfactorily paralleled.
2. The more drooping the curves, the more stable will be the division of load between the generators.
3. With drooping curves, there will be less division of the load effect by slight changes in a generator's curve.
4. The generators may be adjusted by means of field rheostats to give any division of load at any total load desired but, this division will be different at all other loads.

9.4 Compound Generators

Two compound generators connected in parallel in the usual manner are shown schematically in Figure 3. The generators are assumed to be close together with equalizer and buses so short their resistance is negligible.

The equalizer is used to keep points P1 and P2 (Figure 3) at the same potential. If the equalizer is not to be used the curves of the two generators would be as shown in Figure 4. Curve A is for a 50 kW, 250 volt generator, and curve B for a 100 kW, 250 volt generator. The points P3 and P4, P5 and P6 in Figure 3 are the points of paralleling, the equalizer connection being open and the curves taken between those points.

If a total load of 600 amps is put on the two machines each may, for a short time, carry the proper proportion of load, i.e., its rated load. However, eventually there will be some change, possibly in speed, that will cause one of the generators to momentarily carry more than its share of the load. If generator A was carrying only 100 amps and generator B carried 500 amps when this occurred then, the voltage of generator A would become 246 volts and that of generator B would become 249 volts. Therefore, generator B would keep taking more and more load until finally, it would not only carry all the load but, would also drive generator A as a differential compound motor. This is an extreme condition of parallel instability and causes differential compound motor operation which will surely result in a flashover. It should be noted that neither of these generators tends to shirk its load.

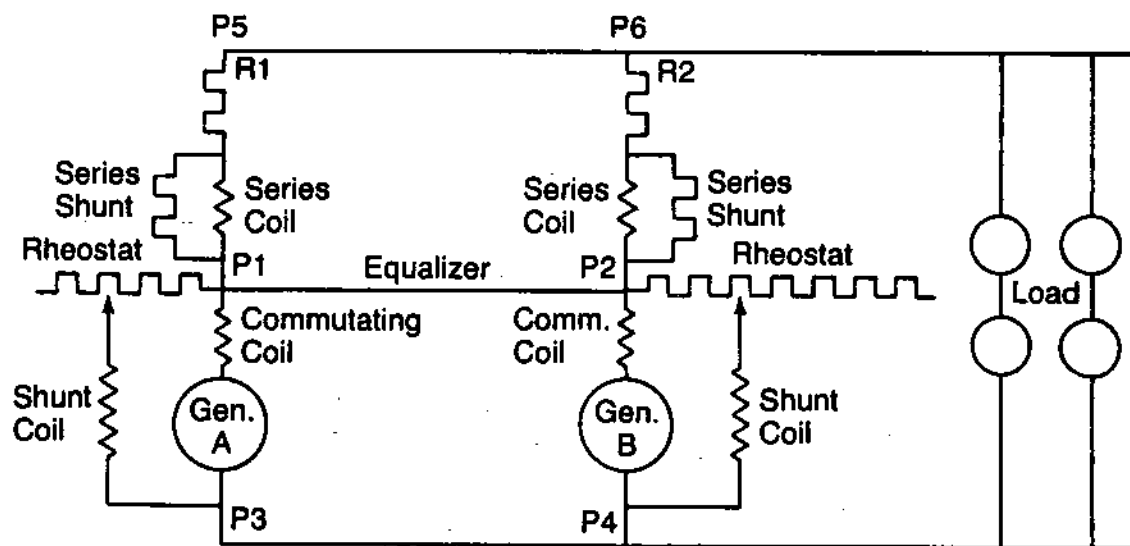


Fig. 3 – Connections for Compound Generators in Parallel, Generators Close Together

The proper method of adjusting these two generators for parallel operation is as follows:

1. Decide what regulation is desired. (Assume for example that it is 236 volts at no load, and 250 volts at full load).
2. Connect the equalizer between points P1 and P2 as shown in Figure 3.
3. Disconnect generator B from the line. Break connections between the generator and the lines at points P4 and P6, Figure 3.
4. Adjust the rheostat of generator A to obtain the desired no-load voltage (236 volts).

5. Adjust a shunt on the series field of generator A, if necessary, so with the same rheostat setting, the voltage of the generator at full load, will be the desired 250 volts.
6. Reconnect generator B to the lines as it was originally.
7. Repeat steps 3, 4, 5 after reconnecting generator B and disconnecting generator A. Adjust generator B as you did generator A.
8. Then, connect a total load approximately equal to the combined ratings of the generators. Leave all the adjustments just made unchanged, and measure the current flowing between points P1 and P5. Also, measure the current between points P2 and P6.
9. Finally, adjust a resistance in series with one of the series fields, R1 or R2, Figure 3, but not both, so the currents will divide between the fields in proportion to the ratings of the machines. In the case of the generators assumed, the resistance should be so adjusted that $\frac{1}{3}$ of the total current flows between P1 and P5, and $\frac{2}{3}$ between P2 and P6.
10. Check the division of load between the two generators. It should now be good.

Series Field Strength

It is apparent that the series field strength of each generator is independent of the load on that particular generator and depends only on the total load on the line. The series field then becomes, on each generator, a type of separate excitation that varies with the line load. The points P1, P2, P3, and P4 are then the real points of paralleling.

If each of the generators whose curves are shown in Figure 4 is equalized and properly adjusted for parallel operation with no-load voltages of 236 and full load of 250 volts, then, the new regulation curves of the generators will be those shown in Figure 5. It will be noted that there is a different curve for each generator for every different total line load.

Assuming the generators were adjusted as described with the total line load being 600 amps at 250 volts and, due to some transient condition, generator B was caused momentarily to carry 500 amps, the following things would happen:

1. The terminal voltage of generator A would rise to 284 volts.
2. The terminal voltage of generator B would drop to 230 volts.

3. A differential or corrective voltage is therefore produced.
4. Generator A tends to take more load.
5. Generator B tends to take less load.

This redistribution of load is continuous until both machines deliver the same terminal voltage when each generator carries its rated load as may be seen from the curves.

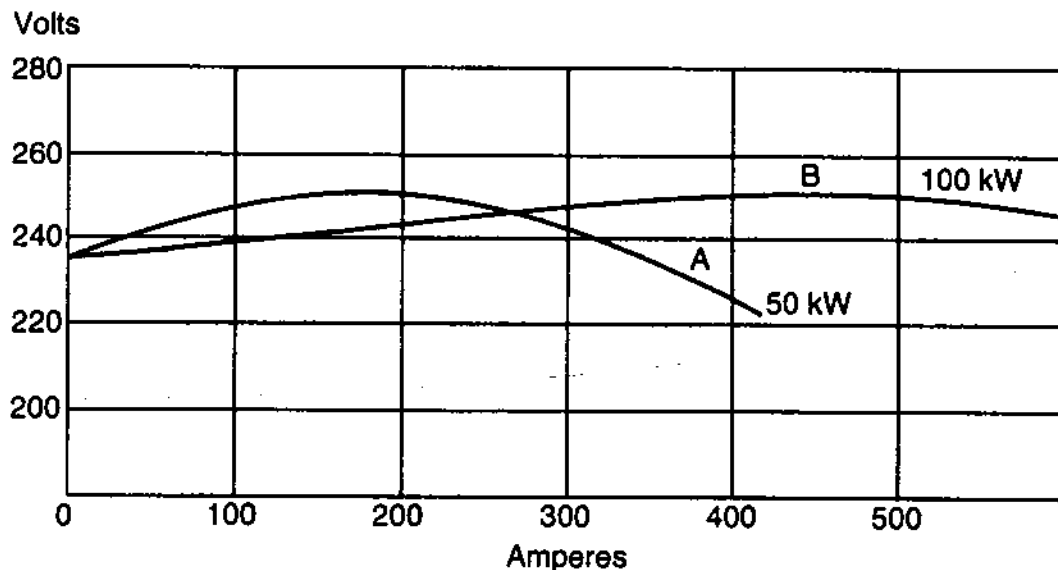


Fig. 4 - Regulation Curves of Two Compound-Wound Generators

9.5 Paralleling Compound Generators

Two compound generators, properly equalized, will operate well in parallel. It should be noted that if the effect of individual load only is considered each generator has a drooping volt-ampere curve. The generators then operate in parallel similar to shunt generators. All the conclusions drawn concerning shunt generators apply, except 9.3 No. 4 which does not apply. By making adjustments of the field rheostats, and of the series resistances, a compound generator can be made to divide the load properly at two different loads instead of one. Usually the adjustments are made for full load and for no load. This technique was used to obtain good operation in the parallel adjusting procedure stated above.

The volt-ampere curve taken at the points of paralleling must not only be drooping, it must be *decidedly* drooping. A few generators, particularly large compensated ones, may be found that do not characteristically have a decided droop. Before paralleling they must be changed to have significant droop. If two compound generators, with their series

fields cut out, will operate satisfactorily in parallel as shunt generators, they should also parallel satisfactorily as equalized compound generators when correctly adjusted. See Figure 5.

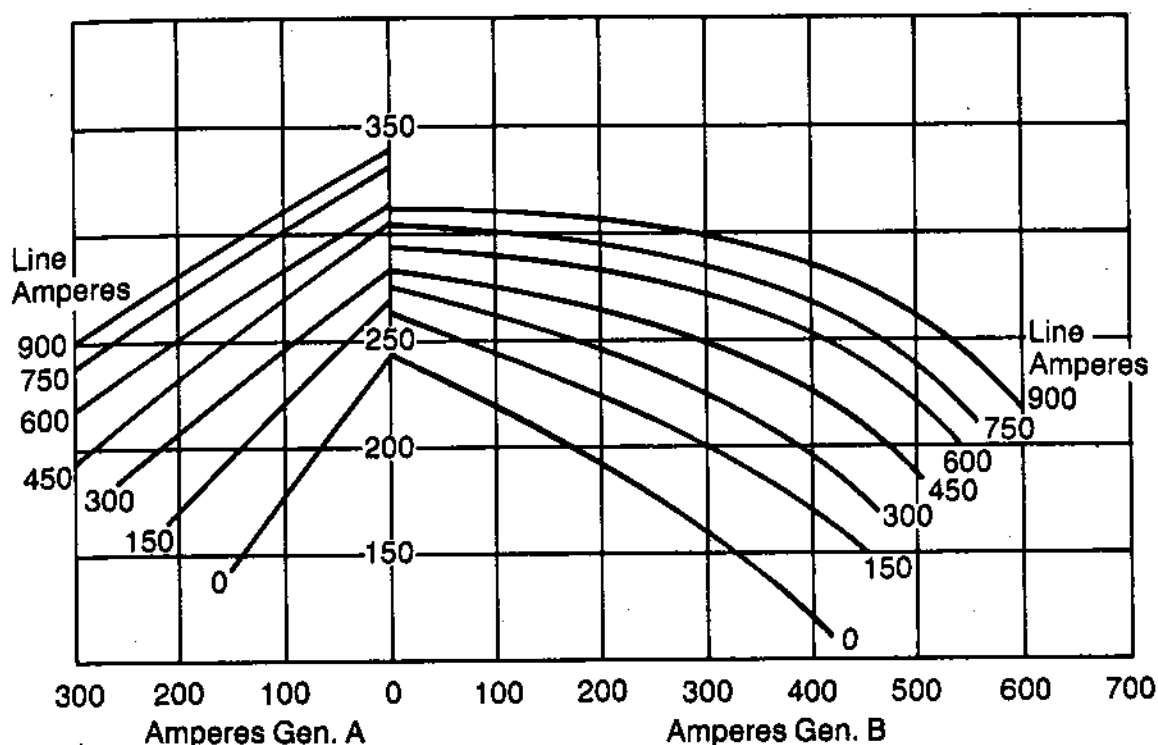


Fig. 5 - Regulation Curves of Two Compound-Wound Generators Which are Properly Paralleled

9.6 Paralleling Remote Generators

Two or more generators situated a considerable distance apart are often paralleled and connected to the same line to obtain sufficient power. This happens frequently in mining service, where one generator will be located at the mouth of the mine, and the other deep in the mine. The generators are so far apart that equalizers cannot be effectively and economically used.

A. Shunt Generator Applications

Assume that the two shunt-wound generators whose curves are shown in Figure 1 are connected to the opposite ends of a line. The total resistance, including the resistance of the wire in both sides of the line, is .2 ohms, distributed uniformly with respect to distance. Assume a total load of 600 amps is applied at a point midway between the generators. The field rheostat of generator A is adjusted so that each generator carries its rated amperes. Curves A and A₁ of Figure 6 show the regulation curves of generator A when adjusted. Curve A shows the regulation at

the generator and curve A_1 the regulation at the point of paralleling. In this case it is the center of the load, or the midpoint of the lines. Curves B and B_1 are similar curves for generator B. (Curves A and B are of theoretical interest only). The curves at the point of paralleling, A_1 and B_1 , are the ones that determine how the generators will parallel.

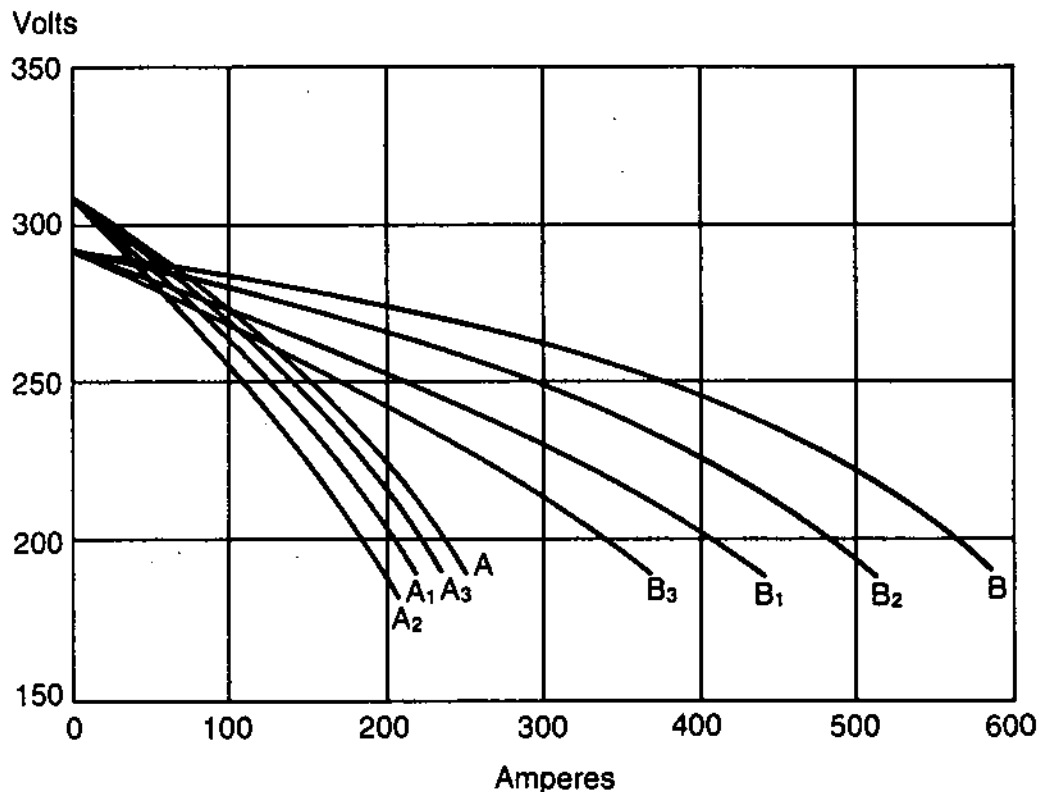


Fig. 6 – Regulation Curves of Two Shunt Generators Paralleled through Lines Having Appreciable Resistance

It should be noted that these curves are even more drooping than those of Figure 1. The generators should be expected to parallel even better than when located close together. This would be true if the load was always in a constant position. If the load moves to a point three times as far from generator A as from generator B the new curves at the point of paralleling would be A_2 and B_2 , Figure 6. With 600 amps load applied at this point, generator A will carry 165 amps and generator B will carry 435 amps. The voltage at the points of paralleling becomes 221 volts. If the load should move to a point three times as far from generator B as from generator A, the new curves at the points of paralleling would be A_3 and B_3 , Figure 6. Then with 600 amps load applied at this point, generator A will carry 230 amps and generator B will carry 370 amps. This indicates that although the resistance of the line makes the division of load more stable and causes it to change less with a change of the amount of load, the resistance also causes a division of load change as the position of load changes. As the load approaches either generator, that generator takes a larger and larger portion of the load.

B. Compound Generator Applications

Compound generators are more frequently used for this type of paralleling than are shunt generators. Figure 7 shows two compound generators in parallel.

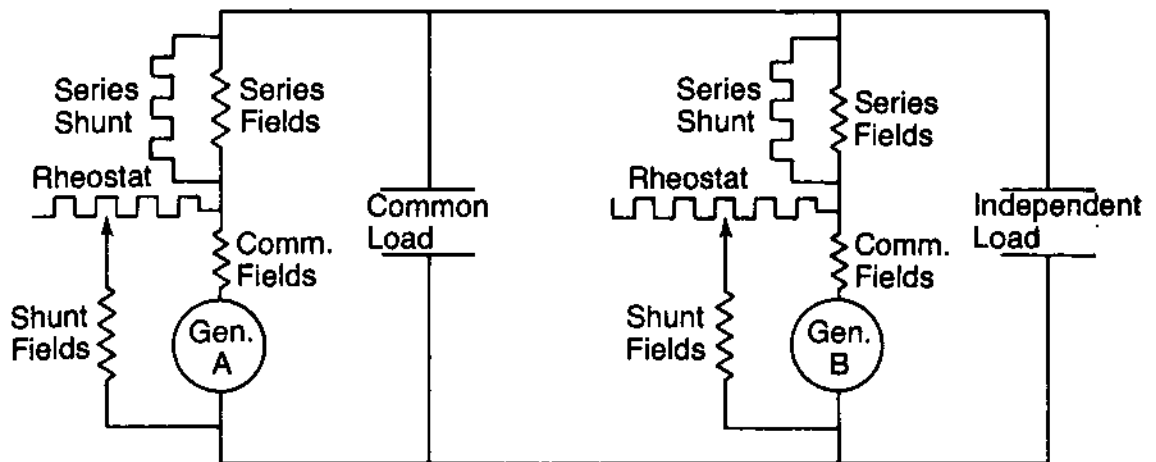


Fig. 7 – Connections for Compound Generators in Parallel, Generators at a Distance

An independent load is shown being placed on generator B but, an independent load may or may not exist. If generators A and B are the same as those whose curves are shown in Figure 4, and the generators are not equalized, the resistance of the line is negligible and there is no independent load; then the curves of the generators, taken at the points of paralleling, would be the same as the curves of Figure 4. Since there is no line drop the voltage at the point of paralleling, (or the center of the load) is evidently the same as the terminal voltage at each of the generators. The curves are rising, not drooping, and the division of load would not be stable.

Next assume that each of these generators is connected to the ends of a line with .2 ohms total resistance, and that the load is midway between the generators. The new curves obtained at the points of paralleling are curves A_1 and B_1 Figure 8. If a total load of 600 amps is applied at the midpoint it can be seen that the voltage at that point will be 217 volts. Generator A will be overloaded, carrying 288 amps, while generator B will be underloaded carrying 312 amps. It can also be seen that the curve of generator B taken at the points of paralleling is decidedly drooping. The division of load, therefore, probably would be stable, although not as stable as it would be if the Curve A_1 were more drooping. However, this division of load, where one generator carries more than its rated load and the other generator less than its rated load, is not as desirable as a division where neither generator is overloaded. It would be more desirable, to shunt current from the series field of generator A until the curve A'_1 , read at the points of paralleling, is obtained.

This curve shows that when a load of 600 amps is applied at the middle of the line, each generator will carry its rated current and, like curve B₁, it is decidedly drooping. When properly adjusted, and the load is concentrated at the middle of the line, the generators should operate well in parallel.

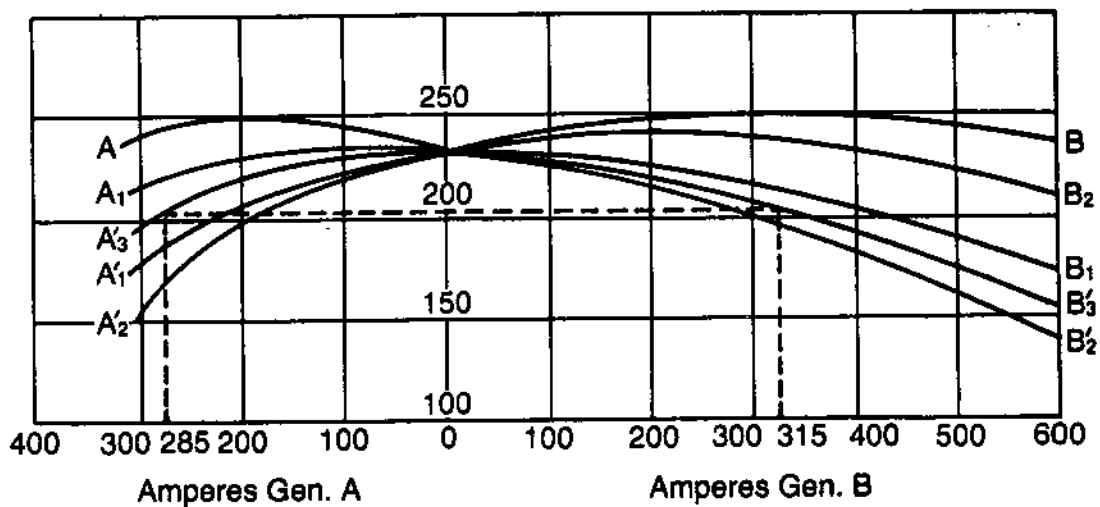


Fig. 8 - Regulation Curves of Two Compound Generators Paralleled through Lines having Appreciable Resistance

When the generators are adjusted for the load midpoint in the line and the load changes its position, the generator which it approaches will take more than its share of the load. If the generators are adjusted to give curves A_1 and B_1 when the load is midway between the generators, and the load should then move until it is three times as far from generator A as from generator B, the new curves at the points of paralleling would be curves A'_2 and B_2 of Figure 8. With 600 amps applied at this point, generator A will carry 90 amps and generator B will carry 510 amps. If the load should move to a point three times as far from generator B as from generator A, the new curves at the points of paralleling would be curves A'_3 and B'_3 of Figure 8. With a load of 600 amps applied at this point, generator A will carry 285 amps and generator B will carry 315 amps. (See dotted lines).

When the independent load shown in Figure 7 is applied, the problem becomes more complicated. Generator B is expected to carry all of the independent load and part of the common load. When both loads are on, and the two loads equal the combined rating of the two generators, then each generator is expected to carry its rated load. If the common load was only 500, instead of 600 amps, and the independent load was 100 amps then, the shunt on the series field of generator A should be adjusted so that it carried 200 amps of the common load and generator B carried 300 amps of it.

Another effect of the independent load should be noted. If two generators with an independent load are adjusted for the desired division of the common load then, when the magnitude of the independent load changes, the division of the common load will change. If generator B is undercompounded at the generator, an increase of the independent load will cause voltage from generator B to decrease, not only at the generator but at all points on the lines. The result will be that generator A will take a greater, and generator B a lesser portion of the common load. If generator B is overcompounded at its terminals, then the reverse is true. If it is flat compounded a change of independent load will have no effect on the division of the common load.

In paralleling two compound generators for operation with loads as shown in Figure 7 and under the conditions described above, follow this procedure:

1. Determine the average point of common load. This need only be approximate.
2. Determine the no-load and full-load voltages desired at the average point of common load (points of paralleling). The greater the decrease of voltage with increase of load, the more constant will be the division of load.
3. Determine the division of common load desired and the magnitude of the independent load to be used in adjusting.
4. Connect generator A to the line, and disconnect generator B.
5. Adjust the shunt-field rheostat of generator A to obtain the desired no-load voltage without common or independent load.
6. Then, apply the rated current load of generator A at the average point of common load. Adjust the shunt on the series field of generator A until the voltage reading at the point of load is the desired full-load voltage.
7. Next, remove the load and disconnect generator A from the line and connect generator B to the line.
8. Adjust the shunt-field rheostat of generator B to obtain the desired no-load voltage as was done in step 5.
9. Now, apply the independent load determined in 3 and, at the average point of common load, apply the portion of the full common load that generator B is to carry. Adjust the shunt on the series

field of generator B to obtain the desired full-load voltage at the average point of common load.

10. To check performance, put generator A back on the line, increase the common load to its full-load value, and check the division of load.

9.7 Using Voltage Regulators to Obtain Paralleling Voltage Load Characteristics

A shunt-wound generator and a compound-wound generator cannot be made to parallel satisfactorily for any length of time. Occasionally large units are involved and the cost and time involved to make a change would be prohibitive. Less cost is involved in applying voltage regulators equipped with IR drop compensation that will give regulator response for division of load. Voltage regulators, when applied to d-c generators, are used to secure voltage characteristics and paralleling results that cannot be readily obtained from the generators themselves. When regulators are applied, the generators no longer demonstrate their natural characteristics but follow the d-c system straight line characteristic imposed by the regulating system.

The problems in d-c systems are varied and complex, often requiring adjusting and readjusting. In many cases the voltage regulator provides an easy way out in making two or more dissimilar generators share their load.

Figure 9 shows a characteristic curve of a generator with the curve of the regulator system superimposed upon it.

The straight line A, represents an ideal voltage regulation system, without droop, up to a full load of 400 amps.

Curve B is typical of a shunt generator having an approximate droop of 8%.

Curve C would be typical of a regulated system controlled by a voltage regulator with an approximate droop of 4%.

When a fixed point of paralleling is established and a regulator using differential type of cross-current compensation is applied, the system regulation is corrected to that shown in curve D.

The curves BC and BD are shunt regulation curves of the generator and demonstrate how the regulator shifts the natural regulation of the generator by changing the shunt-field excitation.

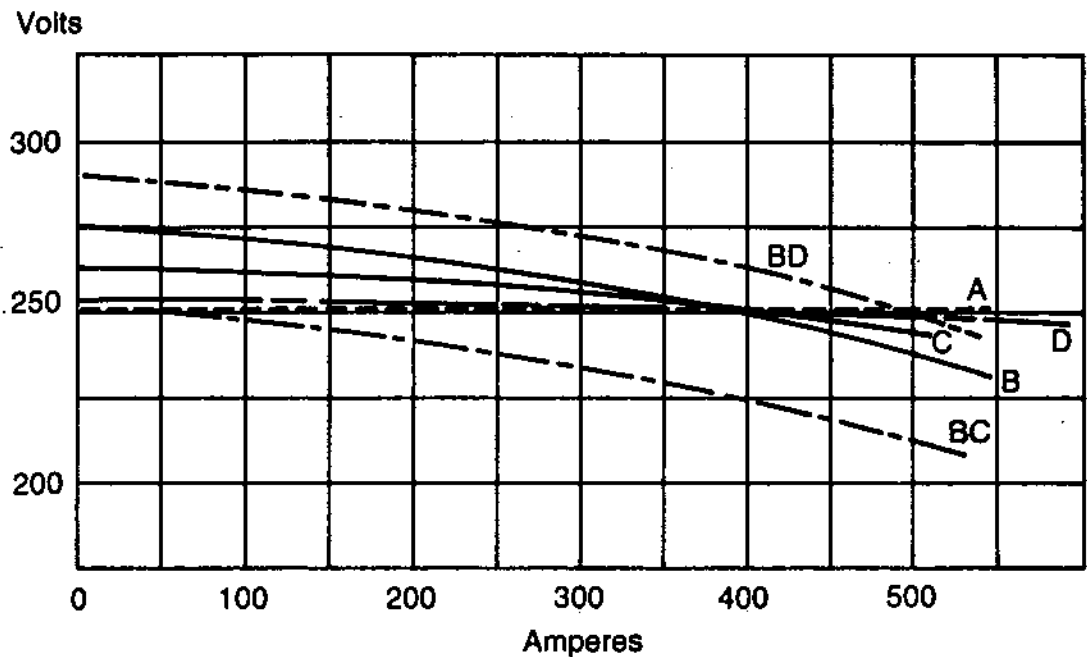


Fig. 9 – Characteristic Curve of Generator and Regulator System

Generators located far apart and having a shifting load center are difficult to adjust. The same generators with regulators have better characteristics. When the load center is fixed better results are obtained. An example of paralleling a group of compound-wound generators and a shunt-wound generator with a fixed load center is shown schematically in Figure 10.

Generators A, B, and C were 200 kW generators operating close together. Generator D was a 750 kW shunt-wound unit at a considerable distance from the group of compound-wound units.

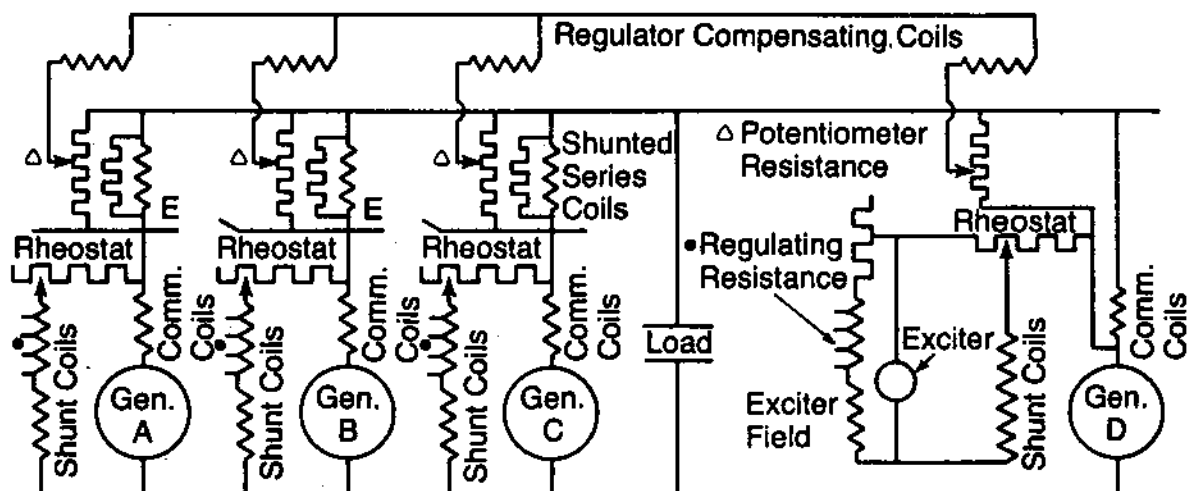


Fig. 10 – Compound-Wound and Shunt-Wound Generators in Parallel with Individual Voltage Regulators

This proves that voltage regulators can be used to obtain results that could not otherwise be secured. They make it fairly easy to adjust for various machine differences and system characteristics but, they cannot cure all of the troubles that arise or may be experienced on a d-c system.

9.8 Summary

If two shunt-wound, or two unequalized compound-wound generators are paralleled by means of lines of appreciable resistance, and a common load is applied between the generators, the following conditions will result:

If each generator has a curve that, read at the point of load, is decidedly drooping, the generators can be satisfactorily paralleled.

The more drooping the curves are, the more stable the division of load.

The division of the load can be affected by slight upward changes in a generator's curve.

Shunt generators may be adjusted by means of field rheostats to give any division of load at any total load desired but, this division may be different at all other loads.

Compound-wound generators can be adjusted by means of field rheostats and series shunts to give any desired division of load for any two total load settings. No load and full load are the two ranges at which adjustments are usually made.

A change in the location of the common load changes the division of that load.

If there is an independent load, a change in that load will probably change the division of the common load.

If the projected cost to change a group of shunt and compound-wound generators is too high, voltage regulators can be applied to each individual generator and its characteristics be made to follow that of the d-c system.

In this treatment the common load was assumed to be a concentrated load. If it is a distributed load, the curves referenced are no longer accurate. However, all conclusions remain unchanged, and the method of adjusting for parallel operation is not affected.

9.9 Series and Parallel Operation of D-C Motors

As the size of drives gets larger and more complex, it becomes necessary and desirable to use two or more motors to supply power for various reasons. Two motors may cost less and will have a lower inertia than a single larger motor and also may offer the possibility of interchangeability as a spare for several other motors in the drive. It may not be possible to physically accommodate a single larger motor, thus requiring the use of two smaller motors to drive the equipment.

This can be done by mechanically coupling the motors and by electrically connecting the motors in series or in parallel. Each of these methods has its advantages and disadvantages.

A. Motors in Series

Perhaps the most common two motor drive consists of connecting the armatures electrically in series as shown in Figure 11 and exciting the shunt fields from a constant potential exciter. The shaft extensions of the two motors must be coupled to a common load either by directly coupling the motors together or by gearing.

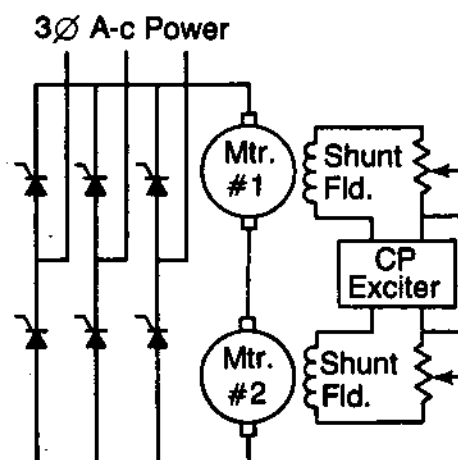


Fig. 11 - Motors Connected in Series

Successful load balance requires that the developed power be nearly the same for each motor. Where motors are connected in series, load balance depends upon having equal or nearly equal CEMF's (counter electromotive force) since the armature currents are the same. Since the motor speeds are the same, the CEMF's can be made the same by making the field fluxes equal. This can be done by adjusting the shunt field excitation properly, and the CEMF's will remain reasonably close to each other without the use of a regulator.

Normally when two motors are series connected, they will be two duplicate motors having the same rating. However in some instances two motors of unequal ratings can be series connected. Since the current ratings must be the same, the voltage ratings of the two motors must be so chosen that they are proportional to the horsepower. For example, suppose that it is required to have a 100 hp motor and a 200 hp motor series connected across a 500 volt bus. The current rating of each motor would be 487 amperes. The voltage rating of the 100 hp motor must be 167 volts and that of the 200 hp motor must be 333 volts. The disadvantage of connecting unequally rated motors in series is that it requires specially designed motors with non-standard voltage ratings.

Warning: Make sure both motors are coupled when installing motors connected in series. If power were applied to a drive with one motor un-coupled, the un-coupled motor would attain double speed and possibly fail.

The disadvantage of using motors connected in series is that the total load current must pass through four sets of brushes instead of only two resulting in higher brush maintenance and brush losses. The motors are operating at one-half line voltage resulting in lower motor efficiency.

B. Motors in Parallel

As the power required to drive a given application increases, it becomes evident that connecting motors in series results in either a voltage that is too high or excessive current. Also for sectional drives such as printing presses several motors are required to power the drive, and the series connection could not be used.

Another method used to maintain voltage and current requirements within conservative limits is the parallel connection of several motors. Four variations of the parallel connection are shown in Figures 15, 17, 18, and 19.

An example of this is the sectional printing press used in printing newspapers. In this case, the press sections and motors are so designed that the total inertia load and horsepower rating of the motors are balanced. The press can then be accelerated or decelerated at the maximum rate with a resulting minimum loss of time for change of rolls of paper, etc. Also, one or more sections can be dropped from operation without effecting the performance of the press as a whole. However, the torque produced by each motor must match that of each of the others within close limits throughout the complete cycle of operation in order that best performance can be obtained without overstressing any part of the press or tearing the paper.

It is known that shunt generators parallel easily, and therefore it is assumed that shunt motors likewise inherently parallel; but this is not the case. Shunt motors do not easily parallel but must be forced to bring successful paralleling about. Under Parallel Operation of D-C Generators, 9.1 A, it is stated "Each of the generators (motors) to be paralleled must tend to shirk its load"; i.e., it must tend to transfer its load to the other machine. It is also stated, "The importance of one thing concerning shunt-wound generators and equalized compound generators must not be forgotten. The volt-ampere (speed regulation) curve taken at the points of paralleling must not only be drooping, it must be decidedly drooping." These rules for successful parallel operation for generators apply equally for motors. Since shunt motors have flat or slightly drooping speed regulation curves, they will not parallel satisfactorily. On the other hand since series and compound wound motors do have decidedly drooping regulation curves, they will successfully parallel.

C. Motors With One Series Field

The manner in which two or more motors, when operated from the same power source and connected to the same load, will divide it between them is determined by their regulation curves. Figure 12 shows such a system using normal standard motors. Assume the series fields have been set to give 10% regulation in each case and the shunt field rheostats have been set so that all units carry 100% load at 100% speed.

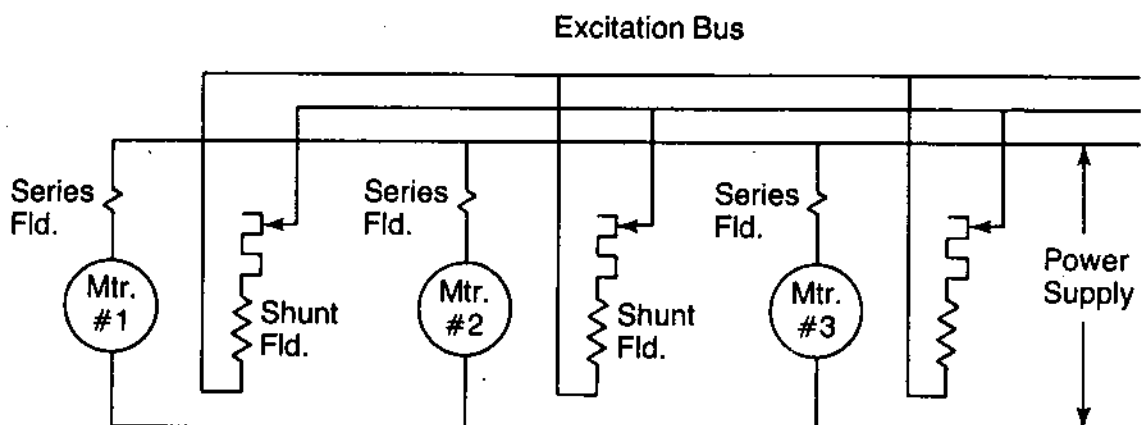


Fig. 12 – Connection Diagram; System With Only Cumulative Series

The regulation curves will then be as shown by the solid line curves shown in Figure 13. This system is then set up for parallel operation and it will function with good load division until some change takes place to upset the adjustment.

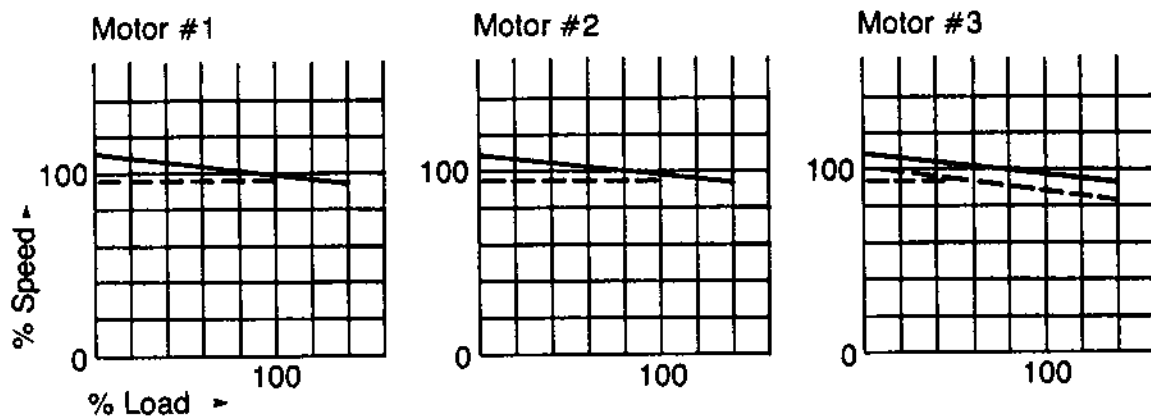


Fig. 13 - Regulation Curves with 10% Droop, System with Only Cumulative Series

To take an extreme case, and using the newspaper printing press as an example, suppose that motors #1 and #2 have been operating continuously and are up to temperature, but motor #3 has been idle and is therefore cold. In addition to this, assume that the effect of this temperature difference is such that the speed load curve of motor #3 is lowered 10%. This is shown by the dash curve for this motor in Figure 13. Now if pages are to be added to the paper and section #3 with its motor is connected into the press and electrical system, the loads will no longer be balanced. The press will operate at 97% speed, and motors #1 and #2 will carry 133% load each, while motor #3 will carry only 33% load. This is quite an unsatisfactory condition of operation as it would unduly stress parts of the press and would probably result in tearing the paper during the accelerating cycle.

Figure 14 illustrates the performance which would be obtained if instead of adjusting the series field for 10% regulation no load to full load, the design and adjustment had been such as to obtain 60% speed droop. In

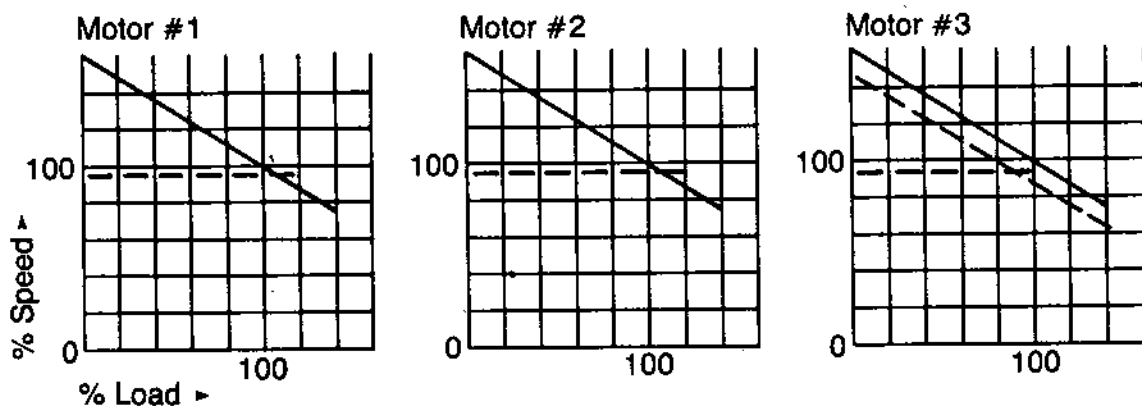


Fig. 14 - Regulation Curve with 60% Droop, System with Only Cumulative Series

this case, if section and motor #3 were added to the system cold, the load division is much better. Motors #1 and #2 would each carry 105.5% load and motor #3 would carry 89% load. The press again would operate at 97% speed. This would be good parallel operation.

However, a regulation of 60% is impossible to obtain if the motors are to be operated over a wide speed range by field control. This range is usually 4 to 1. Regulations of approximately 5% at full field and 15 to 20% at weak field are obtainable in shunt wound motors and result in good maintenance of speed with changes in load.

D. Motors With Two Series Fields

The problem then becomes one of obtaining heavily compounded motor performance for parallel operation while preserving the shunt wound motor characteristic for overall performance. This is obtained by using two series fields in each motor. If one series turn per pole is required to give the desired shunt motor characteristic and four series turns required to give the compound motor characteristic, then the motor is built having a cumulative series of four turns per pole and a differential series of three turns per pole. Figure 15 shows the connection diagram for such a system. The differential series coils are connected between the equalizer bus and one line and adjusted by means of series resistances so that they divide current between them in proportion to the rated current of their respective motors. The shunt field rheostats are then adjusted so that the motors divide the load in proportion to their respective ratings.

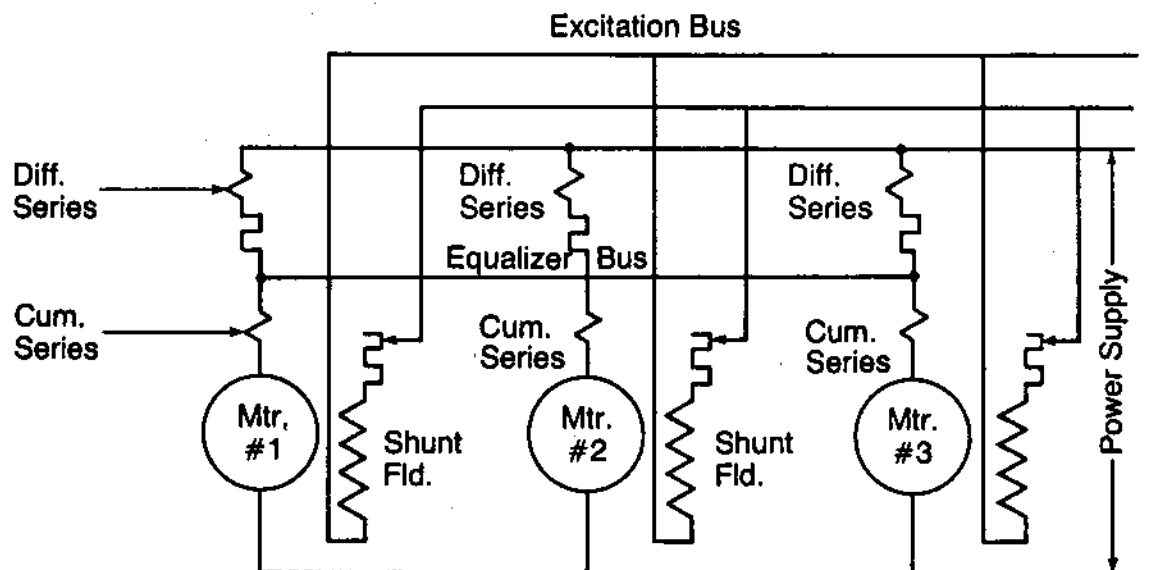


Fig. 15 – Connection Diagram with Cumulative and Differential Series Fields

Any variation in the current division between the differential series fields is compensated by the adjustment of the shunt field rheostat. It, therefore influences the matching of the characteristics of the motors, but division within $\pm 5\%$ is generally satisfactory and not particularly difficult to obtain. Since the voltage drops are low, it is sometimes found desirable to solder all connections to prevent change.

The system will then operate as a combined unit as though each motor driving its section of the press had a regulation curve as shown by the solid lines in Figure 16. However, the motors will divide the load (assuming operation at 100 percent load) as though each had a regulation as shown by the dash lines. This is true because for a given operating condition the power required to drive the press is practically constant. Therefore, current drawn from the power source is also practically constant. The differential series fields will then divide this current between them in proportion to the rating of their respective motors. This was a condition of the adjustment and since we have assumed 100% load operation, this will be rated current in each case.

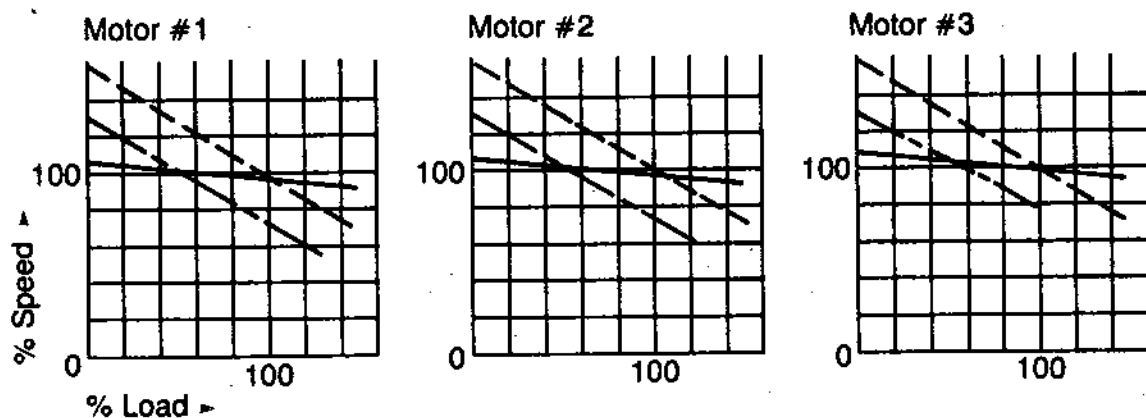


Fig. 16 - Regulation Curves with Cumulative and Differential Series Fields

The equalizer connection isolates the differential series portion of the circuit from that of the motor armatures and cumulative series fields and permits the current to divide in this part of the circuit according to the resulting regulation curve for each unit. Since the differential series field is constant, the combined effect of it and the shunt field is such that, if the motor were uncoupled, it would operate at 160% of full load speed. However, at full load current the cumulative series is such that the field is strengthened and the motor will operate at 100% speed. The motor armatures will, therefore, divide the load in accordance with the regulation curves shown by the dash lines in Figure 16. If the power requirements are reduced so that the total load is only 50% of the sum of the ratings of all the motors, then the resulting regulation curves for load division will be as shown by the dot-dash lines in Figure 16.

This method of paralleling motors has an advantage over the cross compounded connection in that it permits adding or removing motors from service with a minimum of switching required.

This system has also been used for drives having mixed horsepower rating. Care must be used in such cases to match the saturation curves, regulation curves with and without the differential series, and the shunt field design. When this is done, satisfactory performance is obtained.

Another method of using the cumulative and differential series field to obtain the heavily compounded characteristic for parallel operation while preserving the shunt wound motor characteristic for overall performance is shown in Figure 17. Here the series fields are cross compounded; i.e., the cumulative series field of motor #1 is connected in series with the differential series field of motor #2 and vice versa. Balancing of the series field resistances such as was required with the previous method is not required with the cross compounded connection.

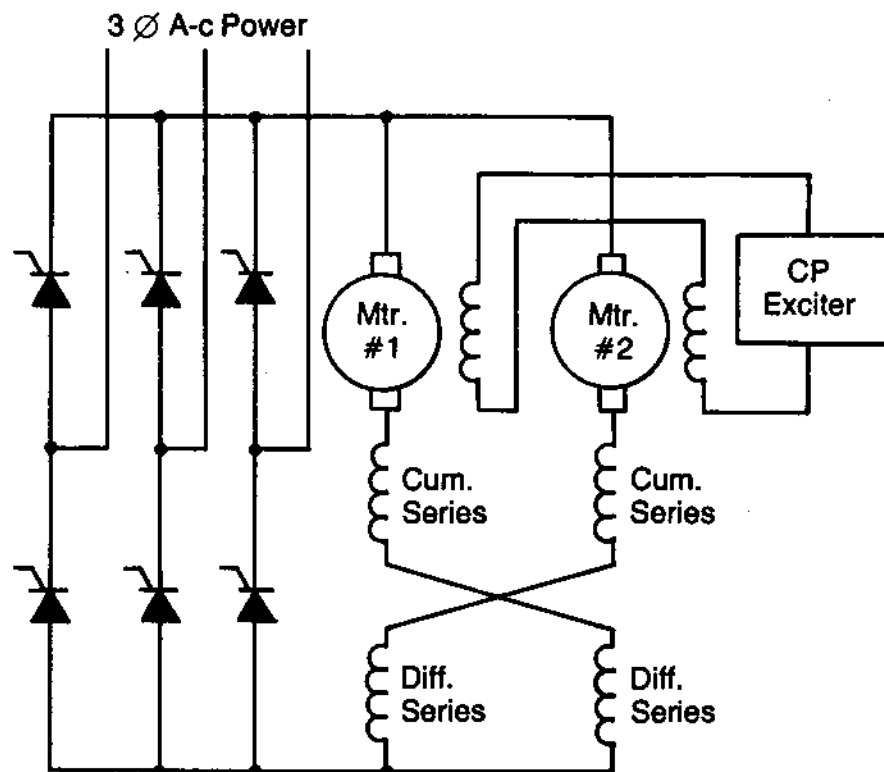


Fig. 17 - Motors Connected in Parallel with Cross-Compounded Series Fields

The cross compounded connection not only permits the introduction of a decided droop in the motor regulation curve by means of the cumulative series field; but it also exerts a forcing action in the second motor by

means of the differential series field. For example, assume that some disturbance causes motor #2 to hog the load. Due to a higher load current it would try to slow down through the strengthening action of its cumulative series field and at the same time strengthen the differential series field in motor #1. The cumulative series field in motor #1 will be weakened because of the hogging of load current by motor #2. The stronger differential series field in motor #1 combined with a weaker cumulative series field in motor #1 results in a definitely weakened net main field flux in motor #1 trying to make it increase speed and take more load. The effect is a shift in load from motor #2 to motor #1 providing good load sharing between the motors.

Both of these connections for paralleling motors provide good load balance without the use of any regulators or load balance control. The cross compounded connection is more forceful in its action and would be more suitable under transient conditions. In both cases special motors with double series fields are required.

An alternative to these two methods which employ the double series field is a regulated power supply for each motor field with load balance control. The circuit diagram is shown in Figure 18.

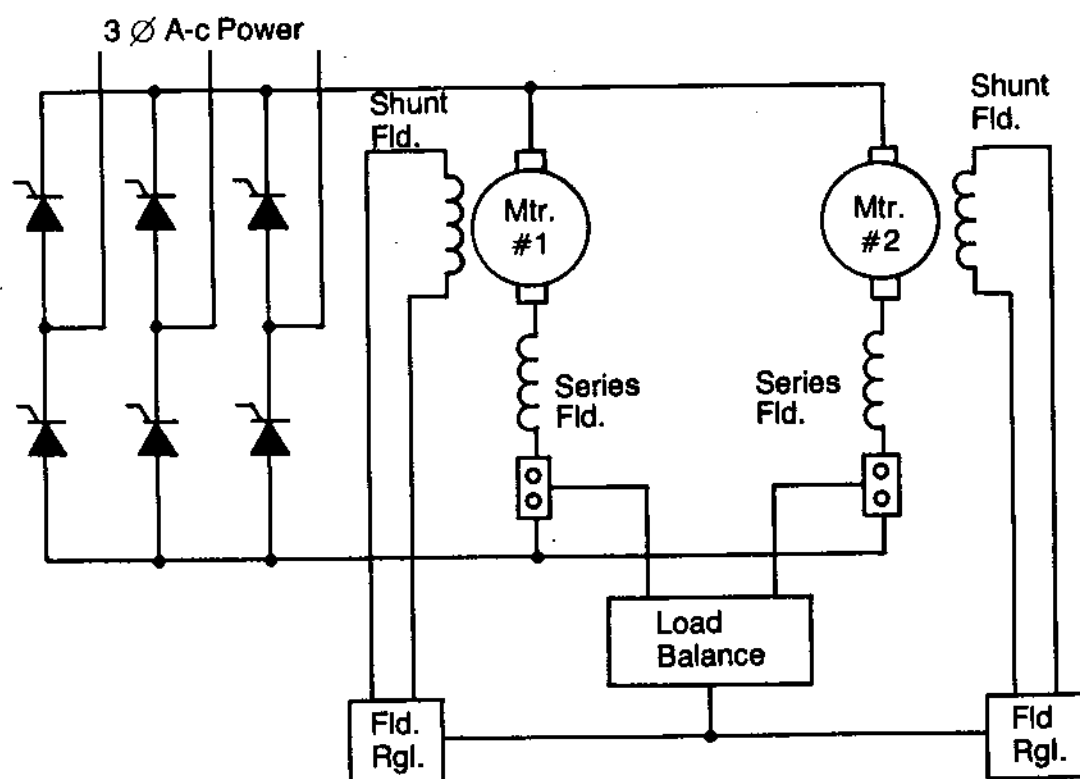


Fig. 18 – Motors Connected in Parallel with Field Regulators and Load Balance Control

The use of this method of sharing in lieu of the double series field would have to be decided by a comparison of costs as well as the degree of load balance required. The regulator would of course provide better load balance.

In the parallel operation of motors the terminal voltages are the same and load division is accomplished by equally dividing the armature current. In the series operation of motors the armature currents are equal and load division is accomplished by equally dividing the terminal voltage. In both cases the division of load is obtained by slight changes in the motor CEMF through the medium of the field flux and field current.

Load balance is taken care of by armature voltage control operating on the individual armature circuit of each motor. However since two thyristor power supplies are required, this method may be the most expensive.

The motors required with these latter two methods which use thyristor power supplies for load balance are standard motors and do not require any special fields.

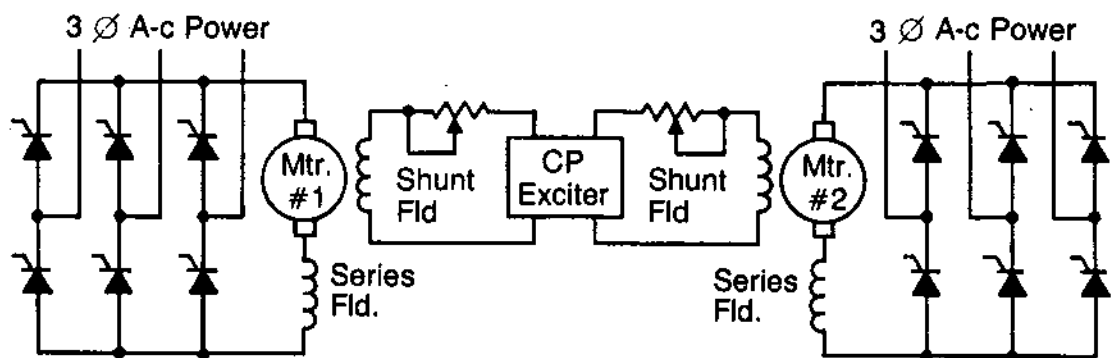


Fig. 19 - Separate Power Supply for Each Motor

D-C Machines and Regulated Drives

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

D-C Machines and Regulated Drives

Direct-current motors are the most frequently used driving means in adjustable speed drives because of their inherent ease of control and flexibility. They can be made to perform exacting functions by means of their own operating characteristics or in combination with a suitable regulating system.

It is important that maintenance people have a knowledge of the operating characteristics of d-c machines so an understanding of performance can help in maintaining optimum service. To maintain a drive system, it is necessary to have a thorough understanding of the drive characteristics and functions. It is necessary to understand if the required performance is obtained through the inherent characteristics of the machines or through the regulator system. This requires a familiarity with the performance characteristics of direct-current motors and generators and their advantages and limitations.

The drive manufacturers instructions should be carefully studied and an understanding of the total system attained before any maintenance work is undertaken.

10.1 General Performance

Figure 1 illustrates schematically the operation of a d-c generator, Figure 2 the operation of a d-c motor. To simplify the illustration only half of each machine is shown and only one brush is indicated. The direction of induced voltage in the armature conductors is indicated by arrows.

The relations of the direction of the magnetic field, the motion of the conductor and the direction of the induced electromotive force and resulting current are known as *Fleming's Right Hand Rule*.

The relations of the direction of the magnetic field, the direction of the current in the conductor, and the direction of the force and resulting motion are determined by *Fleming's Left Hand Rule for Motors*, which is stated as follows: point the forefinger of the left hand in the direction of the magnetic lines, the middle finger in the direction of the current, and the thumb will point the direction of the force or the direction the conductor tends to move. This is illustrated in Figure 3.

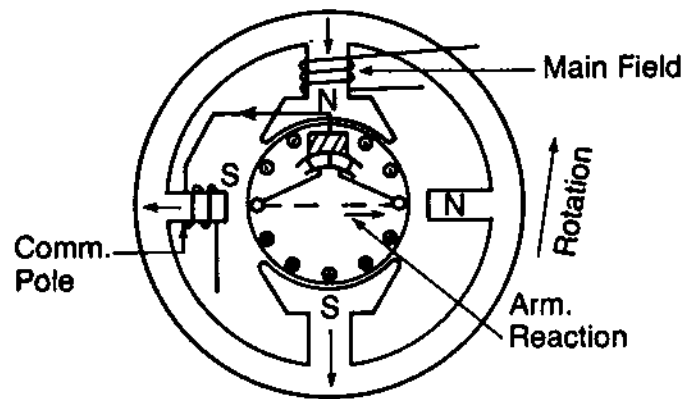


Fig. 1 – Flow of Current in D-C Generators

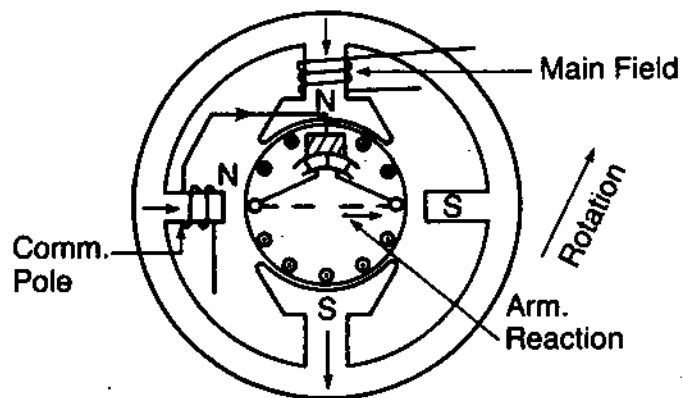


Fig. 2 – Flow of Current in D-C Motors

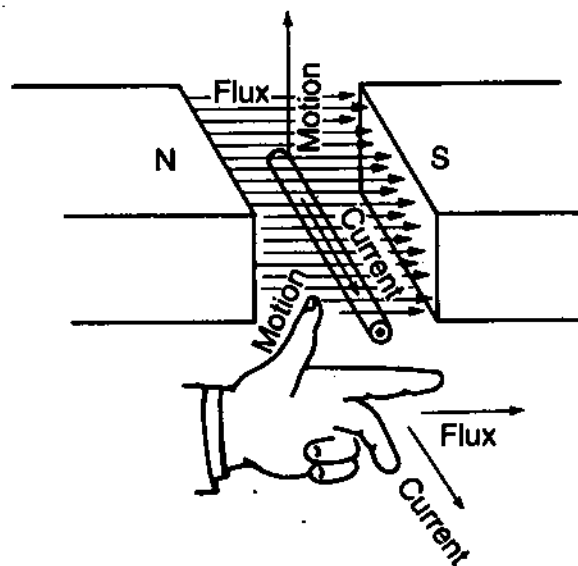


Fig. 3 – Fleming's Left-Hand Rule for Motors

The armature coils being commutated by the brushes are in the zone of the commutating pole flux. No arrows are shown for these conductors in Figures 1 and 2 since the flow depends on a number of factors to be covered later.

The performance of a d-c machine is determined by the following effects (ignoring the effect of IR drop):

Flux in the main poles produced by the shunt or series field, or a combination.

Magnetic distortion produced by the ampere turns of the armature conductors, which change unbalanced saturation in the pole tips and teeth.

Commutating pole flux produced by the difference in ampere turns of the commutating winding and the armature conductors.

Eddy current effects in the solid frame during transient conditions.

Flux effect due to compensating windings on field poles in larger machines.

10.2 Main Flux

The saturation of the iron in a d-c machine is a major consideration. The saturation curve of a machine reveals the relationship between the flux entering the armature from the main pole and the ampere turns required on the pole to produce this flux. When iron is unsaturated, the ratio between the amount of flux and the ampere turns is linear; an increase in the number of ampere turns produces a corresponding increase in flux in the pole. As the flux density in the magnetic circuit increases, the iron begins to saturate, and the increase in flux resulting from an increase in ampere turns becomes less.

The degree of saturation is usually expressed in terms of the *saturation ratio*, (also commonly referred to as the slope-ratio) which is the slope of the saturation curve at the point in question divided by the slope of the linear unsaturated curve (called the air gap line). A typical saturation curve of a d-c machine is shown in Figure 4. The saturation ration may also be expressed by the following equation:

$$\text{Saturation Ratio} = \frac{E_o}{E_N}$$

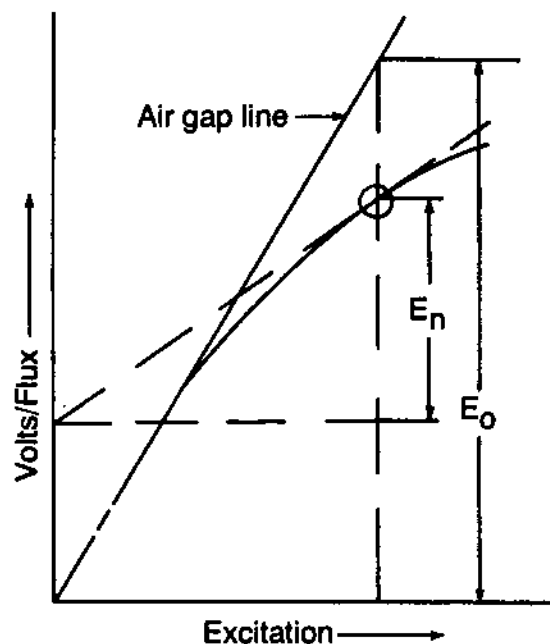


Fig. 4 – Typical Saturation Curve of a D-C Machine

This ratio may vary from two to six depending upon the application of the machine. For non-regulated drives, the saturation ratio should be as high as possible without overheating the field because this produces maximum machine rating with the least material. For regulated drives, it is essential that the saturation be as low as possible, especially where fast response is required. For such applications, the saturation ratio for generators should not exceed 2.5 to assure good regulator performance over the whole voltage range.

Specification of the saturation ratio should be determined for each application to give the best overall performance with the least equipment. For motors with a 4 to 1 speed ratio, the saturation ratio may be as high as 6 to 1 at base speed.

10.3 Armature Reaction

The ampere turns of the armature conductors produce a cross flux as illustrated in Figure 5. This cross flux is at right angles to the main flux and superimposed on it. Their effect is additive at the left pole tip and differential on the right as shown in Figure 6.

The main flux is spread as a constant value over the whole pole face, while the armature ampere turns are symmetrical with respect to the pole center line. Because of saturation, the increase in flux at the left side is smaller than the decrease at the right side so the total flux is smaller.

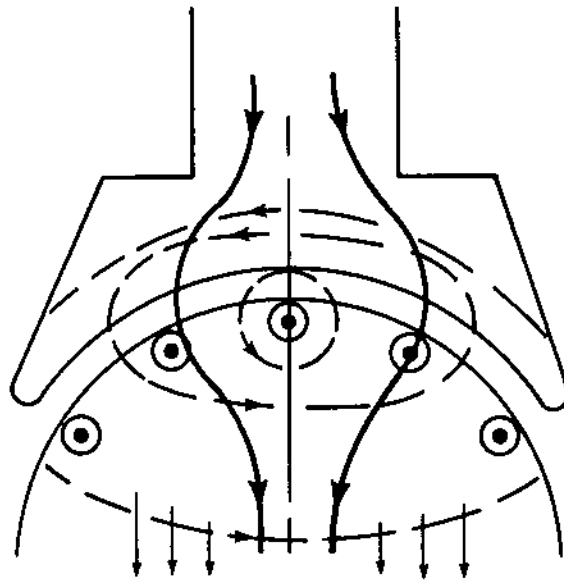


Fig. 5 – Ampere-Turns of Armature Conductors Produce a Cross Flux

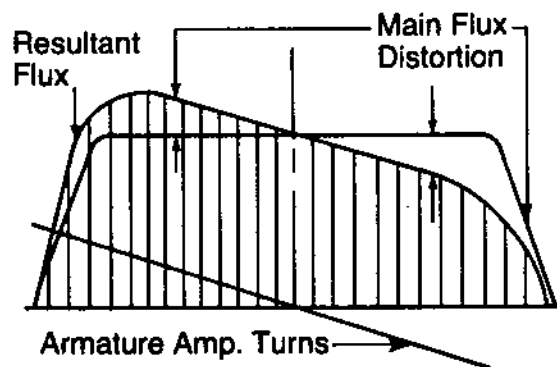


Fig. 6 – Effect of Armature Reaction

The saturation curve in Figure 7 shows that the distortion effect is greatest at the knee of the curve. At maximum flux, where the machine is saturated, the effect is smaller. The effect is also smaller at low flux density where the armature ampere turns alone are not strong enough to produce saturation.

The effect of armature distortion is very detrimental to the operation of the machine, it reduces output, and in a direct-current motor, flux reduction may cause instability.

Figure 8 shows a compensating pole face winding, which is in series with the armature circuit. It consists of a number of conductors located in a pole to neutralize the armature ampere turns. This method is very effective, but for practical reasons it can be applied only to larger machines because of space and cost limitations.

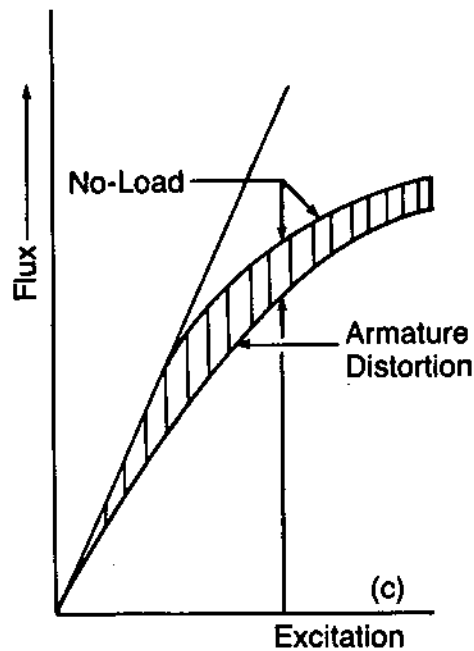


Fig. 7 – Saturation Curve

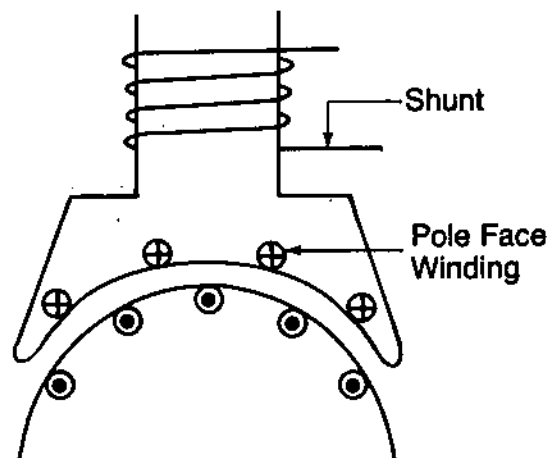


Fig. 8 – Minimizing Effect of Armature Distortion by Adding Pole Face Winding

An inexpensive method of compensating for armature distortion consists of adding a series field to the main pole as illustrated in Figure 9. This compensation is only approximate because the distortion effect is different for various degrees of saturation, as shown in Figure 10. With variable speed motors it frequently happens that they have a flat speed torque curve at average speed. This is due to distortion effect which is greatest at the knee of the saturation curve. The same motor at a lower or higher speed will be overcompensated and has a drooping characteristic, particularly at weak field.

Other factors affecting the shape of the speed torque curve are discussed later.

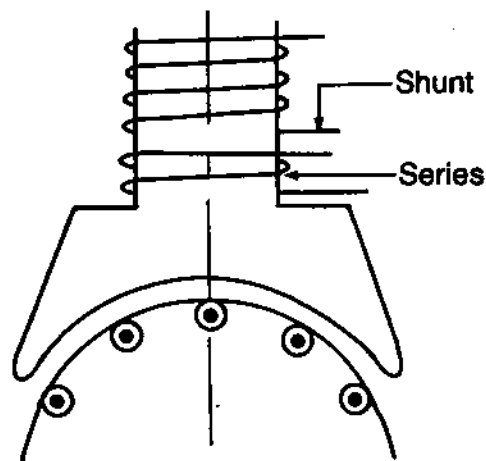


Fig. 9 – Minimizing Effect of Armature Distortion by Adding a Series Field to the Main Pole

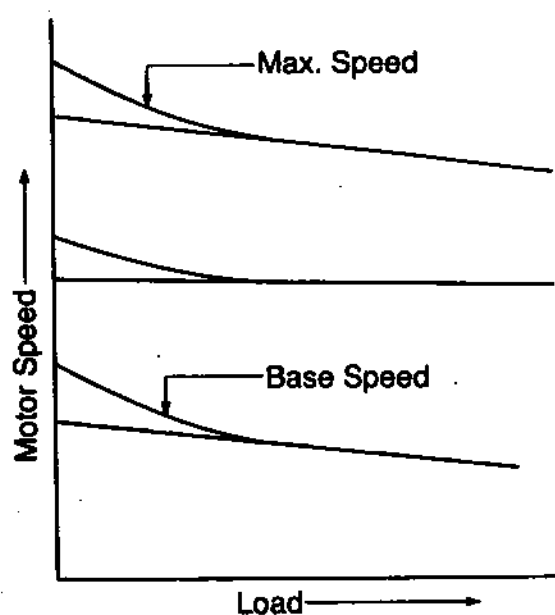


Fig. 10 – Distortion Effect for Various Degrees of Saturation

10.4 Commutating Pole Flux

The flux produced by excess ampere turns on the commutating pole windings is in quadrature with the main flux. Its purpose is to insure good commutation, i.e., to compensate for the reactance voltage in the commutated armature coil which is caused by changing of the direction of current. The remaining ampere turns compensate for the armature reaction and does not have a direct influence on the main flux.

Indirectly this flux plays an important part because overcompensation or undercompensation of the commutating poles produces a circulating current in the shorted armature coil which increases or decreases the main flux. The commutating pole flux affects not only the commutation, but also has a definite influence on the machine regulation.

10.5 Eddy Current in the Solid Frame

Eddy currents occur only during transient conditions, i.e., during flux changes in the main or commutating poles. Flux changes cause a current to flow in a solid frame and produce an effect equal to an evenly distributed and short circuited winding with a certain time delay as shown in Figure 11. For machines rated below 10 kW these currents can be ignored because of the small cross-section of the frame, but they play an increasingly important role as the size of the machine increases.

The effect of the eddy currents is illustrated in Figure 12 which shows a sudden increase and decrease in armature current. The direction of eddy currents is always opposed to the change of flux, so they are of opposing polarity during the increase of armature current, but have the same polarity during the decrease of load. The resultant interpole flux is equal to the sum of the interpole and eddy current ampere turns, and during

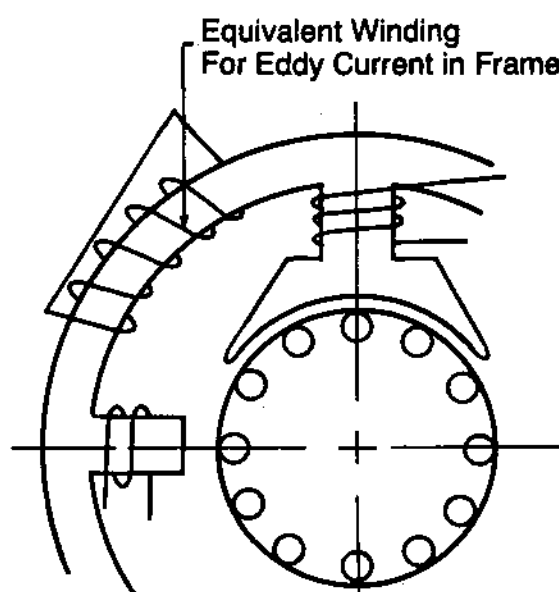


Fig. 11 – Effect of Eddy Current is Equal to a Short Circuited Winding

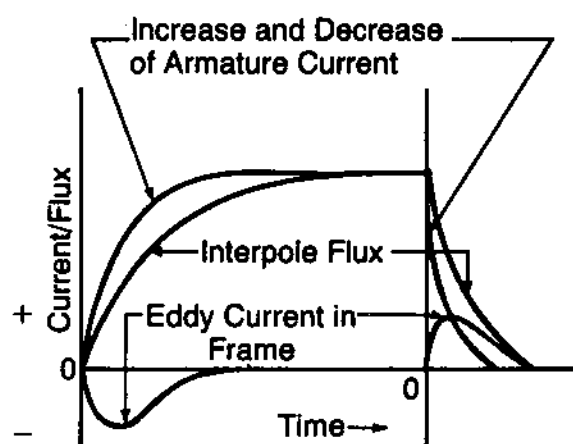


Fig. 12 – Eddy Currents in the Solid Frame and the Delay of Interpole Flux Behind the Armature Current.

an increase in load, the commutating poles are undercompensated, as shown in Figure 12. This has a significant effect on the commutation as well as on the regulation of the machine, especially when used in combination with regulator systems.

10.6 Commutation Factors①

For both performance and maintenance considerations good commutation and long commutator life are of primary importance. The function of the commutator is to change the induced alternating current to direct current. In doing this the current in the armature coil reverses as it moves from one pole to the next; or from position A to B to C as shown in Figure 13.

To change the current in a coil which has an inductance (L), a voltage (e) is induced which is equal to:

$$e = C_1 \times \frac{di}{dt} \text{ or } e = C_2 \times L \times I \times \text{rpm where}$$

L = coil inductance
I = coil current
Rpm = armature speed

This voltage is the reactance voltage and is usually two to ten volts, the latter value being considered high. In general, the higher the machine speed for a kW rating, the higher the reactance voltage will be.

To avoid excessive sparking under the brushes because of this voltage, the motor is designed with commutating poles. The flux of these poles

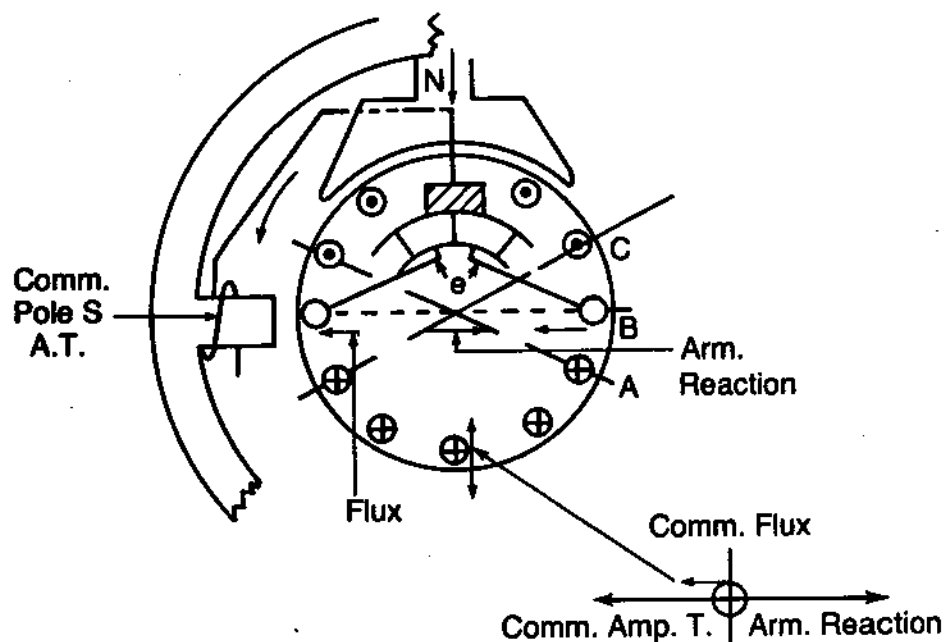


Fig. 13 – Generator Armature Coil During Commutation

① For more information on commutators, see *Westinghouse Electrical Maintenance Hints Vol. 2 Ch. 14. Commutator Care and Maintenance.*

is adjusted so they produce a voltage equal and opposite to the reactance voltage of the commutated coil, which makes the circulating current zero. It is therefore necessary that the polarity of the commutating poles for a generator should be that of the following main pole as shown in Figures 1 and 13.

A. Effect of Commutating Pole Shunting

Adjusting the ampere turns of commutating poles is difficult because these ampere turns must overcome the armature reaction, that is the ampere turns of the armature conductors which are of opposite polarity, as shown in Figure 13. It is only the difference in these ampere turns that is available to produce commutating flux.

As an average value 70% of the interpole ampere turns is used to compensate for the armature reaction with 30% available for interpole flux. If 10% of the current were to be shunted off the interpoles for control purposes, the commutating flux would be reduced 33% which would seriously interfere with commutation. See Figure 14. If more than 1% of the current is needed for supplying power for miscellaneous purposes, the machine manufacturer should be consulted for a suitable commutating coil design.

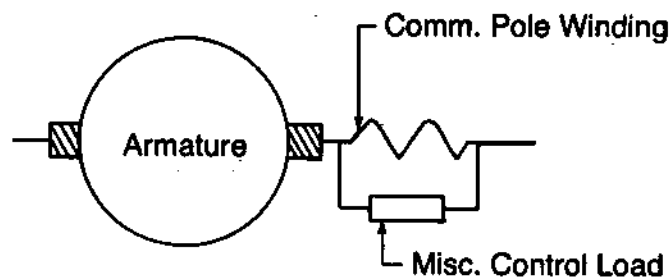


Fig. 14 – Shunting of Commutating Pole Winding to Obtain Current Signal for Miscellaneous Purposes

B. Overcompensation of Commutating Poles

To obtain optimum commutation, the machine may be designed to slightly overcompensate the commutating poles. Figure 15 shows that this produces a circulating current in the commutated coil of such direction that the trailing edge of the brush carries a lower current than the rest of the brush. This partial build-up of the coil current before it carries full current after leaving the brush, helps to keep the reactance voltage low and permits a smoother transition during current reversal.

Overcompensation has another advantage. It provides some forcing of the commutating flux during transient conditions. It can more closely follow the changes of the armature current and so insures good commutation at all times.

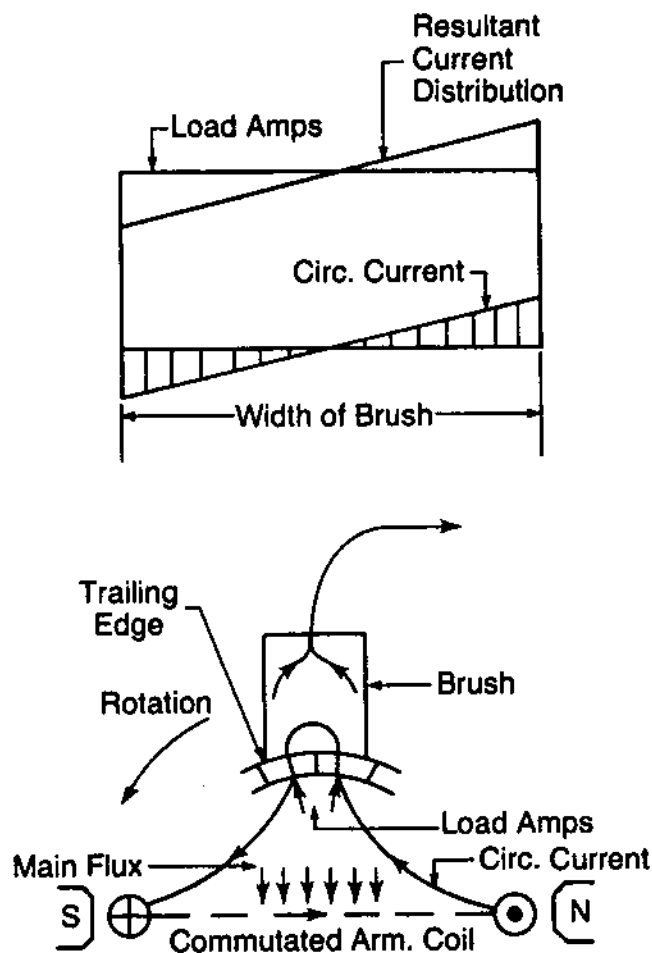


Fig. 15 – Current Distortion Under Brush for Overcompensated Commutator Poles (Generator)

C. Effect of Double Brushes

On large machines the resistance of the armature coil is very small and the reactance voltage tends to be large. Both conditions are factors against good commutation. The resistance of the commutator film is a variable that depends on many conditions, including moisture and temperature. To provide a fixed resistance, machines are often designed with double brushes. The resistance of two brushes in the coil circuit permits better control of circulating current. See Figure 16.

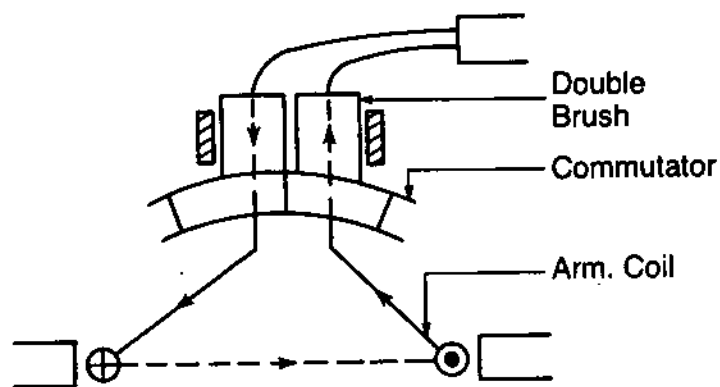


Fig. 16 – Double Brushes to Insure Good Commutation

D. Overcompensation of Adjustable Speed Motors

For machines running at constant speed the effect of overcompensating the interpoles is not critical. Adjustment for commutation is more difficult for adjustable speed motors. For example; at a 3 to 1 speed range with an armature reactance voltage of 5 volts, a commutating voltage of 5.5 volts is being produced by the interpole flux at base speed. This results in a net of .5 volt to produce the desired circulating current. At maximum speed the reactance voltage becomes 15 volts, while the commutating voltage has increased to 16.5 volts. This provides a circulating current 3 times higher, which may seriously interfere with commutation. This difference is further exaggerated by the effect of saturation in the frame which permits a higher commutation flux at weak field for the same ampere turns of the commutating poles. See Figure 17.

This problem led to the past practice of providing variable shunting of the interpoles by means of a rheostat attached to a speed rheostat. This method is not a satisfactory solution due to the unreliability of contact resistance in low voltage circuits and other complications. The practice has been largely discontinued.

Another solution sometimes used, especially for large variable speed motors consists of providing an additional winding on the commutating poles. Shown in Figure 18. This winding is energized with a suitable number of shunt ampere turns of additive polarity. At base speed, it compensates for the saturation in the frame.

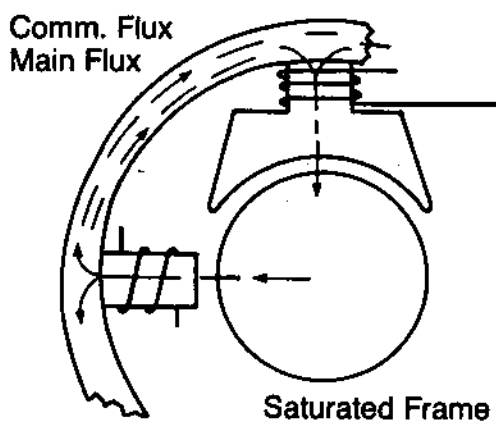


Fig. 17 - Reduction of Commutating Pole Flux by Saturation

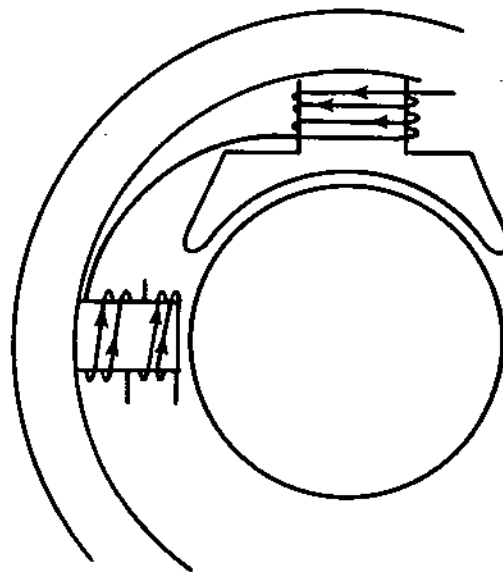


Fig. 18. - Additional Winding on Commutating Pole to Compensate for Frame Saturation

E. Commutation During Transient Conditions

During sudden load changes, the balance between commutating flux and armature reactance voltage at steady state operation is usually upset. The cause for this momentary mismatching lies with the eddy currents in the frame which force the flux to lag behind the armature current. See Figure 12. These sudden load changes may cause sparking of the machine, even though there may be perfectly black commutation during steady state operation. For very heavy duty, reversing service the commutating pole may be designed to include more ampere turns and more air gap to reduce time delay.

Motor starting can to a degree be considered a transient condition. Reactance voltage is low at low speed so the motor will commute better at low speed and can handle high starting current surges without excessive sparking. For this reason it is recommended that the starting resistors be carefully selected to reduce current peaks as the armature resistance is gradually cut out at higher motor speeds. Refer to Figure 19.

The desirability of a tapered starting current and an illustration of undercompensation of the commutating poles due to saturation are demonstrated in the oscillogram in Figure 20. This oscillogram shows the line starting of a 3 hp motor-generator set. The motor handled the starting current of approximately 1300% of full load but flashed over at about 50% speed even through the current had decreased to about 600% of full load.

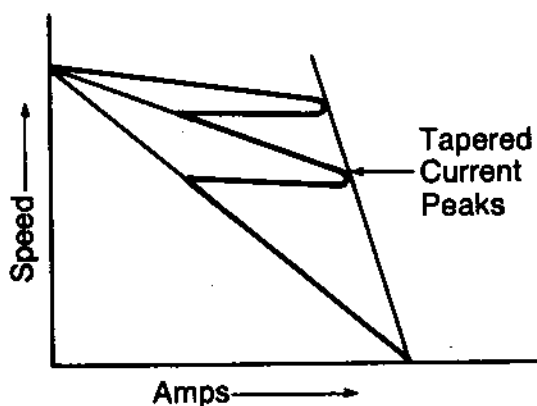


Fig. 19 - Desirable Motor Starting with Tapered Current Peaks

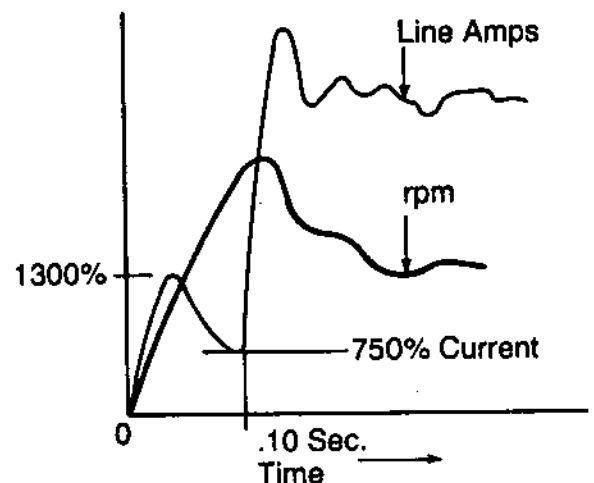


Fig. 20 - Line Starting of a 3 HP, 230V Motor-Generator Set

10.7 Overload and Short Circuit Characteristics

When a machine is heavily overloaded or subject to short circuit, several factors must be considered.

A. The current density in the brushes becomes excessive and their contact surfaces reach a high temperature; carbon has little thermal capacity and is a relatively poor conductor. Experience indicates that a typical d-c machine will stand a short circuit for about $\frac{1}{15}$ second before it flashes over.

B. Under short circuit conditions there is a loss of commutating flux. At a point between 200% and 250% of load the commutating poles begin to saturate and the armature ampere turns produce a strong cross flux, shown in Figure 21. This cross flux generates a voltage in the commutated armature coil which is additive to the reactance voltage. As a result, a very high circulating current will flow in the armature coil. Under short circuit conditions the total reactance voltage of a d-c machine is approximately equal to the IR drop. A generator with 5% IR drop will have a maximum current of ten times full load instead of 20 times the normal current.

C. Under short circuit conditions the shunt field current rises abruptly because the current circulating in the commutated coil is heavily demagnetizing as shown in Figure 21, and causes a transformer action between the commutated armature coil and the shunt field winding. This is illustrated in the oscillograms in Figure 22.

Tests show that the field circuit may increase as much as 500% of normal which is an indication of the powerful demagnetizing action.

The rate of flux decay and armature current decrease depends on the forcing action of the differential ampere turns in the commutated coils and the time delay of the field circuit. To protect the machine against damage, the use of a high value of discharge resistor is recommended, which will cause a high induced voltage surge automatically, as shown in Figure 22.

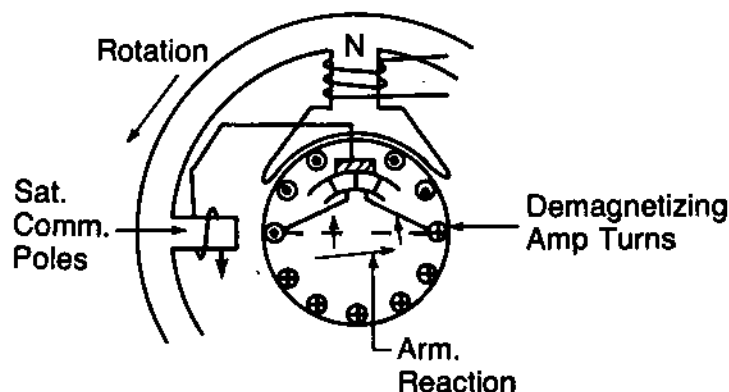


Fig. 21 – Differential Ampere Turns of Commutated Coils During Short Circuit

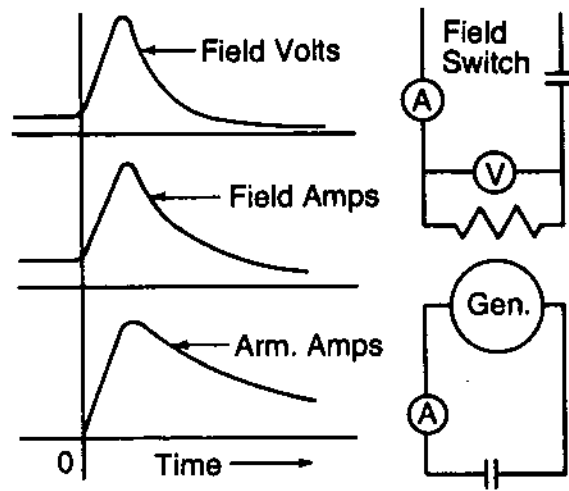


Fig. 22 – Short Circuit Oscillograms of a 1500 KW Generator

To permit a high induced voltage across the field, the field contactor must have a high arc voltage characteristic. Additionally, it should have a high operating speed (especially for large machines) to start the decay of the machine flux instantly. The performance of a special high speed field switch of 2000 volts arc voltage is shown in Figure 23.

Figure 24 shows the forcing action of differential ampere turns in the commutated armature coils for various degrees of overloads. For normal generator load, the decay of the armature current is 9000 amp./sec., under short circuit condition the decay increased to about 120,000 amp./sec. or approximately thirteen times the normal rate.

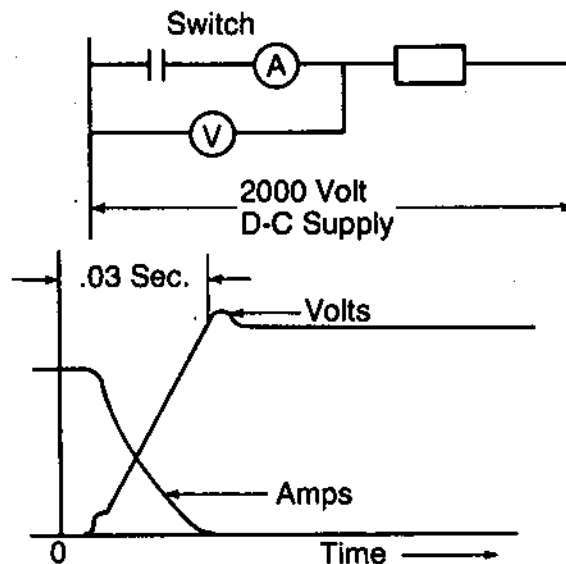


Fig. 23 – Performance of a High Speed Field Switch

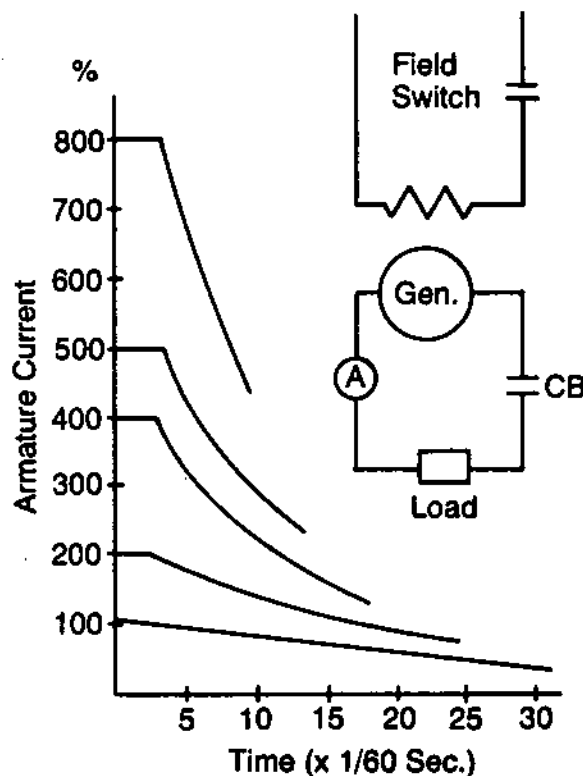


Fig. 24 – Flux Decay of 1500 KW Under Various Conditions of Overload and Protection by a High Speed Switch

10.8 Generator Performance

Generator regulation depends on the internal IR drop and the sum of the various field ampere turns affecting the magnetic flux, the main shunt field, additive or differential series field, armature distortion, and circulating current in the commutated coil. The effect of voltage increase in the various fields is shown in Figure 25. All the effects are essentially linear with the exception of armature distortion which is zero at low current and has a pronounced dip as the pole tips and armature teeth begin to saturate, then flattens again. Armature distortion changes with the amount of main flux and is greatest at the knee of the saturation curve. Typical regulation curves are shown in Figure 26, where the voltage regulation for 10% voltage has been shown in both solid and broken lines because it is difficult to predict unless special precaution is taken in machine design, particularly in the instance of a straight shunt generator.

Usually, the commutating poles are overcompensated to obtain the best commutation; this automatically produces additive ampere turns in the commutated armature coils. At lower generator voltage, with no flux in the frame, these ampere turns may have a pronounced effect and cause a rising characteristic. This effect is undesirable because of possible resultant instability.

Voltage Regulation:

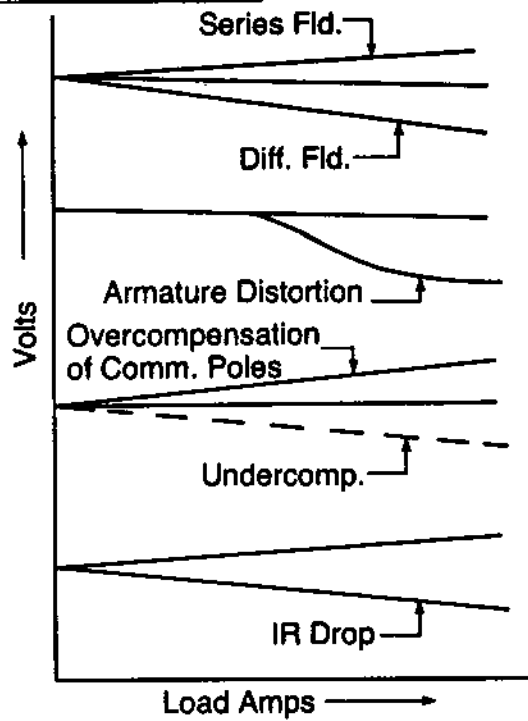


Fig. 25 – Effect of Various Fields on Generator Regulation

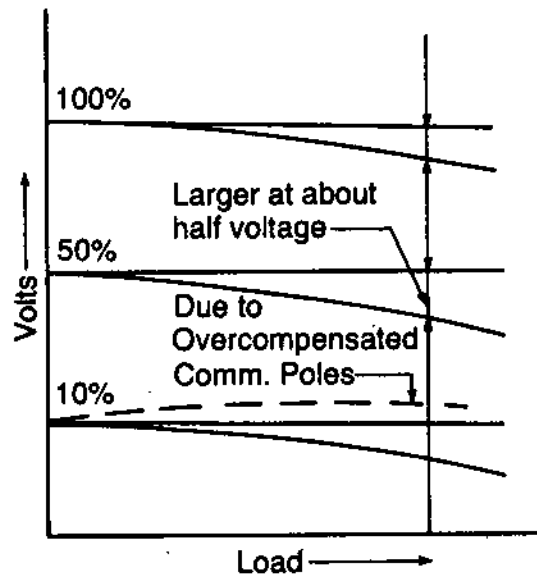


Fig. 26 – Typical Generator Regulation

In general, it is undesirable to have a rising generator voltage at any point of the voltage or load range. Serious instability problems may result if this is not carefully checked, as illustrated in Figure 27 and Figure 28.

Figure 27 diagrams the sticking or threading of a strip mill. If the generator voltage is rising, the rolls will grab the strip and usually break it. Best performance is obtained when there is a slight droop and fine adjustments sometimes made by suitable IR drop compensation.

Figures 28 and 29 illustrate another type of problem caused by a rising generator voltage. Sometimes the generator is provided with a cumulative series field to give a flat motor speed at low voltage. Unless the application is carefully analyzed, the sudden opening or reversing of the generator shunt field will cause a regenerative current by the motor, causing the generator series field to become differential. This condition will further weaken the generator flux and cause additional increase of the regenerative current surge. Due to these factors the system may become unstable and cause a flashover of the commutator, particularly if the inertia of the load is high.

Drives that are subject to heavy duty service are usually provided with differential series field to keep the current surges within acceptable limits.

10.9 Shifting Brushes

Occasionally, it may be found that a motor or generator does not have the characteristics to give the best overall performance. A generator may not have enough droop to insure smooth acceleration or deceleration of a drive, a motor may have a speed torque curve that is too flat to permit parallel operation with other motors mechanically coupled together.

When it is essential that an immediate correction be made to provide better operation of a drive, brushes can be shifted. Figure 30 and Figure 31 show the result of shifting brushes for both motors and generators. Shifting the brushes out of the neutral axis produces either a magnetizing or demagnetizing component of the main flux, as indicated in the diagrams. Because of this, a general rule can be established.

To increase the stability or droop of a generator or motor, the brushes must be shifted in the direction of rotation.

Caution: Consult with the manufacturer before attempting any appreciable amount of brush shifting. Shifting brushes out of neutral automatically tends to move the commutated armature coil out of the commutating pole flux and there is danger of ruining commutation.

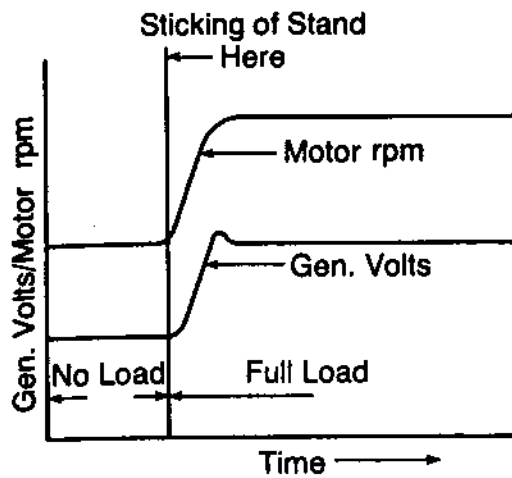


Fig. 27 – Effect of Rising Generator Voltage Characteristic on Mill Motor Performance

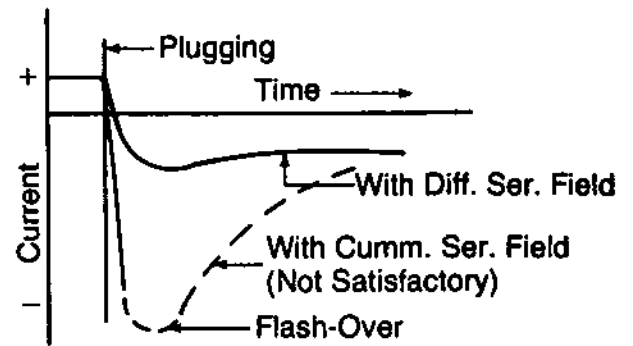


Fig. 28 – Current Surges During Plugging Operation for Cumulative and Differential Series Field

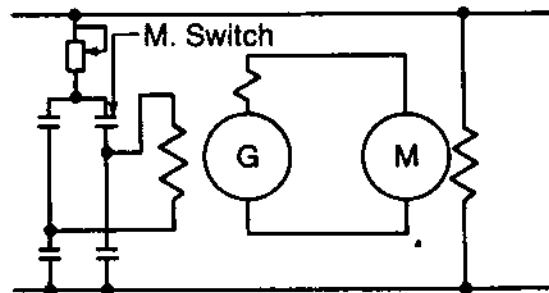


Fig. 29 – Connection Diagram for Plugging Operation

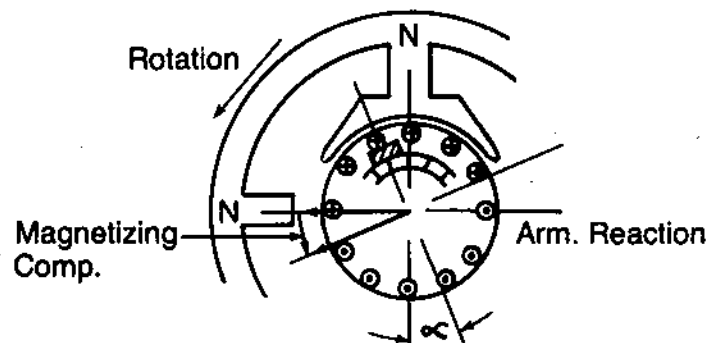


Fig. 30 – Effect of Brush Shifting to Improve Stability of a Motor

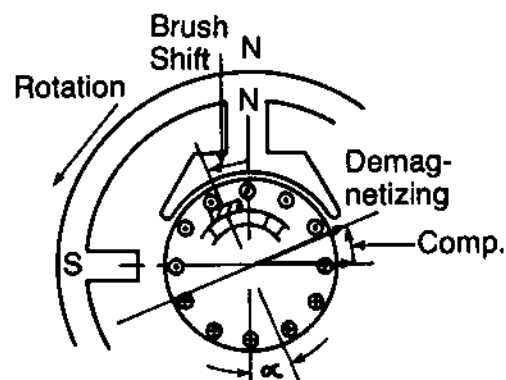


Fig. 31 – Effect of Brush Shifting to Improve Stability of a Generator

10.10 Direct-Current Motor and Generator Maintenance

A. Cleanliness

Cleanliness is particularly important with regard to d-c motors and generators because of their commutators, brushes, and brush rigging. Precautions should be taken to protect them from oil, dust, grease, moisture, corrosive gases or liquids. Commutators and brushes cannot give good performance when exposed to adverse conditions. Metallic objects, tools, bolts, machine parts, etc., which could cause damage should be kept away. A recommended practice is to keep all machines free from dust by the occasional use of low pressure, dry compressed air as a blower.

For further information, refer to *Westinghouse Electrical Maintenance Hints*, Vol. 2, Ch. 14. *Commutator Care and Maintenance*.

B. Insulation

A preventive maintenance test program should be adopted which will detect or provide data on deteriorating influences on the insulation system. The insulation test and maintenance program given in *Westinghouse Electrical Maintenance Hints*, Vol. 2 Ch. 8, *Large Rotating Apparatus* is applicable to d-c motors and generators.

C. The Armature

The armature is the heart of the d-c motor. The main line current flows through the armature, and if the machine is overloaded, the armature is the first to show signs of distress. Under normal operating conditions and with reasonable cleaning and regular inspection, the armature should remain trouble free. Armature repair should be undertaken only by trained and experienced technicians in a properly equipped location.

There are some basic precautions to be taken in handling an armature:

Do not roll an armature on the floor or on a table. A coil may be damaged or a band nicked.

Support or lift an armature only by its shaft or a wide lifting belt under the core.

Never allow an armature's weight to rest on the commutator or core.

All possible care should be exercised to avoid damaging or contaminating the armature while it is out of the motor or generator.

D. Preserve the Windings

Periodic dipping and baking treatments will prolong the life of d-c machines, but such reconditioning requires special facilities and skills. Motors and generators needing this kind of service should be sent to a qualified repair shop where they will be thoroughly cleaned, the winding degreased and such services performed as:

Inspect the coil bands and replace as needed.

Preheat the armature in an oven at 85C to 100C before applying varnish.

Keep the varnish at the manufacturer recommended viscosity.

Immerse the armature endwise, commutator end up, and drain thoroughly before baking.

Bake in a vertical position to prevent varnish piling up on one side would cause out-of-balance operation.

Bake in carefully controlled temperature and for the time specified by the manufacturer. This is usually 8 to 12 hours at 100C.

Repeat with successive treatments as called for by the conditions under which the machine will operate.

The foregoing illustrate why such service requires special equipment and trained personnel.

Periodic treatment of this kind is desirable even when the machine does not operate under adverse atmospheric conditions. Windings dry and loosen in operation and loose windings fail rapidly when subjected to centrifugal stresses and vibration. Periodic varnish treatments will fill voids and crevices, keep the insulation flexible, and hold the coils firmly in the slots.

A new armature winding will deteriorate rapidly unless the coils fit snugly and are held rigidly in place during operation. When winding crane or railway type armatures, it is common practice to preheat the wound core and install temporary bands before the dipping and baking procedure. After treatment the temporary bands are replaced with permanent bands. This procedure assures the coils are pulled firmly into final position in the slots while the insulation is warm and flexible.

Banding techniques have changed with development of polyester filled glass for banding armatures and wound rotors. The inherent risks in the use of metal bands can be eliminated by replacement with polyester glass bands. Replacement of original metal bands with polyester glass can always be done in the space provided for steel bands. Another advantage is the elimination of the need and cost for additional insulation under the band.

The polyester glass band also eliminates all problems of leakage and can be placed against the risers of commutators when desired.

Caution: Do not apply polyester glass banding to an armature which originally had magnetic banding. This will affect commutation. Consult the original machine manufacturer before taking action.

Caution: Polyester glass banding must be applied by trained and experienced technicians. Improperly applied polyester glass banding can cause machine failure.

Properly trained, experienced, and equipped people can perform rebanding at the machine plant location. It is not always necessary to send the motor or generator rotors to a repair shop. Consult a reputable repair service for recommendations.

E. The Commutator

The care and maintenance of commutators is sufficiently critical and complex to merit a separate chapter. See *Westinghouse Electrical Maintenance Hints*, Vol. 2 Ch. 14. *Commutator Care and Maintenance*.

F. Field Windings

When it is suspected that a field winding is defective, the first step is to carefully inspect all rheostats, switches, and other devices in the motor circuit, they can produce the symptoms of defective windings.

Where there is evidence of defective field winding, connections and leads should be examined and tested to verify that they are electrically and mechanically satisfactory. If the series field winding of a compound wound motor is misconnected in the reverse direction, the motor will probably flashover by the time full voltage is applied.

Warning: Do not operate a motor with a misconnected field winding at full voltage. It may be unstable and overspeed which can cause motor failure, severe personal injury or death, and damage to property.

If it becomes necessary to energize such a machine it must only be jogged at reduced voltage. A machine in this condition will have unsatisfactory operation and sparking at the commutator will probably occur.

If the field winding of any d-c motor is open circuited, the motor will fail to start or will operate at excessive speeds at light loads and severe sparking will occur at the commutator.

G. Field Coil Heating

Heating of the field coils may develop from any of the following causes:

Speed too low.

Voltage too high.

Forward or backward lead of brushes too great.

Partial short circuit of one coil.

Overload.

Faulty performance, resulting in poor commutation, improper speed, and armature overheating is frequently traceable to defective field windings or improperly connected field coils.

If the field circuit is free of grounds and a shorted shunt field coil is suspected, resistance measurements should be made of the individual coils and compared with the resistance of a similar coil known to be in good condition. It is preferable to make the comparative measurements when the field windings are hot or are near normal operating temperature.

The shunt field coil is made of a large number of turns of relatively small sized conductors. There is a possibility of defective insulation between turns on adjacent conductors so a coil which has the correct copper resistance value when cold may show a lower value when heated. The coil may not develop short circuits until expansion has occurred with increased temperature.

If the correct resistance value of a good coil is not known, comparative checks with either a Wheatstone Bridge or by the voltmeter-ammeter method will usually provide a reliable indication of the condition of the coils. If neither a bridge nor an ammeter is available, a clue to the condition of the coils can be obtained by connecting all shunt coils in series to a source of constant potential and measuring the voltage drop across the individual coils.

H. Replacing Field Coils

To remove a shunt or series coil, the coil should be disconnected from adjacent coils and the bolts which secure the pole pieces to the frame should be removed. This will make possible the removal of the pole piece and coil, after which a new pole piece with its coil can be installed. Care should be taken in replacing the pole and coil that all the steel liners between the frame and the back of the pole are replaced. Failure to do so can change the original air gap of the machine. In reconnecting the coil, check to make sure that the proper polarity of the coil is obtained.

A compass can be used to test polarity. The compass can be as simple as a needle or piece of steel wire suspended horizontally by a string. With a d-c power supply applied, the polarity should be alternately north and south around the frame. The power supply can be from a battery or other source, even the exciter. As the compass needle is brought within the magnetic field of any pole, one end will be attracted, that end should be repelled by the adjacent pole, and so on around the frame. If reversal of the needle does not occur, there is a wrong connection of the field coil.

10.12 Bearings

The bearings of all electrical equipment should be carefully inspected at scheduled intervals to assure maximum service. The frequency of inspection and lubrication is best established by the analysis of operating conditions and experience. The subject of bearings is covered in some detail in *Westinghouse Electrical Maintenance Hints*, Vol. 1, Ch. 9. *Bearings*.

The newer types of sealed sleeve bearings require very little attention since the oil is protected from contamination and leakage is negligible. Maintenance of the correct oil level is often the only upkeep required over years of service.

Older types of sleeve bearings require more frequent inspection, checking for wear, and oil changes.

Safe temperature rise for a bearing is about 40C above ambient. At this temperature, the bearing feels only comfortably warm to the bare hand.

When electrical equipment must operate under extreme differences in temperature, such as very hot summers, very cold winters, a lighter oil may be desirable in the cold weather.

Reclaiming lubricating oil for re-use as a lubricant is not recommended. The filtering operation must be positive to remove all contaminants.

A too warm bearing is probably due to one or more of the following:

Insufficient lubricant.

Excessive belt tension.

Failure of oil rings to revolve with the shaft.

Rough bearing surfaces.

Improper fitting of journal boxes.

Bent shaft.

Misalignment of shaft and bearing.

Poor or dirty oil.

Loose bolts in bearing cap.

End thrust due to improper leveling. A bearing may become heated because of excessive pressure exerted by the shoulder of the shaft against the side of the bearing.

End thrust due to magnetic pull with rotating parts attracted into the field because it extends farther beyond the field poles at one end than the other.

Excessive side pull because the rotating part is off center.

If a bearing becomes hot, some immediate actions are necessary:

Reduce the load if possible.

Feed lubricant freely.

Loosen nuts on bearing cap.

Slacken belt tension.

If these measures do not bring the temperature down the machine should be shut down, or better kept running slowly until the shaft is cool to prevent the bearing from seizing. The oil supply should be renewed before restarting the machine.

A new machine should always be run unloaded and if possible at low speed for at least an hour to assure that it operates properly. At this time, the bearing should be carefully monitored to check that the oil rings are revolving and carrying a plentiful supply of oil to the shaft.

10.13 Belts

On belt connected machines, the belt should be tight enough to run without slipping but not so tight as to cause the bearings to heat. Belt joints should be smooth so there is no jolt or vibration as it passes over the pulley. The crowns of the driving and driven pulley should match so the belt will not wobble. If wobbling is caused by improper joints the belt should be replaced or the joints broken and remade.

A flapping or wave motion of the belt is usually caused by slippage between the belt and pulley. This may be caused by grease spots on the belt, or it may be a warning of overload. The condition can sometimes be corrected by increasing the tension but the first correction made should be to thoroughly clean the belt.

A back-and-forth movement of the belt on the pulley is caused by unequal stretching at the edges of the belt. If the condition is not self-corrected in a short time, the joint should be examined. If the joints are properly made, the only remaining alternative is to replace the belt.

Charges of static electricity of sufficiently high potential to cause discharges to ground sometimes occur on belted machines, especially in dry weather. If the frame is not grounded, these charges may jump to the armature or field winding and then to ground puncturing the insulation.

To prevent this condition, the belt and frame may be statically discharged by placing a number of sharp metal points, carefully grounded, close to the belt at a position near the machine pulley. If the machine frame is grounded, this action will eliminate any danger to the insulation.

10.14 Insulation of Frames

The desirability of insulating machine frames is questionable. The strain on the insulation of the windings is decreased when the frame is grounded, but the penalty for doing so is that the risk to the machine attendant is increased when the machine is insulated from ground. There is also a likelihood of flashing to ground with high-voltage machines.

Warning: Ground or de-energize wall or ceiling mounted belted motors before performing any service on them. If the attendant must be mounted on a crane or in contact with other grounded part of the building there is danger of severe injury if the motor is not grounded.

Direct connected units necessarily have their rotating part grounded through the driven machine and the piping. The stationary parts can be insulated but it is difficult to do so and assure the machine is firmly mounted on its foundation.

10.15 Renewal Parts

Renewal parts are best obtained from the original manufacturer. To assure receipt of the correct parts; complete identification should be given as shown on the nameplate of the machine, including the serial number of the machine, and as follows:

Rotors are usually identified by stamped lettering at the end of the shaft.

When ordering coils, NEMA standard insulation should be specified and it should be stated if insulation for the windings is desired.

Individual small components will normally have a manufacturer's part number stamped on them.

The shipping notices sent by the manufacturer when the apparatus is shipped should be retained. These papers give shop order numbers under which the apparatus was built. They are an excellent means of identification and enable the manufacturer to locate all records of the equipment. These notices, instruction books, and parts lists should form a basic part of the maintenance file on the apparatus.

Rotating Equipment Vibration, Alignment, and Noise

Vibration	2:11.1
Sources of Vibration	2:11.3
Electromotive Forces	2:11.5
Mechanical Factors	2:11.5
Vibration Analysis Checks	2:11.6
Balancing Techniques	2:11.12
Realignment	2:11.17
Correcting Alignment	2:11.26
Shim Calculations	2:11.28
Motor Noise Factors	2:11.30

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Rotating Equipment Vibration, Alignment, and Noise

Even after proper installation on a firm foundation it is possible that rotating equipment will require realignment, rebalancing, or noise suppression measures.

Each time a large rotating unit is started, sustains a large overload, is stalled, or must be suddenly decelerated, torsional forces are produced. Severe operating conditions produce cyclical torsionals that can eventually cause movement in some fixed part of the machine.

One of the prerequisites for a good solid foundation is piling or concrete piers resting on bedrock. Reinforced concrete foundations are specified wherever massive rotating equipment must be supported. These precautions are the result of long experience with the problems of foundation settling.

Periodic inspections are recommended and tightening of accessible hardware should be a routine maintenance function.

Bolts can stretch, foundations can crumble or develop stress cracks, and foundation settling can be expected. Alertness on the part of maintenance and operating people can detect changes in performance. Any such changes should be investigated. Corrective action taken before damage is done can save expensive shutdown and repair.

11.1 Vibration

Vibration is readily detectable, even without instruments. A simple vibration check is to stand a coin on edge on a running machine. On a well balanced machine the coin will not fall over. New motors, depending on type and speed, will have been balanced to operate within 0.5 to 2.5 mils (one mil = 1/1000 inch). Factory tests are made using accurate instruments, with the motor resting on a resilient support. Large motors are bolted to the test floor bedplate.

Factory balancing is precise, a half-key is used to compensate for the unbalance of the shaft extension keyway if the motor is shipped without half of the coupling mounted. Balancing checks are always made after the coupling installation at the factory. The coupling, as delivered by

the supplier, is seldom precision balanced. Motor manufacturers must compensate for the added coupling weight. An unbalanced condition places excess strain on bearings and if allowed to progress can result in very bad machine performance.

Vibration effects commutation on direct-current machines. It can destroy brushes and eventually cause fatigue cracks in welded or brazed assemblies inside the machine, where repair requires shutdown and disassembly.

Excessive vibration, if not transmitted from some other source, is always a symptom of something wrong. Some driven apparatus is designed to vibrate violently; stokers, screen separators for grading size of crushed rock, coal, coke, or gravel, and other equipment such as ball-mills or rock crushers, transmit vibrations to the driving motor. Many of these are belted applications and the vibrations are damped by the belt drive, but some are direct drive. In these situations greater attention must be directed at assuring that vibration does not damage the driving motor. Motors react to conditions of vibration even when not directly coupled to the apparatus producing the vibration. This is one reason why motor maintenance is high in steel mills, foundries, quarries and other applications where considerable shock forces are transmitted through floors, steel structures, and underground.

Effects of Vibration

Excessive vibration is a serious condition requiring immediate correction. There are many negative effects of vibrations, direct and indirect:

It imposes unnecessary forces and stresses on equipment. Standard motors are not designed or warranted for use where there is excessive vibration.

The effect on foundations can be so severe as to cause them to shift and cause misalignment. Concrete can be deteriorated by the powdering of the bonding materials. Weight combined with torsional forces can cause foundations to shift, producing cracks and changes in elevation. These are conditions that may remain hidden until cracks appear and misalignment occurs.

Vibration frequently creates objectionable noise which can make working conditions intolerable, and if not corrected can result in hearing loss. Such noise levels are not acceptable under OSHA standards.

When several units of rotating equipment are operating simultaneously they produce a variety of vibration frequencies. Since drive motors and coupled equipment constitute a system, there are many

variable frequencies which can combine to set up vibrations not inherent in the operation of any of the machines.

Ambient noise and physical vibration often result from cyclic variations in the vibratory forces in a resonant system. Analysis usually reveals a relationship between impressed forcing frequencies and the resonant frequencies inherent in individual machines. The amount of vibration that results from frequency coupling and cyclic variations in several dissimilar frequencies is obviously beyond the control of the machine manufacturer. When encountered, these problems must be solved by the user. Often this requires bringing in service specialists who can recommend or take corrective action.

11.2 Sources of Vibration

The subject of vibration analysis has been thoroughly researched and a considerable body of literature has been published and is available in any well-equipped engineering library.

Medium a-c motors are designed and built so the resonant frequencies of the motor components, individually or as part of an assembly, are well above any known forcing frequency. Resonant frequency of rotating parts is at least 25 percent above known forcing frequencies.

It is possible that some combination of mass or stiffness in the mounting base or driven machine will result in a different system resonant frequency after assembly of the motor on its foundation and coupling to other equipment. This may be a system resonant frequency that lies too close to the rotating speed of the motor. When this occurs, excessive vibration is produced. This vibration can be traced to its source by separating the couplings and running vibration checks on the individual apparatus. If the uncoupled motor operates within established limits for vibration when checked on an approved mounting base or specified type of foundation, the driven equipment should be checked. It should be operated at rated speed from a separate source, and its vibration checked. Compensating balance weights may be needed or, some other factor, such as misalignment, may be causing the problem.

Any rotating mass has some unbalance. High speed, or variations in speed, can cause a small residual unbalance to produce more vibration at certain speeds. Most high speed machines have one or more such speeds, called *critical speeds*, through which they must pass each time they are started or stopped. Sometimes a critical speed is encountered at a relatively slow speed, sometimes at mid-range or higher.

The rotors of motors are initially balanced within accepted limits for general application. Performance is guaranteed on a new motor, since it must meet NEMA standards for measurable vibration when tested under controlled circumstances without outside influences.

NEMA Balance Procedures

When balance tests are made, vibration is measured at normal running speed, and any unbalance is corrected until NEMA standards are met as established in paragraph MG1-12.06, *Method of Measuring Dynamic Balance*. This standard gives the following instructions:

1. Place the motor on an elastic mounting so proportioned that the up and down natural frequency shall be at least as low as $\frac{1}{4}$ of the test speed of the motor. To accomplish this it is required that the elastic mounting be deflected downward at least by the amounts shown in the following table (Table 1), due to the weight of the motor. When a flexible pad is used the compression should in no case be more than $\frac{1}{2}$ the original thickness of the flexible pad.

Table 1 – Motor Test Pad Deflection

RPM	Compression in Inches
900	1
1800	$\frac{1}{4}$
3600	$\frac{1}{16}$
7200	$\frac{1}{64}$

2. The amplitude of vibration shall be measured on the bearing housing, in any direction, with the axis of the shaft in the normal position. With the motor operating at no load, it shall be balanced with one half a standard key in the keyway, that is, a key of full length flush with the top of the keyway.

An alternating-current motor shall be operated with rated voltage and frequency applied, and a direct-current motor shall be run at base speed. Series and universal motors shall be checked at operating speed.

The values for acceptable vibration limits are shown in the table below (Table 2). For standard motors these values are taken from NEMA MG1-12.05, MG1-20.52, and MG1-23.51.

Table 2 – NEMA Standard Vibration Limits in Inches Peak-to-Peak

RPM	NEMA for Medium Motors	NEMA for Large Motors
3000-4000	.001	.001
1500-2999	.0015	.002
1000-1499	.002	.0025
999 and below	.0025	.003

These NEMA standards for motor vibration are based on the experience of motor users and motor manufacturers.

This experience has shown that motors running at these values can be expected to provide normal service, and that reducing vibration below these levels seldom results in more reliable operation.

If a motor is overhauled in a repair facility, and vibration levels below those specified by NEMA are desired, the required vibration levels should be made part of the repair negotiation.

11.3 Electromotive Forces

Uneven air gap or a rotor in which the outer surface of the iron is eccentric, produces unbalanced magnetic forces on the rotor and the stator. These forces can produce excessive vibration but disappear the instant the power to the motor is cut. This fact is the key to their detection.

11.4 Mechanical Factors

Even a well balanced motor can be affected by the type of motor mounting and method of coupling of the driven equipment. Other factors can also intensify vibration, such as: vibration produced by connected oil lines and sheet metal ductwork. Overhead cranes and other equipment can create a condition capable of increasing vibration and causing objectionable noise.

Vibration transmitted between adjacent machines can also increase the vibratory forces associated with their normal operation. Operating a motor at higher than rated voltage can increase vibration and noise.

Many mechanical causes of vibration develop after the equipment has been installed and operated for some time. Skilled maintenance people develop the ability to detect small changes in sound. Each operating unit produces an identifiable sound and an experienced operator or

maintenance person is sensitive to a sudden change in ambient noise or the introduction of an unfamiliar sound.

Changes in noise level or an increase in vibration can be caused by many things. New equipment, with more than normal noise emission, will usually become more quiet and run more smoothly after it has been in service for a while. Motors and other rotating equipment tend to become more noisy and often develop a higher level of vibration as they age. This is due to many subtle changes that range from bearing wear to loosening of the iron. Coil shrinkage can develop in certain types of coils; this is followed by loose slot wedges. Commutator eccentricity and other mechanical changes occur as the machine ages or is abused.

This description of the deterioration of electric motors is somewhat exaggerated but to an extent these things do happen over a long period of service, even in normal operation. Heating, cooling, and running with insufficient lubrication before the bearing surfaces are coated, occurs each time the motor is operated. Starting under load, stalling, or operating at above rated load current for prolonged periods will eventually create the need for major maintenance. Motors should be closely monitored and serviced at prescribed intervals.

11.5 Vibration Analysis Checks

Vibration analysis under operating conditions must consider all the possible contributory causes. In many circumstances a shutdown is out of the question until a definite cause has been established and time allocated for correction. Because of this requirement various methods have been developed to check vibrating equipment and to measure vibration without shutting down vital processes or stopping production. There are a number of diagnostic procedures but they largely only establish the size and critical nature of the problem. Rebalancing or realignment require shutdown for some time so work is usually done in two stages, first evaluation, then corrective action at the earliest time when shutdown can be tolerated.

Vibration is an oscillating motion. One of the factors needed to evaluate the extent of motion is the distance traveled, or the excursions occurring at each cycle. The amplitude of motion is usually expressed in mils peak-to-peak. A one mil excursion in one direction is actually two mils peak-to-peak amplitude.

Frequency is the rate at which oscillations occur. The unit of measurement is cycles per second (cps) or cycles per minute (cpm). Frequency does not always indicate true revolutions per minute, it can contain a number of harmonics.

Velocity and acceleration are two other vibration parameters that may enter into calculations to accurately evaluate the effect of vibration. A vibrating body or a rotating mass, such as a motor, moves with a given amplitude and frequency. The speed at which it moves (velocity) is expressed in inches per second (ips) and is directly related to displacement. Any change in velocity affects vibration, it may increase or decrease depending on changes in stresses produced by rotation.

Acceleration or deceleration of massive rotors in turbines and large motors is always accompanied by some vibration. At critical speeds oscillations can cause flexing and bending of the supporting shaft. For this reason machines are accelerated and decelerated through their known critical speed as rapidly as possible. Prolonged operation at critical speed can damage a machine by breaking a shaft and destroying bearings, and other components.

There are formulas that permit exact calculation of vibratory forces stemming from any of these conditions, but readings must be taken with calibrated and accurate instruments. Several instruments may be employed simultaneously to obtain data which, when graphically plotted, will show vectorially where the unbalance exists and any change in relationship or amplitude when compensating moves are made.

The techniques of measurement have advanced from simple vibrometers requiring much analysis of their output, through oscillographic and light beam devices, to today's electronic measuring equipment. Some high speed apparatus is manufactured with built-in sensors which are connected to recording devices to monitor vibration.

Most vibration measurements are obtained by using portable electronic equipment. Electronic pick-ups, hand-held probes or proximity sensors are used to feed electrical signals into the analyzer. The electrical impulses produced by even minute amounts of vibration are amplified and read directly from meters on the vibration analyzer. A trained operator can take these readings and convert them to data which will show the amplitude level, and frequency of the measured vibrations.

Often an oscilloscope will be used in conjunction with the instrument to permit viewing of the wave shape. Generally vibrations have a complex wave shape caused by several frequencies being present. An instrument with a tunable filter can separate the frequencies and amplitudes and display them as direct readings on the meters.

Use of modern equipment results in accurate measurement of amplitudes, indicates phase angles of displacement, and, if an oscilloscope is used, visually display the wave form. An experienced service engineer

with proper instruments can very quickly locate the source of vibration without resorting to complex mathematical calculations. While the basic procedure is easily learned there is a real skill involved in correcting vibration.

Balance corrections are made by adding, removing, or shifting balance weights to cancel out oscillatory motion causing the vibration. Figures 1 through 6 illustrate the procedures used and point out the need for the use of several types of test equipment when complex problems are encountered.

Figure 1 shows a vibrograph in use to make a permanent tracing of the vibration at the inboard bearing pedestal of a synchronous machine. The vibration is transmitted through the probe to a stylus which traces it on a moving celluloid strip.



Fig. 1 - Vibrograph in Use to Make a Permanent Tracing of Vibration

Figure 2 shows a similar reading being taken using a direct reading analyzer. The hand-held probe is transmitting an electrical impulse which varies with the amplitude of vibration at the point of contact. The amplitude of vibration (mils) is read directly on the meter the operator is observing.

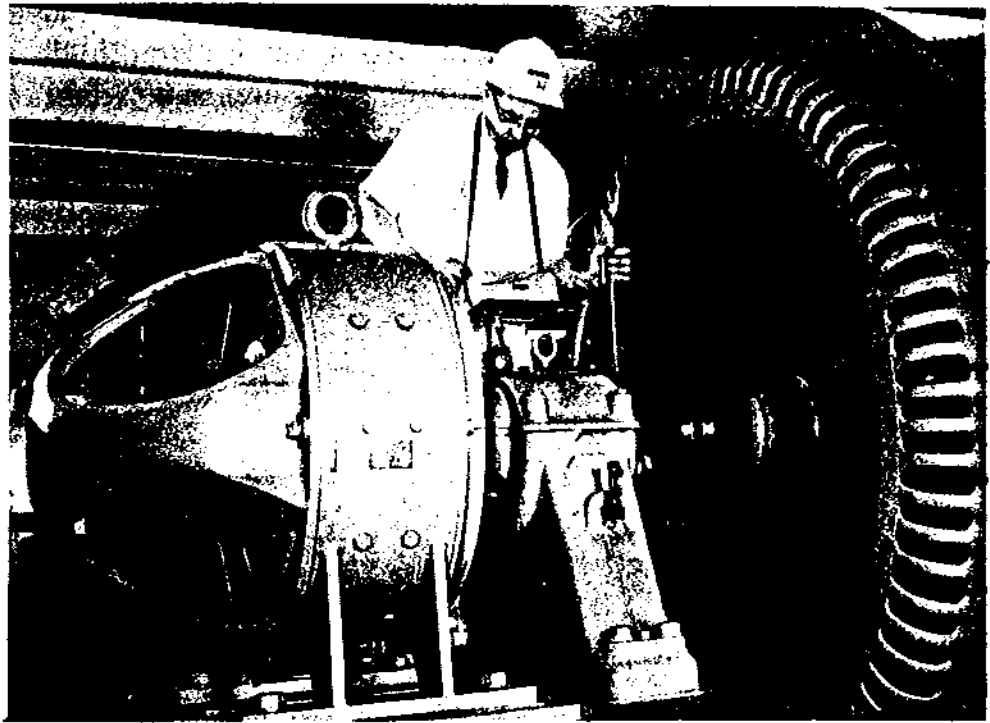


Fig. 2 – Reading Being Taken with an Electronic Direct-Reading Analyzer

In Figure 3 a different hand held probe is being used. Here the measurements are being made on one of the slip ring brushes and a proximity pick-up (arrow) has been installed to measure the shaft vibration amplitude of the exciter. The operator can see the wave form on the oscilloscope and also compare the frequencies making up the wave form by observing the amplitude meter readings.



Fig. 3 – Hand Held Probe in Use

Figure 4 shows how a velocity probe, equipped with a magnetic shield, is held in place by a permanent magnet. Also, a small clamp holds a proximity probe in place (arrow). This probe measures shaft vibration without touching the shaft. This arrangement eliminates any motion except that produced by the machine.

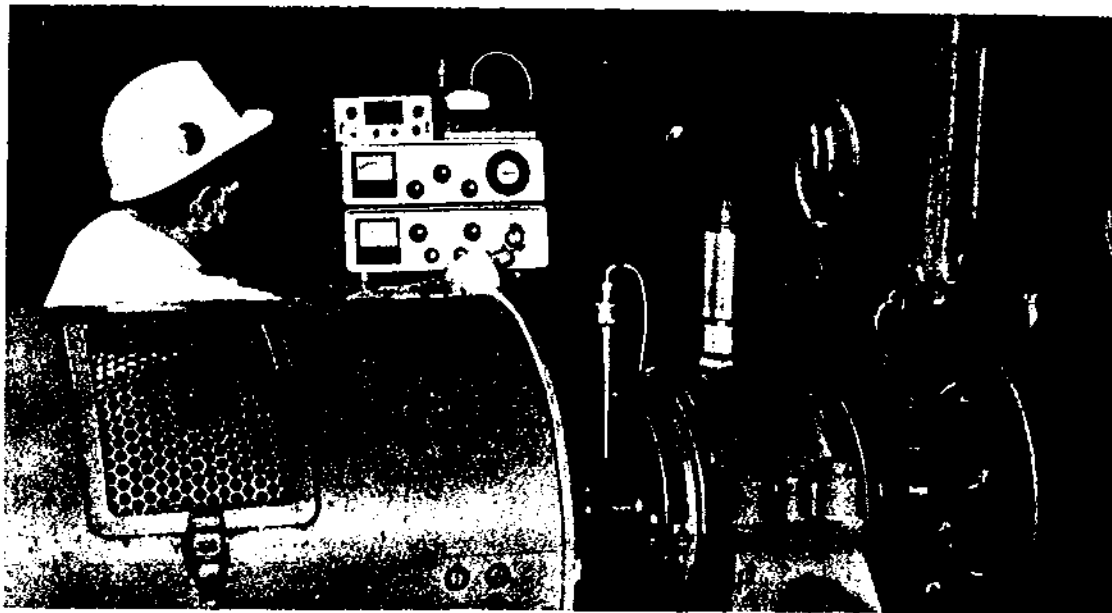


Fig. 4 – Velocity Probe Held in Place by a Permanent Magnet

Figure 5 is another example of the practical use of electronic balancing equipment. Vibration amplitude caused by any collector ring runout will be indicated on both the oscilloscope and the amplitude meter of the vibration analysis equipment. The illustration shows measurements being taken on the exciter of a turbo-generator set in a power house. The engineer is using a specially developed hand held probe modified for taking measurements on high speed collector rings and brushes. It is a seismode type probe.

Note the ear protection worn by the engineer making the test. The noise level becomes quite high when sound deadening barriers are removed from high speed equipment.

Caution: Use ear protection when working near high speed equipment where the sound level is high enough to cause hearing impairment.

In Figure 6 an inertia dynamometer used for testing airplane wheel brakes is being checked for balance. This, at the time of the check, was a new installation so the machine had to be checked for all possible combinations of inertia loading.

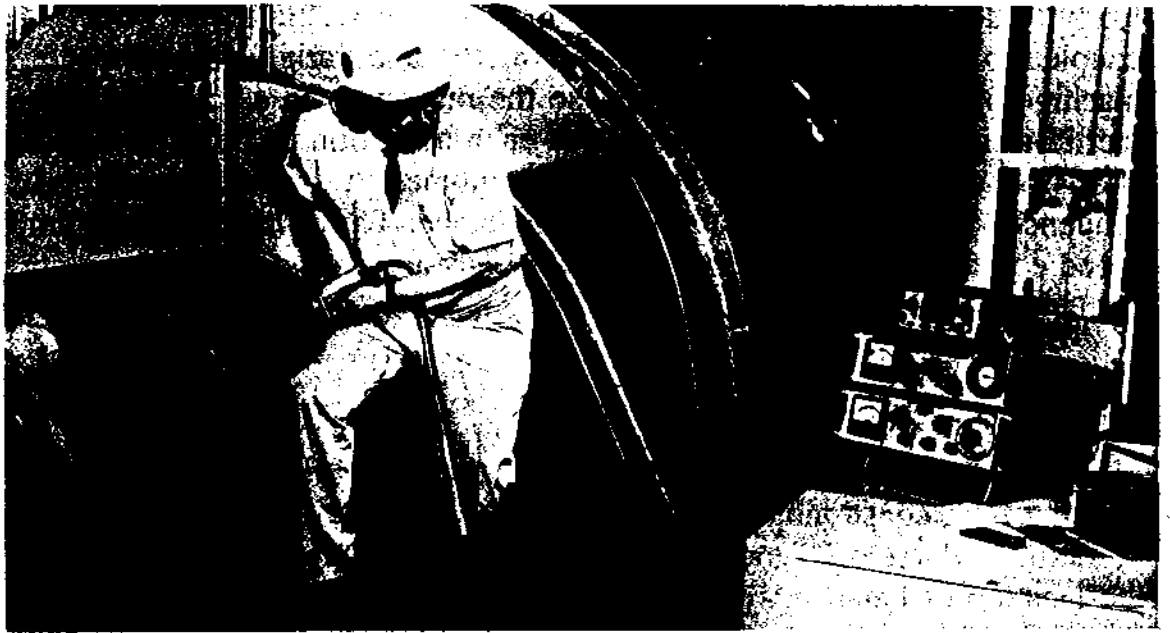


Fig. 5 – An Example of the Practical Use of Electronic Balancing Equipment

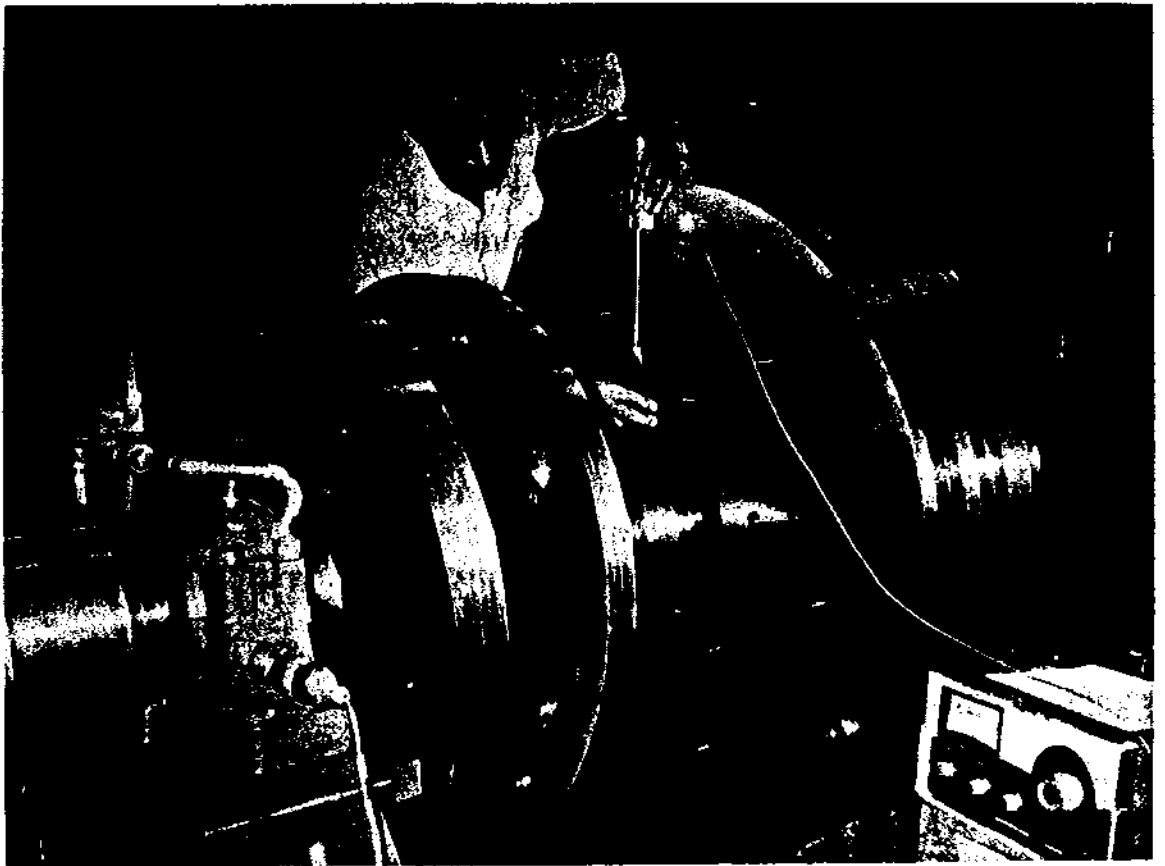


Fig. 6 – Inertia Dynamometer Being Checked for Balance

Note the number of discs which can be added for various test requirements. In this instance a fish-tail shaped stick connected to the probe picks up any shaft vibrations. This is the area where vibrations are most

likely to develop if the inertia plates are not properly balanced when coupled to the shaft. This is a variable inertia and variable speed machine operating up to 3000 rpm, so the machine and each separate inertia weight had to be in balance for each condition of flywheel effect. If this balance were not attained the dynamometer test results would be influenced by inherent vibration and unbalance. This is true of any high speed equipment operating at variable speeds and loads. Each operating mode injects variables that affect balance at a given speed.

11.6 Balancing Techniques

Modern vibration analysis equipment has eliminated the need for the tedious, time consuming trial and error procedure. When amplitude of vibration and vectorial location have been determined, the next step is the location of balance weights. At one time the procedure for balancing was to put the rotor between balancing weights and let gravity establish the heavy spot. Compensating balance weights were then attached at diametrically opposite positions for counter balance. This would correct for static unbalance, but other factors may be involved. When machine was run on test and had excessive vibration on the shaft high spot had to be found while running, using a chalk or grease pencil marker. Then extensive calculations had to be made to determine the correct weight change. There are new simpler methods.

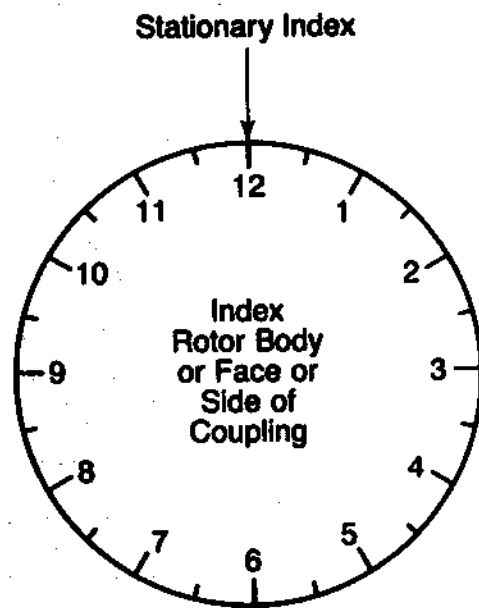
On high speed machines, particularly turbines, the time required was increased because the balance sometimes changed when the turbine was installed and running at operating temperatures. Several balancing operations may be required to smooth out vibrations on a steam or gas turbine after installations. The variety of elements affecting turbine balance, including induced vibrations from other machines and resonance in the foundation, and greatest of all offenders thermal induced changes in alignment, make turbine balance so involved it is best left to qualified service experts, trained and equipped for the purpose.

There are a number of manufacturers of portable electronic balancing equipment who offer training courses in the use of their equipment.

The stationary index system of measurement of phase angle displacement and vectorial plotting is probably the easiest to learn, simplest to use, and equally as accurate as other more complicated methods.

A. Balancing Procedures

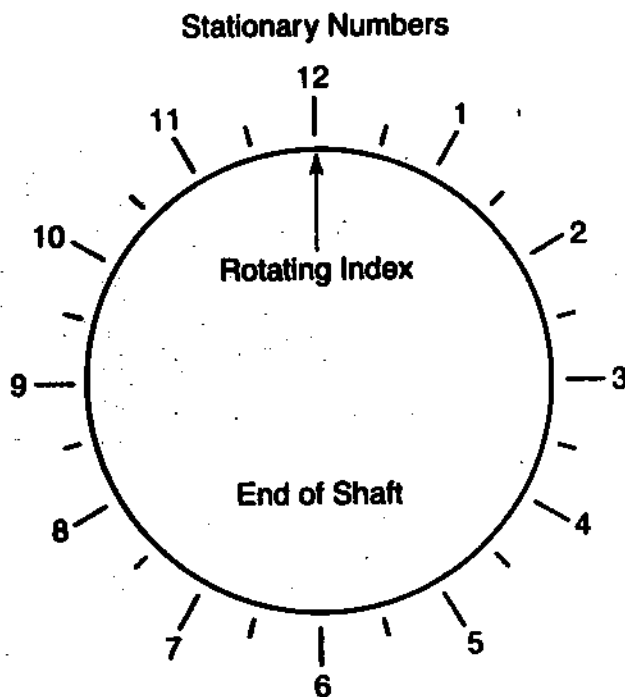
Either the stationary or rotating index system may be used to plot vectors. See Figure 7. The stationary index is the more frequently used. Figures 8 and 9 illustrate the marking of the rotor body or the coupling prior to using a strobe light to stop rotational motion effect. Use chalk



Preferred System

Stationary Index System

The Index (or Reference mark) is on the frame or bearing housing. The numbers are on the shaft.



Rotating Index System

The Index (or Reference mark) is on the shaft. The numbers are on the frame or bearing housing.

Fig. 7 – Reference Marking Systems for Obtaining Phase-Angle Data with a Strobe Light

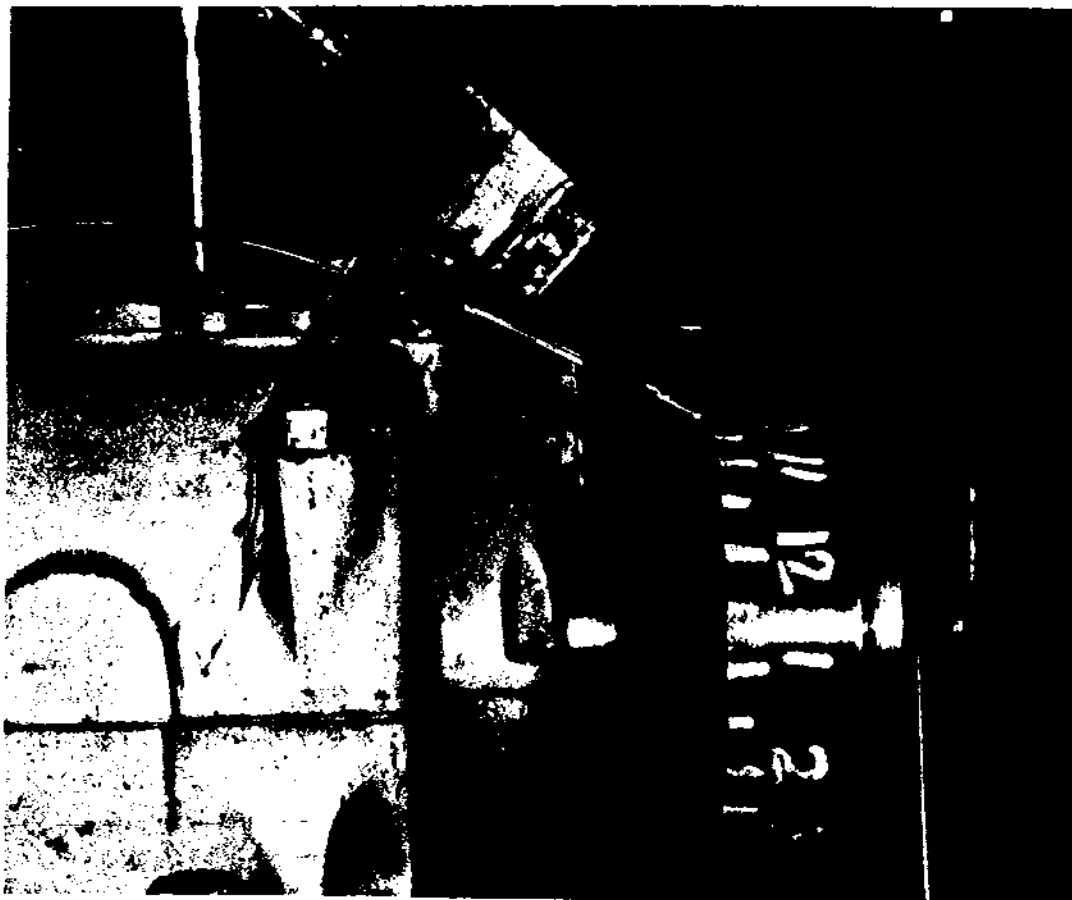


Fig. 8 – Use of the Stationary Index System



Fig. 9 – Use of the Rotating Index System

or yellow grease pencil to make the markings. Make sure the rotor or coupling face is divided into 12 or 24 equal segments. If it is not convenient to remove shrouds from the motor, mark the coupling side in equal segments. Number as a clock dial, if 24 divisions are used, number 12 marks letting the unnumbered marks correspond to the half-hour marks on a clock face.

Make a stationary index mark on the frame at the 12 o'clock position in the form of an arrow, using chalk or yellow grease pencil. Position the strobe light so it will illuminate both the rotating numbers and the index pointer. When taking readings, motion of the marks on the shaft can be slowed and stopped by tuning the oscillator circuit on the test set to the revolutions per minute of the shaft.

If the rotating index system is used, it makes a difference in how the vectors are plotted. The rotating index system is used only on machines in which the shaft end is the only accessible rotating part. Numbers are marked on the bearing pedestal face and the pointer rotates past them. When this system is used, vectors are plotted counterclockwise.

When using portable electronic balancing equipment and a strobe light for taking phase angle measurements it is very important to tune the filter circuit with the built-in tuning meter (if the set has one) or the oscillator. The strobe light should be checked frequently during the test to assure it is responding properly to timing impulses. If the shaft rpm should happen to change when the oscillator check is being made, the filter circuit will need to be readjusted since speed variations will change phase angle. A preliminary speed check with an accurate tachometer should be made to establish if operational speed is constant or varying with line voltage. The balancing instrument is operating from a separate line voltage supply or on self-contained batteries. A power dip can change the input voltage to the motor but would have no effect on the test set. It is important to keep the filter circuit properly tuned at all times to insure accurate data is being recorded. When strobe light tests are being made, the light should be clamped or taped in a fixed position on the machine. This permits the operator to devote full attention to instrument and record data.

With the state of imbalance established vectorially, it is necessary to determine how much counter-balancing weight is needed. Experience and skill are required to avoid much time consuming trial and error adding, subtracting, and shifting of weights.

No two balancing jobs are alike, and no two solutions are identical. It is necessary to be familiar with a variety of balancing equipment and with the two indexing systems, the Stationary Index System and the Rotating

Index System. Using the stationary index system the weights must be shifted clockwise to rotate the resultant vector clockwise. Using the rotating index system weights must be shifted counterclockwise to rotate the resultant vector counterclockwise.

B. Precautions

All possible causes of vibration should be investigated and ruled out before deciding a machine must be rebalanced. Consider these possibilities:

1. A new motor should not need to be rebalanced unless it has sustained damage in transit or during installation. Check first for a bent shaft and correct alignment with driven equipment.

2. If the motor is in good alignment and doesn't have a bent shaft, investigate for resiliency in the bedplate structure or the supporting foundation.

3. A well balanced motor may vibrate excessively if mounted on a resonant base. To check, run the motor uncoupled on rubber pads in accordance with NEMA standard MG1-12.06. If the motor runs smooth on rubber pads the balance is good and the trouble is elsewhere.

4. Shock loading, overtemperature operation, frequent abuse, and bearing wear can affect mechanical relationships of components or cause distortion of parts resulting in excessive vibrations.

5. Heavy deposits of dirt on a rotor or a change in air gap due to a frame shift from a bump or loosening of hold-down bolts can alter normal vibration characteristics. Fans are a source of trouble if heavy deposits of dirt are allowed to build up on the blades or squirrel cage blower.

6. Movement of any kind in a solid coupling or even lack of oil in a flexible coupling begins a process of fretting corrosion. This starts a vicious circle of more wear and more movement. A build-up of oxides, rust, or scale can also start an increase in vibration. The simple process of re-dipping and baking an armature and truing up its commutator in a lathe, can affect the operating balance.

7. Never jump to conclusions. If it is a new machine and pre-operational balance is being tested, results can be misleading unless factory balancing conditions are duplicated. Factory tests are conducted in accordance with NEMA Standard MG1-12.06 *NEMA Standards for Methods of Measuring Motor Vibration*. Do not assume the motor is out of balance unless it is tested under these conditions.

11.7 Realignment

Proper alignment of apparatus is essential to good service and long life. To the untrained and inexperienced it can be complex and confusing. In the more difficult situations it is often advisable to call in a service engineer who is trained and equipped for the job.

Realignment procedures are much the same as the alignment procedures covered in this volume in Chapter 8, *Large Rotating Apparatus*, except that physical moves are kept to a minimum since only one or two units of a composite line-up may have become misaligned.

Equipment must be kept in good alignment to avoid excessive maintenance. Wear, stress, and vibration caused by misalignment are the reasons manufacturers emphasize the need to make good initial installations and to recheck at yearly intervals to determine if alignment conditions have changed.

With optical techniques, the time required to make an alignment check is relatively short. It may require as little as an eight-hour shutdown and if misalignment is found another eight hour shutdown for realignment.

The fatiguing effect of twisting and bending on metals is that eventually something breaks. Eccentric rotation of coupled shafts that are misaligned has a pounding effect on bearings at any speed. Operation in a state of severe misalignment, unless corrected, leads to poor performance and eventual destruction of equipment. For this reason it is common practice for electric utilities to have a regular maintenance routine and scheduled shutdown of turbines and generators for inspection and test. This practice is being profitably extended to industry.

Misalignment puts excessive stress on coupled apparatus. Shaft flexing from misalignment can cause cracks which may not be visible. The twisting effect of shaft whip and misalignment can not only cause a shaft to break unexpectedly, it also initiates a chain of events that affect all other coupled units in the same line. A sudden increase in vibration may be the first symptom, but other warning signs may have been present for sometime. A machine which requires frequent bearing replacement, or is operating with unexplained high bearing temperatures is usually out of alignment. Refer to *Westinghouse Electrical Maintenance Hints*, Vol. 1 Chapter 9. *Bearings*.

Industrial plants are now adopting systems of scheduled maintenance shutdown periods for complete inspection and diagnostic testing. These surveys can reduce maintenance costs in the long run since they detect conditions that would lead to future trouble. This kind of preventive maintenance helps to avoid long time shutdowns waiting for replacement or repair of expensive equipment. See Figures 10 and 11.

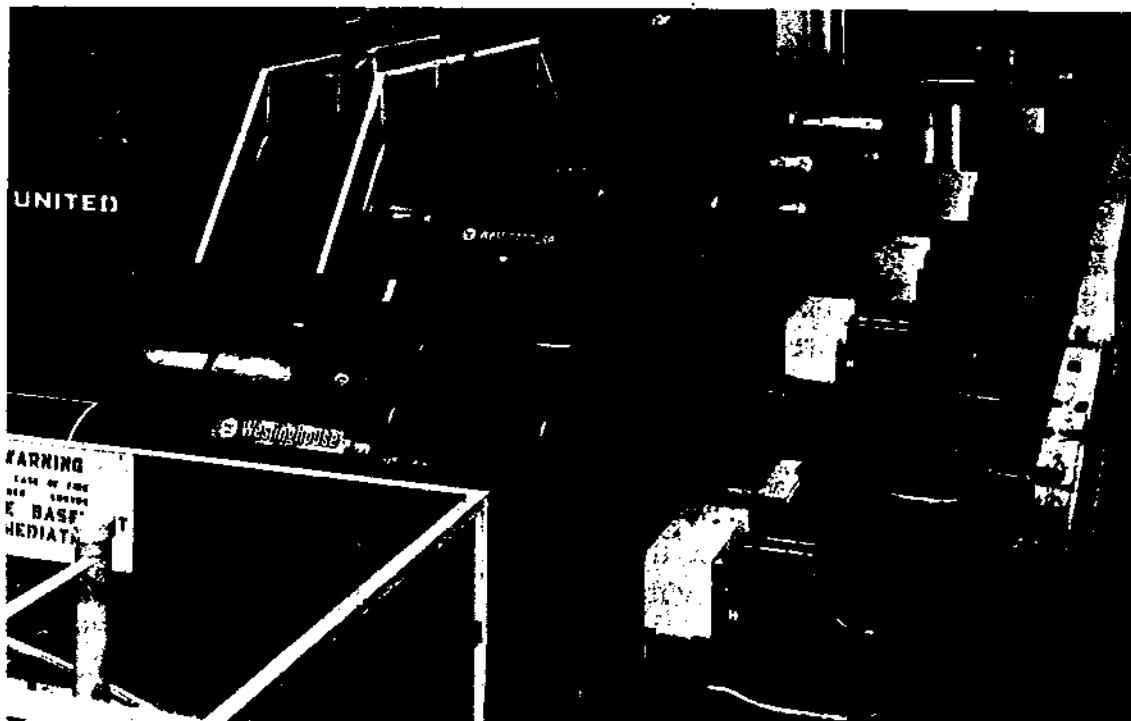


Fig. 10 – Line-Up of Large Mill Motors



Fig. 11 – Exciter-Generator Units

Misalignment and vibration are basic causes of apparatus failure and scheduled vibration analysis and optical alignment checks are becoming a common practice. Specialized electrical field service organizations are frequently used to do this work. Their trained, experienced people are equipped with the proper instruments to conduct these examinations. A team of service engineers can check out an alignment in as little as one eight hour period. Complete data is gathered for an analysis and comparison and any needed changes are recommended. Their analysis can go so far as to determine cause and recommended ways to eliminate it. If corrections are indicated, they can usually be made at the next scheduled shutdown.

The technique used is called Optical Alignment Analysis^①. It is a proven method of determining if changes have occurred which may ultimately damage the equipment. This technique does not require separation of any couplings, and except for removal of a minimal number of coupling guards or acoustical barriers, all original data recording points are readily accessible. Compared to the method of checking alignment by separating couplings and using feeler gauges to check parallelism on coupling faces in a line-up of exciter generator sets, optical alignment analysis offers distinct advantages. Figure 11 illustrates an exciter generator line-up.

Optical alignment analysis is extremely accurate and radically different from other methods. Historically three methods were used, depending on the degree of accuracy required. They were the tight-wire procedure, the bore-sight optical method, and the spirit level and feeler gauge technique. The external optical method, optical alignment analysis, has proved superior to any of the traditional methods. See Figure 12.

Only new installations can be aligned with the tight-wire procedure, because alignment is performed before any of the rotors or shafts are in place. A wire is stretched the length of the assembly, down the center of the bores, and radial dimensions between the wire and the bearing surfaces are measured accurately. The analysis must be done by a highly skilled operator; even then different operators may get different readings, and a single operator often has trouble duplicating his own readings. Temperature changes and air movement may also cause inaccurate readings. The checking is done without the shafts and rotors whose added weight may affect the final alignment.

Bore-Sighting also must be done before rotors are in place. The operator places a centered target in each bearing and sights down the bore with a

^① Optical Alignment Analysis is an alignment technique developed by Westinghouse Apparatus Service.

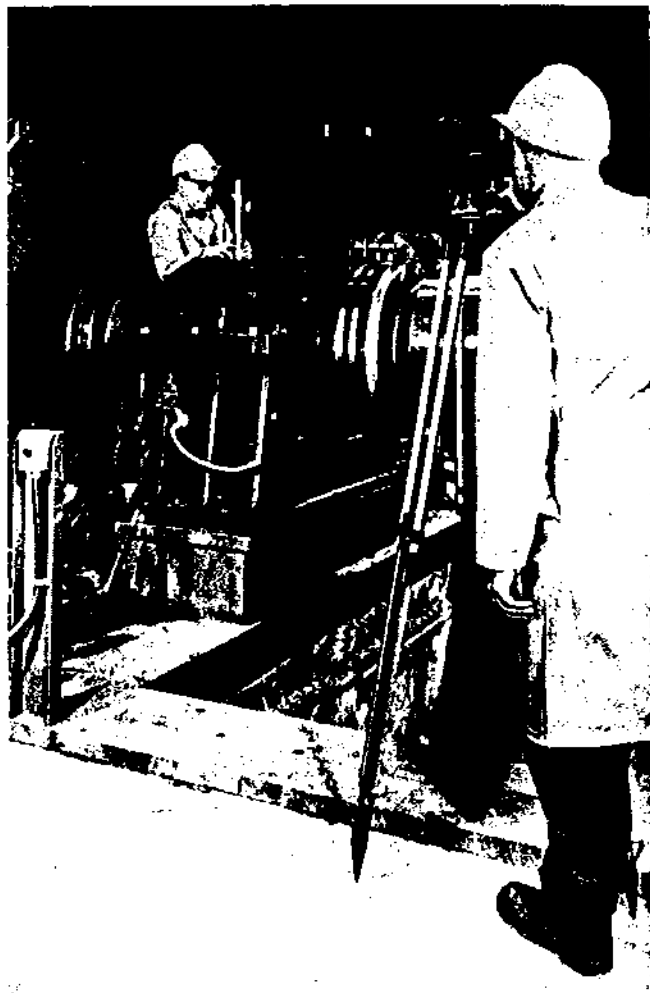


Fig. 12 – Optical Instrument Being Used to Check for Positive Alignment

telescope. The bearings are then set at the elevations corresponding to a correct alignment curve. This method cannot reveal initial distortion induced by the weight of the rotor and shaft, and it cannot be applied to a unit already in service.

To make a check with spirit level and feeler gauge, all bearing pedestal caps must be removed, all couplings loosened, and the shafts checked with a shaft level.

A feeler gauge is then inserted between the coupling mating faces at top, bottom, and each side to see if the faces are parallel. This technique makes in-service alignment analysis possible but is very time consuming. (An analysis of a nine-bearing flywheel m-g set cannot be accomplished during an eight-hour shutdown.)

Feeler gauge readings can be misleading in some units due to the sag of a shaft that extends beyond a bearing. This is illustrated in Figure 13 where the generator armature is supported by bearings I and J. Proper

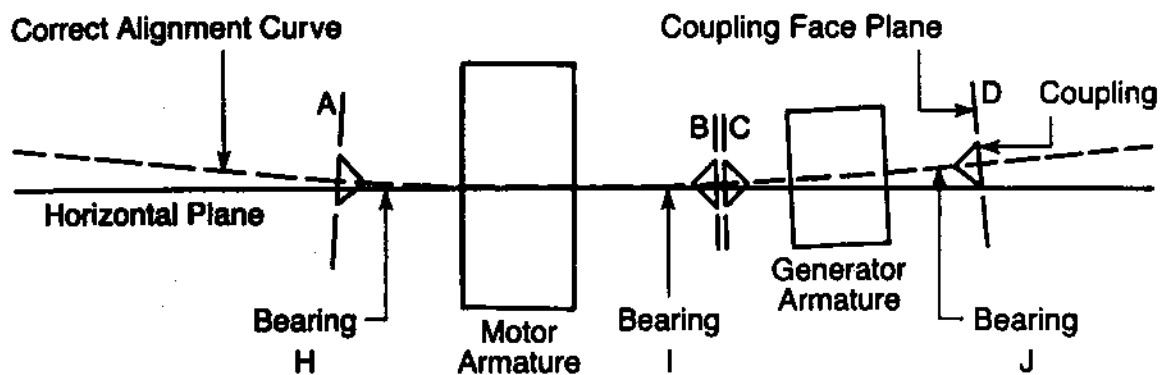


Fig. 13 – Motor and Generator Supported by Three Bearings

support requires a tight coupling at B-C; if these coupling bolts are loosened, the shaft centerline drops at the overhanging coupling. The coupling faces part under the shaft, and a feeler gauge would read this as a misalignment. A shaft center-line analysis should be made with all couplings bolted so the rotating assembly is measured intact.

A shaft center line, in elevation view, is not a straight line because the weight of heavy elements makes it sag between bearings. In the simplified diagram shown in Figure 11 the sag between bearings H and I tilts the coupling faces A and B at the ends of the motor shaft so they are not vertical. Because the planes of mating coupling faces must be matched accurately to prevent flexing strains on both couplings and shafts, the outboard bearings (J) of the adjacent unit must be elevated as indicated.

Optical Analysis Procedure

In the optical alignment analysis method, the couplings remain bolted together. In this external optical method a complete vertical and lateral alignment analysis can be made without dismantling any bearings. The excessive time required with level and feeler gauge is saved. Optical alignment analysis is faster, more accurate, and less costly than other alignment methods. An optical alignment analysis can usually be completed within two eight-hour shutdown periods.

The technique relies on the ability to establish accurate horizontal and vertical reference planes. Refer to Figures 12 and 14. To establish a horizontal reference plane, the telescope is leveled and swung in a horizontal arc. Distances from this reference plane to the shaft of the machine being examined are measured at many points along the assembly to obtain the elevation view of the shaft center line. Similarly, the plan view is obtained by establishing a vertical reference plane and measuring from it to the shaft. Measurements are made at exposed shafting, on journals, and at couplings.

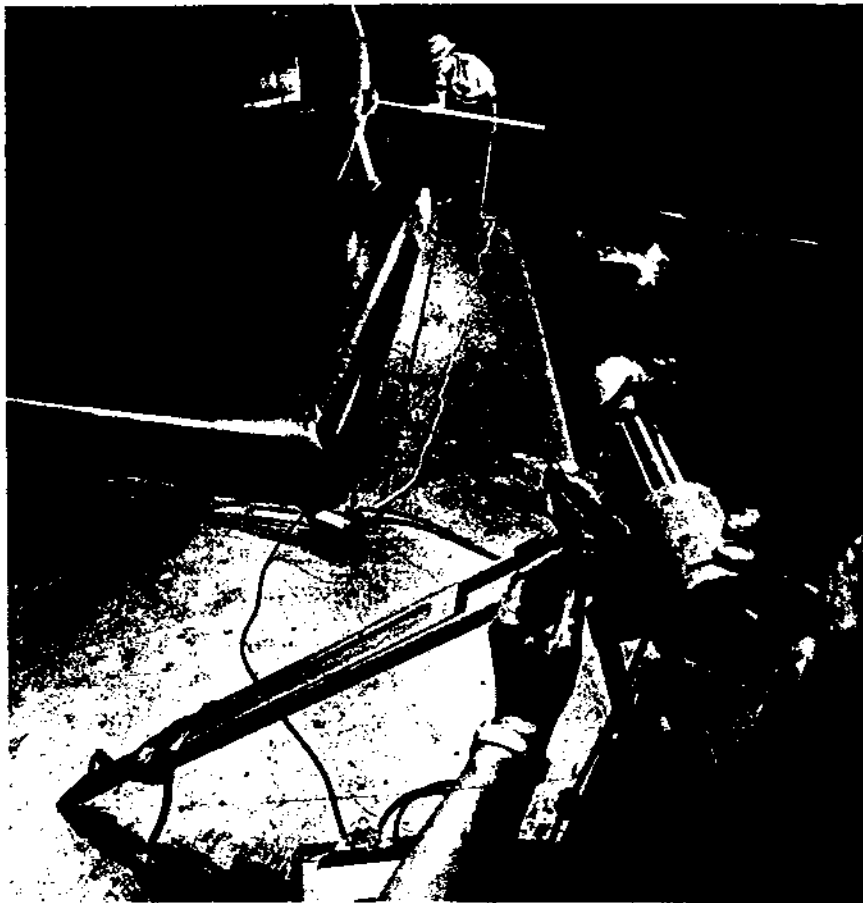


Fig. 14 – Alignment Telescope Being Used to Measure Lateral Alignment

The vertical alignment is measured first, then a transit is set up at one side of the machine and swung through a level horizontal arc, keeping the bubble on the instrument centered. See Figure 15. On a large assembly it is usually necessary to take sights from several positions. In each move at least two points are cross checked to calibrate the difference in elevation of the transit at the new position. Sighting arcs overlap at the shaft to maintain continuity of the horizontal reference plane and the elevation readings. Accuracy is within .003 inch at 100 feet, and most vertical readings are taken from within 20 feet. Readings are taken at as many points as possible along the top of the shaft from one end of the unit to the other. A scale held vertically on top of the shaft is used as a sighting target. This scale is calibrated accurately in tenths of an inch, and the sighting telescope has an optical vernier to read between the .01 inch marks to .001 inch. Refer to Figure 16.

Special fixtures pass through oil-ring inspection holes so readings can be taken right off the top of the journals. These readings establish the elevations of the top surfaces of the shaft, journals, and couplings.

Shaft and coupling diameters are found with a pi tape. The pi tape is easier to use than a large micrometer; it is wrapped around the clean



Fig. 15 – A Transit Set-Up at One Side of the Middle Portion of the Machine

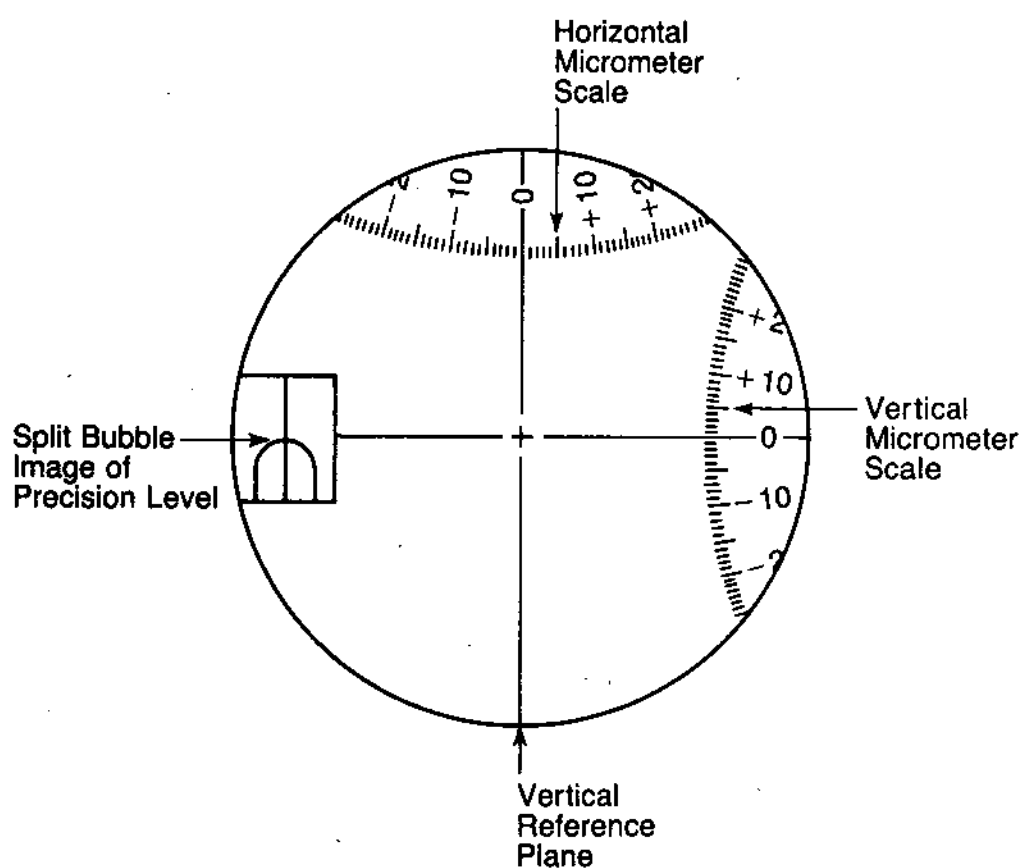


Fig. 16 – View Through a Typical Alignment Telescope

shaft. Although it actually measures the periphery, it is calibrated to read diameter directly in thousandths of an inch. This reading is accurate to within .002 inch, well within manufacturing tolerances. Radius dimensions ($\frac{1}{2}$ the diameters) are added to the shaft contact readings taken with the telescope to find the shaft center line.

An elevation check may be performed on the bedplate by measuring from both sides of the bedplate on the center line of the bearing pedestals.

Lateral shaft alignment is read from a horizontal scale positioned at the side of the shaft. This scale is shown in position for a reading at the top of Figure 16.

Large assemblies are supported by up to three bedplate structures resting on a common foundation. The bedplates should follow the correct alignment curve - level in the center under the motor and flywheel, and rising slightly toward the generators at the ends. After a large assembly has been in service, weight and torque forces may have caused some changes in the elevation of the bedplates.

An elevation drawing of the shaft center line is made with the elevation curve superimposed on it. The locations and amounts of misalignment are determined from the plots of actual measured shaft elevations, thus providing a permanent record of the elevation alignment at the time of the analysis.

To measure lateral shaft alignment, the telescope is set up near one end and to the side of the m-g set, and at the height of the shaft center line, see Figure 16. Vertical cross hairs establish the vertical plane which is the optical alignment reference.

A special fixture is used to transmit the lateral measurements from the shaft surfaces to the line of sight. This fixture is aligned so it is both horizontal and perpendicular to the shaft. Half the shaft diameter is added for plotting the lateral center line alignment curve.

Precise and accurate data can be obtained upon the initial alignment of the equipment, it has great value in providing a record against which the results of future alignment checks can be compared. In Figure 17 the white line represents the shaft centerline, the broken line represents the alignment at the time of installation, and the solid black line represents the alignment measured after a period of service. These comparative data allow a trained analyst to establish a relationship between the alignment changes and possible causes. Figure 18 is an actual plotting of an instance of severe misalignment due to foundation settling. The align-

ment check indicated there was also a wiped bearing at pedestal #8. Investigation confirmed this, though the operator of the equipment was unaware of the lost bearing.

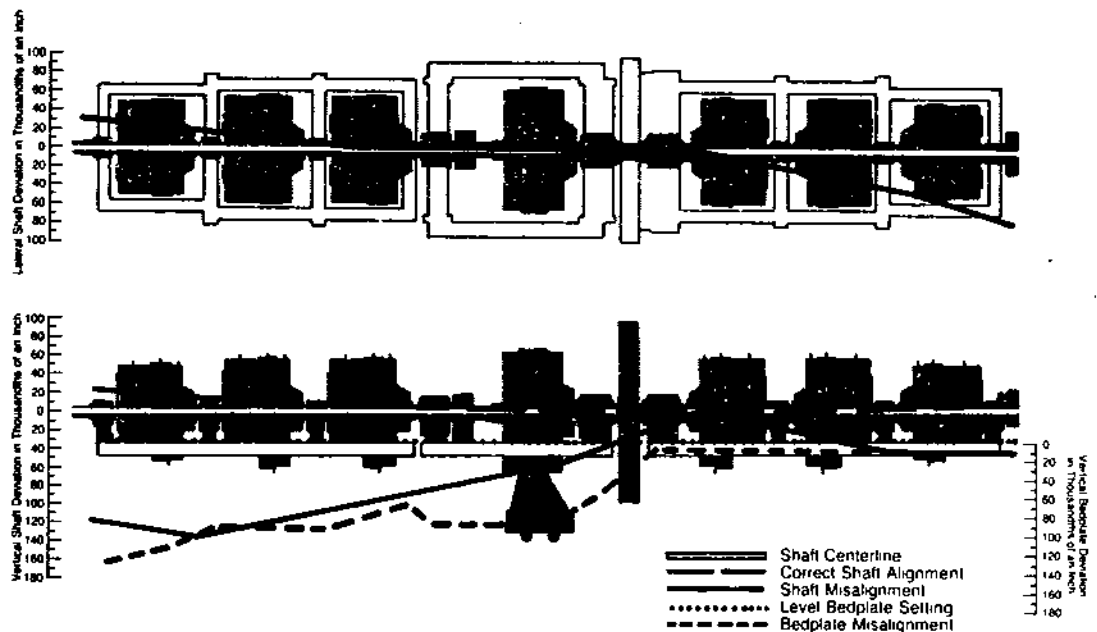


Fig. 17 – Outline Drawing of a 7-Unit M-G Set Showing Vertical Deviations

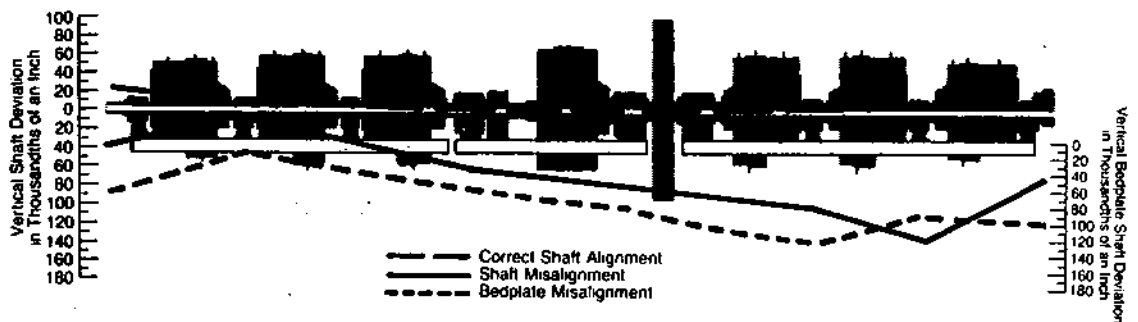


Fig. 18 – Actual Plotting of a Severe Case of Misalignment Due to Foundation Settling

Original data on the unit shown in Figure 18 shows that vertical shaft deviation was approximately .020 mils. The new alignment data showed that the bedplate had settled. It was causing severe misalignment and overloading at the #8 bearing, second from the right. Shaft alignment was seriously disturbed and bedplate deviation at its worst point was approximately 100 mils. Because of misalignment and consequent bearing failure, this undisclosed operating condition could have caused the shaft to break if it had not been detected and corrected immediately.

Even more severe cases of vertical and lateral misalignment have been revealed by optical alignment analysis as shown in Figures 19 and 20. The only recourse is to shutdown and make compensating changes for lateral and vertical deviation by adding or removing shims.

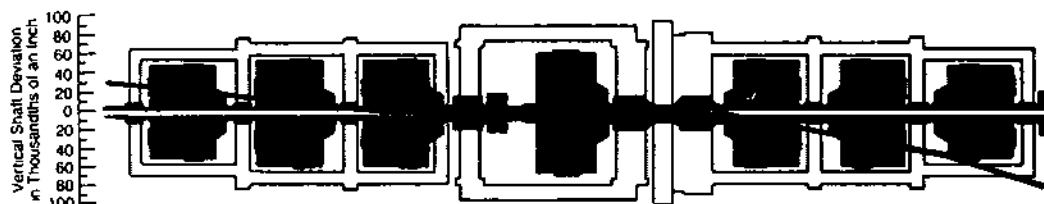


Fig. 19 - An Example of Lateral Displacement



Fig. 20 - An Example of Vertical Displacement

11.8 Correcting Misalignment

To raise a shaft shims are added on both sides of the bearing pedestal. This corrects only for vertical shaft deviation. If lateral shaft deviation is to be corrected, the desired amount of shim, must be added to one side of the pedestal and a calculated amount subtracted from the other side of the bearing pedestal. This rotates the pedestal about a pivot point established by the hold down bolts and will shift the shaft laterally. See Figure 21. This innovative procedure saves considerable time and expense compared with the conventional approach. The conventional method is to slide the pedestal laterally the desired distance, redrill and ream both pedestal and bedplates and insert oversize dowels. Sometimes it is also necessary to enlarge bolt holes and retap the bedplate for larger hold down bolts. In the rotating method dowels need not be changed or bolt holes bored out. The dowels are pulled and the hold down bolts are loosened only. Jacks are used to raise the shaft which raises the pedestal, and shims are slid under or extracted, dowels are reinserted and the bolts tightened, and alignment rechecked. See Figure 21.

There is an accurate method of calculating shim changes at predetermined locations to offset both lateral and vertical shaft misalignment. To restore the original settings for individual machine elevations and compensate for changes in lateral alignment, drawings are made which show each shim location and the amount of correction needed.

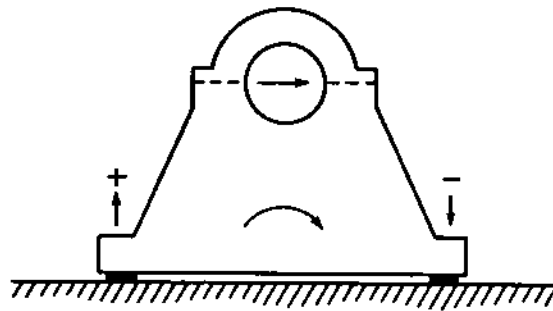


Fig. 21 – The Rotational Effect Produced by Adding and Subtracting Shims Under a Bearing Pedestal

Figure 22 is a typical shim change diagram. Adding or subtracting shims at various locations can correct both horizontal and vertical alignment. Shims in the amount calculated at each bearing pedestal will restore proper alignment but it is also necessary to recheck and sometimes change the elevation of stator frames to maintain concentric air gaps. Note that a difference in shim values between two sides of a bearing pedestal indicates that the pedestal is being rotated to correct for lateral misalignment as well as raised or lowered for vertical correction.

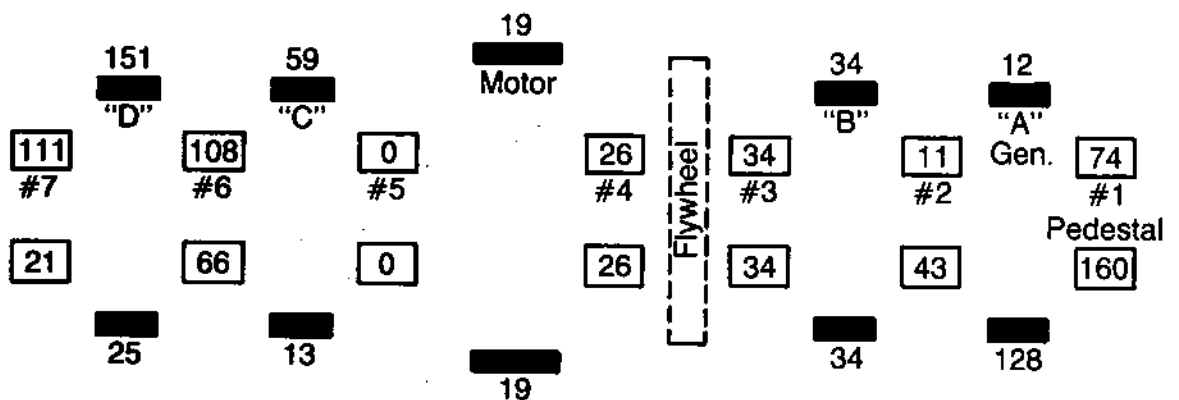


Fig. 22 – A Typical Shim Change Diagram

Optical alignment analysis at the time of installation assures correct shaft alignment to within a few mils on a multiple unit assembly; it is fast and economical. An alignment recheck by the same method assures the accuracy is maintained. Shaft couplings need not be separated to make feeler gauge readings for angularity at the parallel faces. Dial indicators are unnecessary and not used. An alignment recheck provides reassurance or indicates needed correction, it increases the safety for personnel working around the machine. Operation under severe misalignment can cause an unexpected catastrophic failure if a shaft should break or a coupling fail.

Optical analysis can also detect the origin of excessive bearing wear due to misalignment. This prevents unnecessary down time and expense associated with bearings changeout. The major benefit of an annual alignment check is the reassurance that valuable apparatus is not being threatened by operation in a misaligned condition.

11.9 Shim Calculations

There has been developed a simple, straight-forward method of calculating shim requirements that reduces to a matter of a few hours what formerly could require days of cut-and-try shimming.

The method is basically analogous to the rotation of a wagon wheel. Figure 23 illustrates how changes in elevation relate to this theory. The motor to be aligned is assumed to have the fixed points shown in the diagram as A, B, and C. If the motor is visualized as being placed on the wagon wheel so the lower outside corner of the coupling coincides with the center of the hub of the wagon wheel, the coupling and the motor will pivot around the axle when the wheel is turned. If the top of the coupling is moved, all other points on the wheel will move a corresponding amount, depending on the ratio of the radii of the respective points.

If the top of the coupling is to be moved to open or close with respect to another coupling face, the exact thickness of the shims to be added or removed at points B and C can be calculated. (There are four shim locations though only two are shown on the diagram.) The same thickness of shim must be added or removed from the front or back feet depending on whether the coupling faces are being opened or closed. To remove more from one side than the other creates a rotating effect as illustrated in Figure 21.

If the coupling gap is to be changed by plus or minus .004 mils, the shims under points B and C should be added or removed as shown below.

$$\text{Pad B} = .004 \times \frac{B}{A} = .004 \times \frac{17}{21} = .003$$

$$\text{Pad C} = .004 \times \frac{C}{A} = .004 \times \frac{44}{21} = .008$$

In this example distance A, coupling diameter, is 21 inches. The distance from the face of the coupling to the centerline of the bolt hole of frame foot B is 17 inches. The measured distance from the face of the coupling to the center line of the bolt hole in frame foot C is 44 inches. These horizontal distances are always measured from the plane of the coupling face.

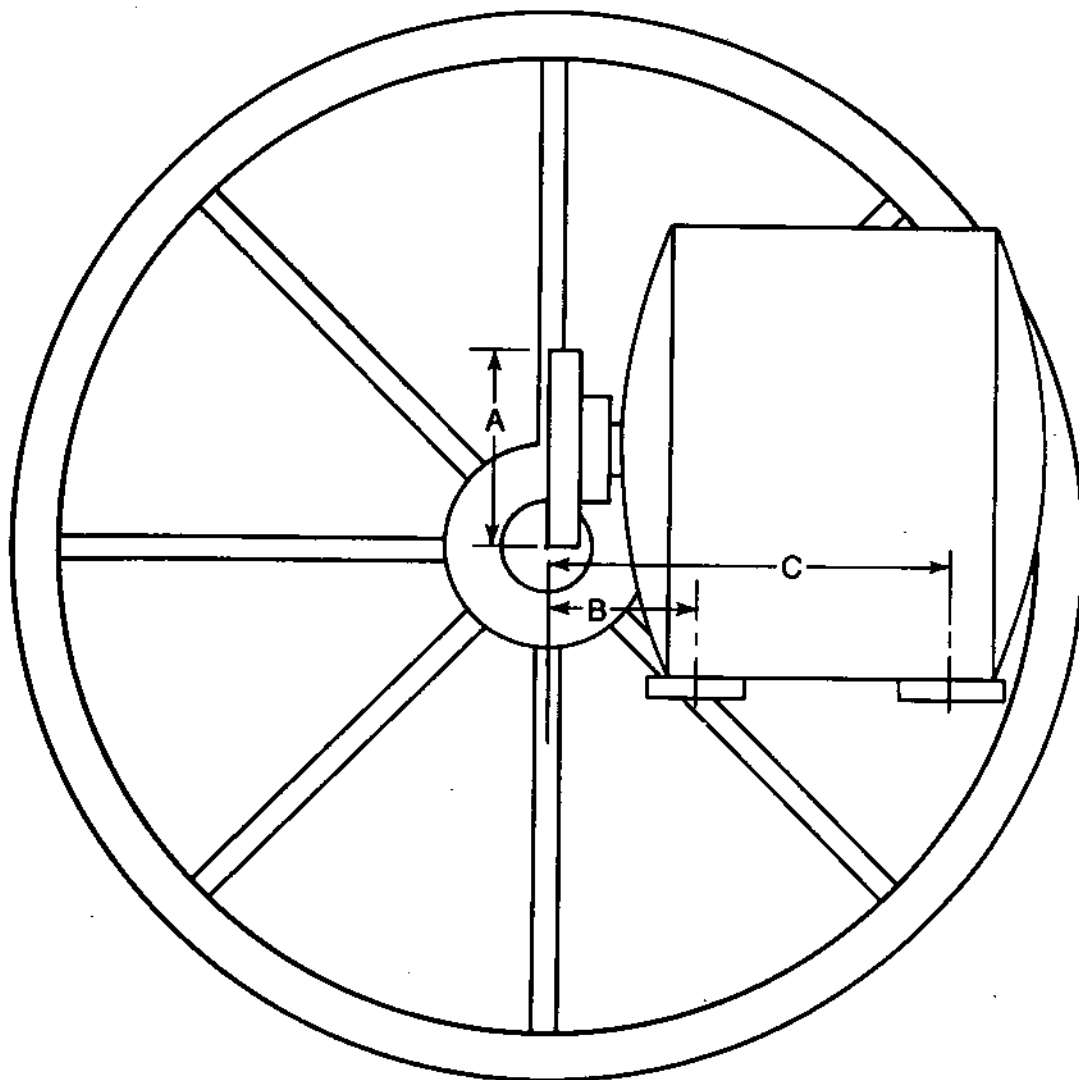


Fig. 23 – Alignment Principle Illustrated with the Wagon Wheel Analogy

If, in addition to the adjustment of the coupling gap, it is also necessary to raise the motor coupling .010 mils to match the stationary coupling face, the .010 amount must also be added. The addition of .003 mils of shim stock at pads B and .008 mils at pads C will close the coupling gap but will not change the height since the coupling relationship is rotating about its lower corner. To increase the elevation by the desired amount, a .010 mil shim must be added under each frame foot making the total shim pads at B .013 mils and .018 mils at C.

On this basis the values from one set of measurements for difference in elevation and coupling gap can be used to calculate the total amount of shimming required and all shims added at one time.

The same procedure is used when correcting misalignment on multiple unit motor-generator sets. On new installations, before bedplates are grouted in, the entire line up of machines can be established using this method. An experienced engineer can calculate the exact amount of

shimming to be used, not only under the bedplate-but also under each machine frame and bearing pedestal. The results are quite accurate when coupling and alignment checks are made.

Air gap corrections can also be made by calculation of shim changes without redoweling being required. Figure 24 shows the procedure to be used when correcting air gap misalignment. Note that two types of pedestal bearing machines are shown; one is flush mounted on the bedplate, the other is a low profile unit with part of the machine below floor level. In one case the distance between hold down bolts is 120 inches in the other 72 inches. In view A the ratio multiplier is $60/24$ or 2.5 to 1, in view B it is $36/40$ or .9 to 1. The calculations are made as shown in the table below the diagrams. The amount of shimming to be added or removed is indicated as the total correction in mils of change to be made at points *m* and *n* per view A and *mm* and *nn* in view B.

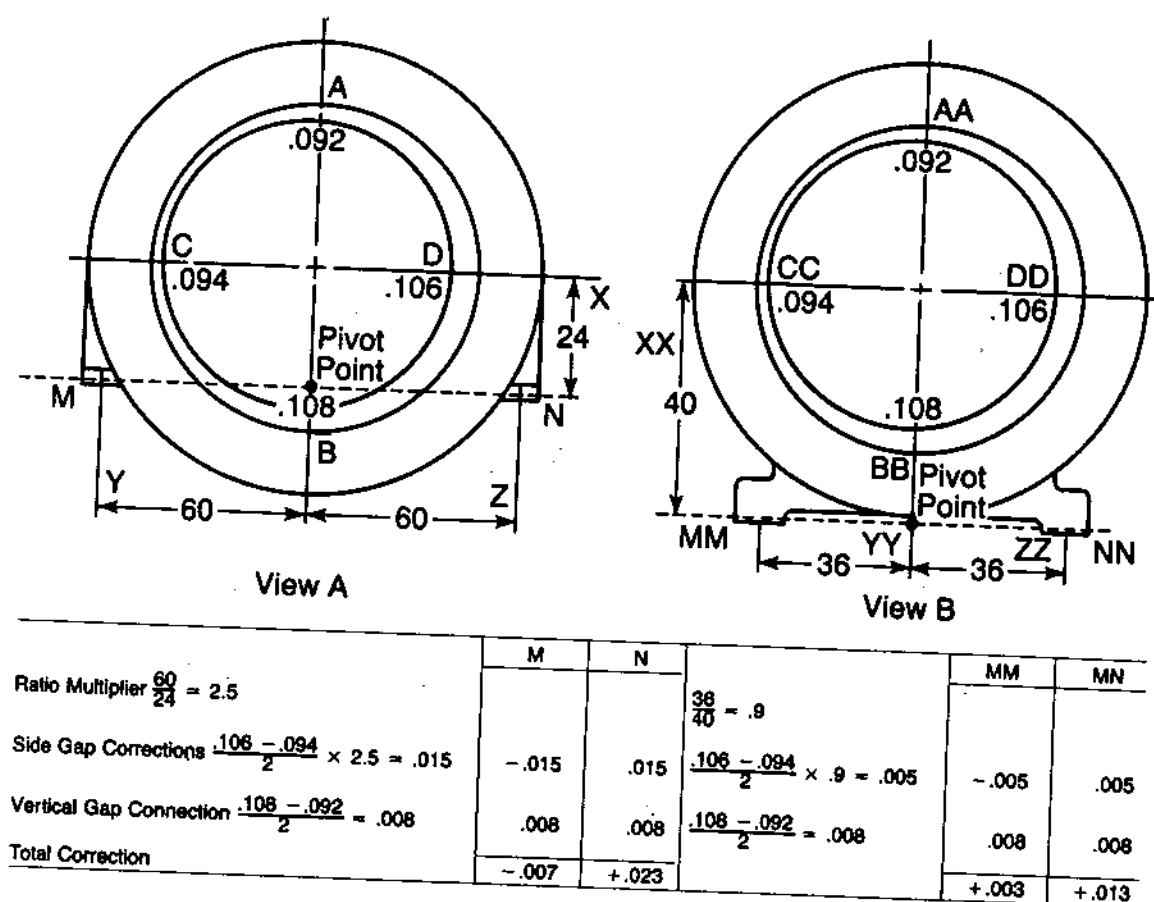


Fig. 24 - Air Gap Correction Calculations for Pedestal Bearing Machines

11.10 Motor Noise Factors

The complex nature of noises associated with some types of industrial activity requires some understanding of what may be classified as the psycho-acoustic effect on human senses and the psychological effects of noise as well as the many physical aspects of sound.

The trend in industry is the need for motors rated at higher and higher speeds and horsepower. This is accelerating the need to cope with the noise problem. The wide range and diversity of motor applications precludes any simple solution. The only way to reduce motor noise is to change design and test for effect. There is no such thing as an absolutely quiet motor.

The sound pressure level produced by a motor in operation is a combination of a number of variables:

The latent ability of the motor to produce noise at rated speed and load.

The acoustical environment in which it operates

The distance from the motor and the directivity index of the motor.

The sound power level (PWL), or noise emission, which is a force measurable in decibels.

Noise frequency, especially frequencies within the range of 1200 to 9600 hertz, the range over which the human ear is most sensitive.

A. Sound Measurement

A scale has been developed to measure acoustics in terms of decibels and a range has been established by OSHA (Occupational Health and Safety Administration) for sound levels which must not be exceeded in industrial plants.

One of the first considerations in evaluating noise specifications for a motor is to determine the application and the ambient noise level. The motor may add little to the noise level where it will be used or it may emit noise that will override all other normal sound and become a predominant and objectionable noise factor.

Audible sound is a force produced by pressure and air in motion. Sound at sea level travels 1100 feet per second.

The sound pressure level of a motor is a function of its inherent ability to produce noise in an acoustic environment. The amount of noise a motor will produce depends on the environment, the distance the sound must travel before it is heard or is measured, and the directivity index of the motor. Few noises radiate sound in all directions with equal intensity and this variable can be determined for each motor. It is called the directivity index.

When attempting to establish limits for the sound power level of a motor it is necessary to specify the conditions under which it is measured. Sound level testing to meet noise emission standards for motors is performed in an anechoic chamber under closely controlled conditions. An engineering analysis provides a critical in-depth study of the frequency, recurrence rate, amplitude, and modulation characteristics of the motor operating in this controlled environment.

Because a motor meets industry standards in the controlled test atmosphere does not assure that it will not have a higher sound level output when installed. The motor sound level is frequently raised by the type of mounting base on which it is installed and by the surrounding surfaces. Such factors as non-acoustical walls, ceilings, and floors, or installation in a small enclosed room can greatly raise the noise level. In a large room sound will disperse and be much less noticeable, particularly if there is other machinery with different sound characteristics, operating in the vicinity.

In motor design analysis for noise level a frequently used method is to measure the sound developed over each of the eight standard octave bands. This is done with acoustical instruments that are tunable and activated by the sound picked up by a microphone. Tests can also be made with self contained portable sound level meters as shown in Figure 25.

It is sometimes necessary to study the sources of noise emanating from a motor. To do this it is necessary to analyze sound readings taken at various distances and directions from the motor. Excessive noise may be caused by mounting structures or resonant couplings with other machines. Often measurements are made and recorded on tape which is then sent to a laboratory for analysis. The laboratory analysis will breakdown the sound into specific band widths and transfer the frequencies and intensities to a graphic form for study to isolate the noise characteristics and determine the source. See Figure 26.

Once the frequencies are known and the cyclic occurrence or resonant factors have been established, the data can be used to determine noises and develop ways to subdue them. When the noise source has been identified it is sometimes relatively simple to resolve the problems. See Figure 27. Sound absorbing barriers, acoustical tile, and resilient mountings may be all that is required. There may be highly complex problems which require analysis up a great volume of data, best suited to use of a computer.



Fig. 25 – Intensity and Frequency of Sound Being Transferred to a Graduated Strip Chart for Study



Fig. 26 – Sound Chart Being Studied for Frequency Band Width and Occurrence

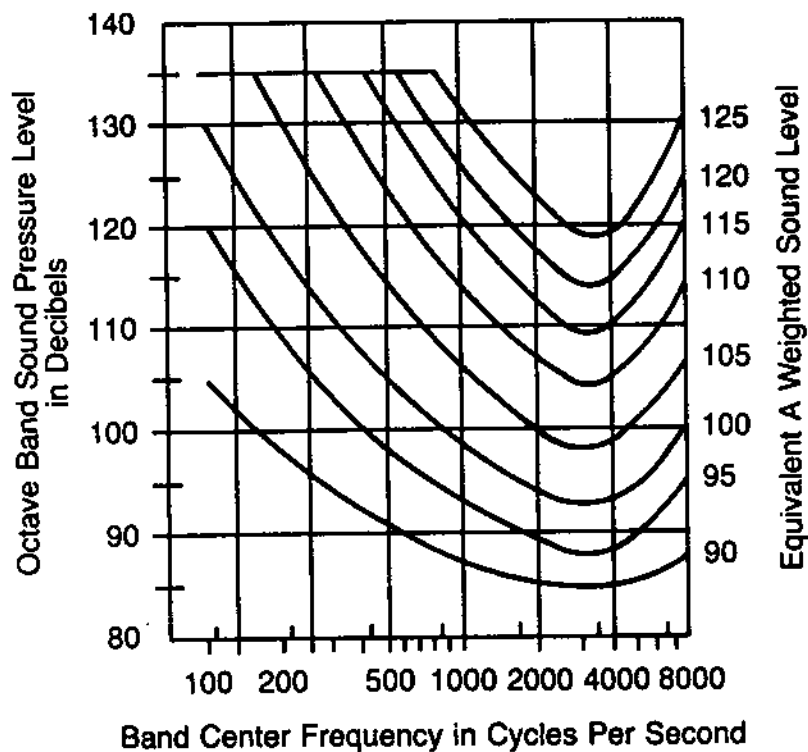


Fig. 27 – Equivalent Sound Level Can Be Determined When Noise Levels Are Measured by Octave Band Analysis

The sound pressure level at a specified distance from a motor is determined by the sound emanating from the motor and the acoustical environment. The sound emitted by a motor in reverberant surrounding will build up to a point where the sound energy is dissipated at a rate equal to that at which energy is supplied. If there are no enclosures and there is ample room for the sound to dissipate, the sound energy is free to travel far enough to diminish and disappear.

If the motor is operating in a closed room, with harsh acoustics, and little or no sound deadening material nearby, there will be a considerable build-up of noise due to reverberation.

B. Sound Level Control

Frequent checks are recommended to insure noise levels do not exceed permitted limits. High sound levels have been determined by OSHA to subject persons exposed to them to possible hearing loss.

Often, noise levels which do not exceed permitted limits become an interference factor in spoken communication. Noise in certain octave bands interferes with such communication more than others. Octave band frequencies of 600-1200, 1200-2400, and 2400-4800 hertz are normal voice frequencies. Sound interference at these frequencies make spoken communication difficult.

More information on noise is available in American Standards Institute and IEEE publications. NEMA has adopted the IEEE Standard #85 as an Industry Guide. It is entitled *Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery*. ANSI publishes various acoustic standards such as S1.31; S1.32; S1.34; S1.35; and S1.36 that deal with broad band noise sources, narrow band noise sources, determination of sound levels, etc. These should be referenced along with IEEE No. 85.

Where two or more sound sources are to be combined the NEMA publication *Sound Level Predictions for Installed Electrical Machines* is a good information source.

Motor manufacturers have made great progress in reducing the noise levels of electrical machinery. Noise in an electric motor is produced as a function of horsepower and speed. As the size of the motor increases, the sound increases at the rate of about 1.7 per horsepower, especially at low frequencies. At higher speeds, especially in motors with large rotors, more cooling air is required. Fans and blowers are usually added which cause turbulence and increase noise. Special construction is required to reduce the noise levels.

To overcome aerodynamic noises caused by fans, air flow, turbulence, and windage caused by rotation, enclosures are usually provided. The addition of enclosures also suppresses magnetic noises (120 hertz magnetizing frequencies and any harmonics). Enclosures also reduce mechanical noises caused by vibration, the whine of high speed bearings, and the noise produced by brushes passing over high speed commutator bars.

In high speed open motors of medium size the predominant noise is produced by the fans. In large high speed motors with radial ducts in the rotor and stator for ventilation, the noise produced by air in motion can create a siren effect which must be suppressed. In totally enclosed motors, cooled by fans, or water or air heat exchangers, the noise level will be lower regardless of size or speed and any audible noise will be mostly magnetically produced. In fan cooled motors the aerodynamic noises will predominate and will mask many mechanical or magnetic noises.

If standard motors will not meet noise level requirements there are two alternatives to be considered; pay the necessary higher price for motors with reduced noise levels or change the local environmental conditions. Sound barriers or sound proof rooms can reduce sound levels and permit use of standard motors. If sound emission cannot be brought to permissible limits, personnel exposed should be provided with ear protection and required to use it.

Medical Surveillance

New workers should be given a Base Line Audiometric examination.

Others who are exposed to a noise above a time weighted average of 85 dbA routinely must be re-examined annually. The examinations must be conducted in accordance with current OSHA standards.

Capacitors

Function of Capacitors 2:12.1
Capacitor Design 2:12.2
Capacitor Rating 2:12.4
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Capacitor Tests 2:12.9
Capacitor Maintenance 2:12.11

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Capacitors

12.1 Function of Capacitors

The function of a shunt capacitor in a power system is to supply magnetizing current at the point where it is connected. The loads on a power system require two kinds of current. One kind is the power current, or in-phase current, that does the work of heating a lamp filament or running a motor. The other kind is the magnetizing current, or out-of-phase current, that stores up energy in magnetic fields twice in each cycle of current, but which does not cause any permanent transfer of energy from the generator to the load. Capacitors also have the ability to store energy twice in each cycle, but not at the same time the magnetic fields store energy. This makes it possible to shift the magnetizing current and energy back and forth between the capacitors and the magnetic fields. When this happens, the capacitors are said to supply magnetizing current or lagging reactive power.

When capacitors are used to supply magnetizing current, there are a number of other effects on the power system. One of the most important effects is the increase of voltage at the capacitor location. If the magnetizing current comes from the generator, it causes voltage drop in the lines between the generator and the load. If a capacitor near the load supplies the magnetizing current, the voltage drop does not take place and the voltage near the capacitor and load is higher. It is possible to hold the voltage between certain limits by automatically turning on more capacitors when the voltage gets low and turning them off when the voltage gets high.

Magnetizing current flowing through resistance between the generator and the load causes power loss. Even though the magnetizing current does not carry any power to the load, it does use some power in reaching it. If the magnetizing current comes from capacitors near the load, these power losses do not occur.

By supplying magnetizing current from a point near the load instead of from the generators, capacitors make it possible for the generators, transformers, lines, etc., to carry more in-phase current. This means that it is possible to get more useful power to the load over the same system which results in more power sales for the same investment in lines and transformers. The only additional costs are the capacitors and generating costs.

The effect of capacitors is sometimes described as raising the power factor. This is just another way of describing the changes that take place when the magnetizing current is supplied from capacitors. The power factor is the ratio of the in-phase current to the total current. When the magnetizing current is small, the total current is just a little larger than the in-phase current and the power factor is high. When the magnetizing current is large compared to the power current, then the total current is much larger than the power current and the power factor is low. For any load, the in-phase and out-of-phase currents (and therefore the power factor) are determined by the load itself. Capacitors cannot change the load power factor. They can only change the power factor of the circuit between the capacitor and the generator.

Capacitors are much more valuable in places where the generator power factor is low and needs to be raised, than where it is already high. It is possible in extreme cases to supply more magnetizing current than the load can absorb; the power factor becomes leading and the losses may be increased instead of decreased. Capacitors are also more effective when the line impedance is mostly reactance and only a small part resistance. They can cancel out the voltage drop through reactance more effectively than the drop through resistance.

Capacitors cannot be used in every part of every system with good results, but most systems have some suitable locations. They must be carefully and properly applied in order to do the job that is intended for them. Capacitors can save money by reducing losses, by increasing load carrying ability and by regulating voltage. Capacitors are a good investment whenever the savings they effect are greater than their cost.

A. Capacitor Design

A capacitor is a device consisting of two large metal plates separated by an insulating material. This insulation is commonly referred to as the dielectric, and is the actual working element of the capacitor. There is no metal connection inside the capacitor between the two metal surfaces. When these two surfaces are connected to a source of potential, current flows in the capacitor and energy is stored in the dielectric. If the source of potential is direct current, current flows for a limited time and a definite quantity of energy is stored. The amount stored depends on the area and thickness of the dielectric, its characteristic, and the voltage applied.

If the voltage is reversed, the energy will be removed and restored with the opposite polarity, after which the current again drops to nearly zero. When the source is alternating current, energy will be stored and removed during each half cycle. This constant charging and discharging will result in a continuous current flow, as indicated by an ammeter.

The current measured on a sine wave voltage will depend upon the electrical size of the capacitor in microfarads, the voltage, and the frequency in cycles.

Where E = kilovolts, C = microfarads, and frequency is 60 hertz:
(amperes) = $E \times .377 \times C$

Since the insulation is the principal working element in capacitors, it must be used efficiently. While insulation is important in all electrical equipment, it nevertheless usually plays the secondary role of keeping conductors separated. In most apparatus it is convenient to use it generously, and two thousandths to twenty thousandths of an inch of insulation is used for each 100 volts applied. The art of building capacitors resolves itself into the art of developing special types of insulation having remarkable quality and uniform characteristics which permit the use of very thin layers of insulation. Individual winding voltage and dielectric system thickness and composition are chosen to give the lowest cost consistent with dielectric strength and corona starting voltage requirements.

Most a-c power capacitors include a discharge resistor which is assembled inside the case for the purpose of automatically discharging them after they are disconnected from the circuit. Since this value of resistance is low compared to the resistance of the insulation itself, the current which such a capacitor will draw on a d-c circuit will be determined largely by the value of this resistance. A measuring of resistance, therefore, does not give any information on the conditions of the insulation in a capacitor containing internal discharge resistances.

The capacitor case is of welded sheet steel construction, with mounting brackets.

The bushings which bring the leads through the case are made of porcelain, with threaded studs for making connections. To give long resistance to the weather, the units are fabricated from stainless steel cases painted with one coat of alkyd zinc chromate primer and one coat of oven-cured acrylic enamel.

The electrical size of a capacitor is technically measured in microfarads. A more convenient term for a-c capacitors is kVAR (kilovolt-amperes-reactive.) This is simply the product of the rated current in amperes, and the rated voltage in kilovolts. A 15 kVAR, 480-volt capacitor is simply one which will draw a current of 31.25 amperes when connected to 480 volts at the rated frequency. The microfarad value a 15 kVAR capacitor must have in order to draw 31.25 amperes on 480 volts depends on the frequency.

$$\frac{15,000 \text{ volt amp.}}{480 \text{ volt}} = 31.25 \text{ amperes}$$

If a 15 kVAR capacitor on 480 volts draws 31.25 amperes, it must have a reactance of 15.36 ohms.

$$\frac{480 \text{ volts}}{31.25 \text{ amp.}} = 15.36 \text{ ohms.}$$

The capacitance this unit must have in order to have a reactance of 15.36 ohms depends on the frequency. If the frequency is 60 hertz, then the capacitance corresponding to a reactance X_c of 15.36 ohms is:

$$\text{Capacitance in mfd.} = \frac{1 \times 10^6}{2\pi f X_c} = 173$$

If the frequency were 120 hertz, the capacitance needed would have been 86.5 microfarads.

B. Capacitor Ratings

Standard power capacitor units for use on primary distribution circuits are rated 50, 100, 150 or 200 kVAR, single phase, with one or two bushings and from 2400 volts to 24940 volts. In addition to the single phase units available, there are three phase units rated at 300 or 400 kVAR three phase and voltage ratings from 4160/2400 to 24940/14400.

Each unit receives many tests, including a complete insulation test at the factory to make sure its strength and characteristics are up to standards for its voltage class and rating. The tests include both 60 hertz and surge voltages.

C. Capacitor Application

It is essential that consideration be given to the arrangement of capacitor units and complete equipment as an installation to provide adequate ventilation and dissipation of losses. Capacitors are designed to operate at a lower temperature rise than most other types of apparatus, for the following specific reasons.

Capacitors operate at full load continuously which eliminates the benefit of an average temperature rise derived from the usual load cycle under which most other apparatus operates.

Capacitors are designed to operate at comparatively high dielectric stresses for reasons of economy. The combination of these stresses with operation at excessive temperature for extensive periods of time will result in gradual deterioration and shortened life.

Capacitors which are mounted in the open are cooled by freely circulating air and by radiation. Mounting many units side by side reduces the radiation of heat. Mounting the units in vertical arrangements without proper ventilation, causes the warm air from the lower rows to rise around the top rows. Any housing restricts the free movement of air and may raise the capacitor operating temperature. Capacitors in standard racks and housing will operate at a safe temperature as long as the surrounding air temperature is not above the rating. Carefully check capacitors in nonstandard housings to be certain that they are operating within their temperature limits.

Standards have been established which allow a maximum permissible operating voltage of 110% of the capacitor voltage rating. Protect capacitors which are exposed to high transient voltages by station-type or line-type lightning arresters located as near as possible to the capacitors. If the capacitors are indoors, the arrester may be located at the line entrance to the building. Allowable transient voltages are limited by the insulation strength of the capacitor rather than by heating. It is possible that capacitor can be subjected to high transient overvoltages by faulty switches and circuit breakers which allow restrikes. Switch capacitors only by devices which are capable of opening the circuit without harmful restrikes.

Power capacitors are designed to carry 135% of their rated kVAR. This extra capacity is put in to allow for fundamental frequency over-voltages up to 110% limit and for harmonic voltages. When harmonic voltages are generated in a power system by saturation in transformers or other devices, harmonic frequency currents tend to flow in the capacitors as well as in other parts of the system. The product of the harmonic voltage and harmonic current is a harmonic kVAR which is added to the fundamental frequency kVAR to determine if the capacitor is overloaded. Normally, the harmonics are small, and do not interfere with the operation of the capacitor. On the rare occasions when harmonic currents do cause trouble by overheating the capacitor or blowing fuses, it can be eliminated by the proper use of filters which limit harmonic currents by changing the circuit impedance.

The method of mounting capacitor units generally depends on the size of the bank. Banks ranging from 150 to 1800 kVAR, may be purchased as complete assemblies, which include capacitors, oil switches, and

mounting racks, wired and ready to mount directly on poles. See Figures 1 and 2.

When larger banks are needed, they are usually placed in substations. Capacitor units may be placed in open structural steel racks, or enclosed in metal cabinets. The enclosed type is used where appearance and space are important, or where safety demands completely closed housings. See Figure 3. Structural racks are less expensive in direct cost and, for most uses, will prove satisfactory.

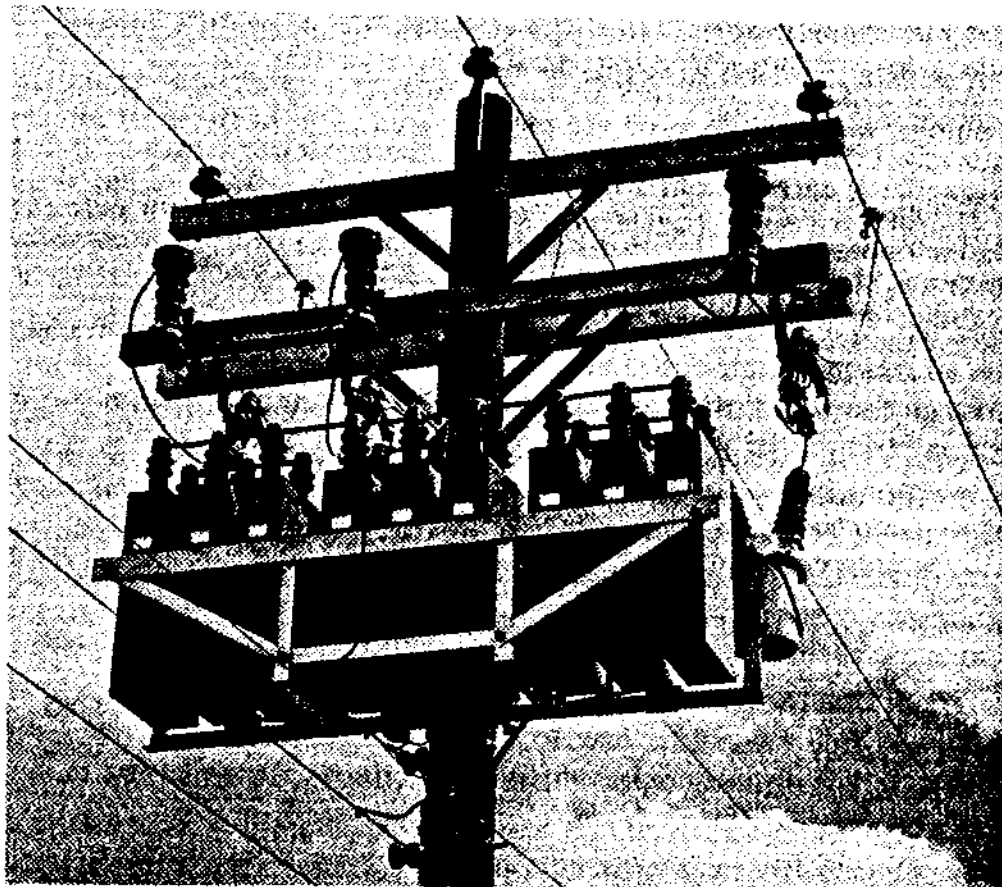


Fig. 1 – Typical Pole Mounted Capacitor Installation

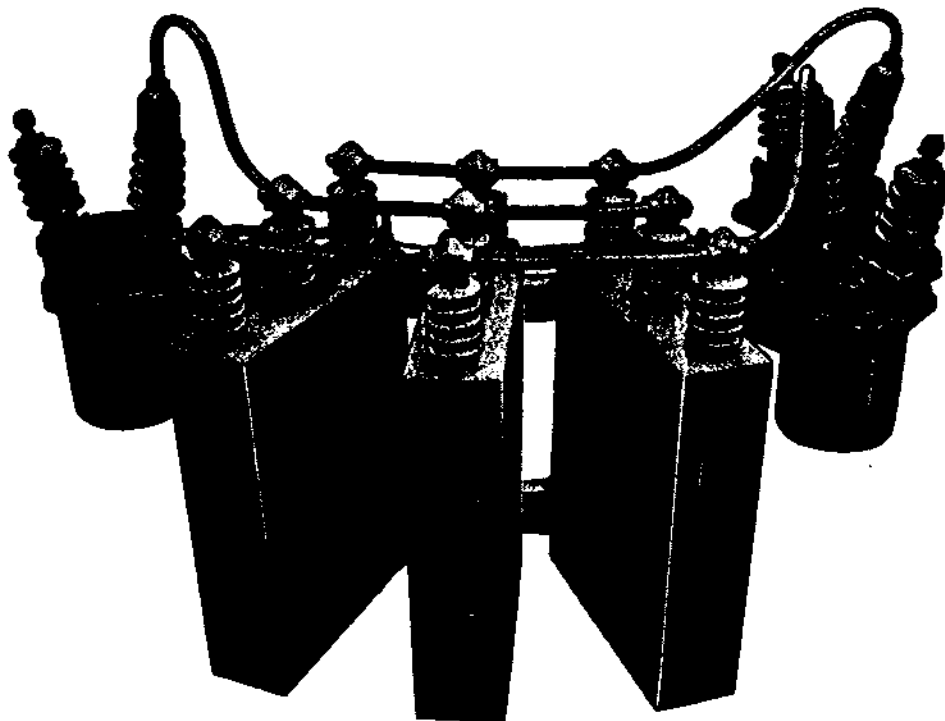


Fig. 2 – Typical 900 kVA Pole Mounted Switched Capacitor Bank

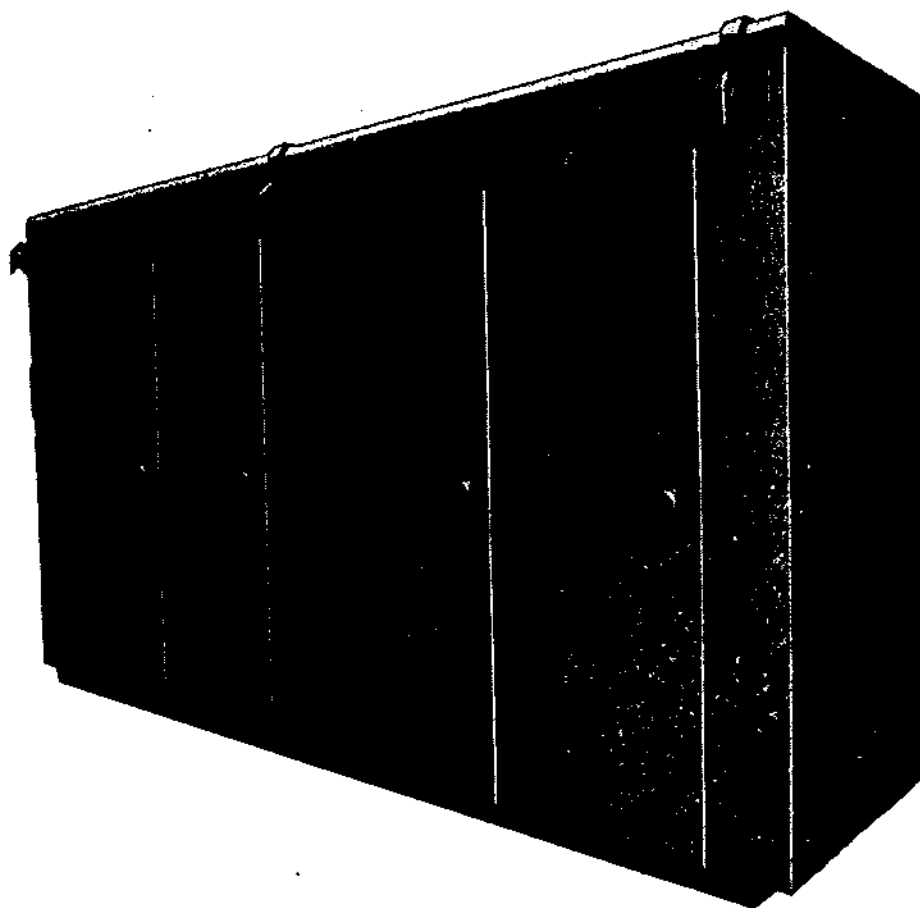


Fig. 3 – A Low-Profile Metal Enclosed Capacitor Bank

12.2 Capacitor Installation

Make inspection within eight to twenty-four hours after installation of a capacitor unit or equipment, and at the first periods of light load on the circuit when maximum overvoltage will be obtained.

Warning: Follow the manufacturer's capacitor discharge instructions. Before touching any parts of a capacitor, disconnect it, allow time for the capacitor to discharge, then short the terminals together and ground. Failure to heed this warning can result in severe injury or death by electric shock.

Readings of voltage and current in each phase should be made to determine that:

phase voltages are balanced within the limits of the capacitor rating.

harmonic currents in excess of allowed values are not present, by comparing operating current to kVAR rating.

Allowance should be made for the fact that manufacturing tolerances are minus zero to plus 15% on individual capacitors.

Regular inspection of capacitor installation on an established schedule should include a check of ventilation, fuses, temperature and voltage conditions. Clean capacitor bushings and insulating surfaces periodically, depending on the rate of accumulation of conducting material on the insulators.

Capacitors to be installed under conditions covered by the National Electrical Code are provided with means of reducing the residual voltage in accordance with code requirements. This is usually accomplished by means of discharge resistors built into the capacitor units.

Capacitors not subject to the requirements of the National Electrical Code are provided with means of reducing the residual voltage to approximately 50 volts within five minutes after the capacitor is disconnected from the source of supply. (One minute for low voltage capacitors, 600 volts and below.)

12.3 Unit Inspection and Testing

Warning: Before performing any tests or handling any capacitors, read the manufacturer's instructions with special attention on safety instructions, failure to do so can result in severe personal injury or death by electric shock.

A. Capacitor Tests

1. Visual Check: For damaged or dirty bushings, obvious leaks, and finish damage needing touch-up.

2. Capacitance Check: Probably the most important and easiest test to perform on the unit. After insuring the capacitor is discharged (refer to the manufacturer's instructions for safety information), a measurement can be made. The measured capacitance should be between 100% and 110% of nominal capacitance. If the capacitance of a unit tests between 90% and 100% or 110% and 120% of nominal capacitance consult with the manufacturer for comparison with original factory test value. Capacitance higher than 120% of nominal generally indicates one or more short circuited groups of internal windings, and the capacitor should be considered defective.

Capacitance readings should be made when the capacitor temperature is at 20 to 30 degrees Celsius (68-86 degrees Fahrenheit).

Nominal capacitance values for standard capacitor units can be determined by using the following formula:

$$C_{\text{nom}} = \frac{1000 \times \text{kVAR}}{(\text{kV})^2 2\pi f}$$

C_{nom} is in microfarads.

kV is rated voltage in kilovolts.

f is rated frequency in hertz.

Rated kVAR, voltage, and frequency can be found on the capacitor nameplate.

3. Dielectric Strength Tests: Preferably made using a direct-current voltage of 75 percent of original factory test level equal to 3.2 times the nameplate voltage rating. The test voltage should be held for ten seconds. On single phase units this voltage is applied bushing-to-bushing or bushing to ground stud for single bushing capacitors. On three phase wye-connected units apply voltage phase-to-neutral at a direct-current voltage of 3.2 times the rated one line-to-neutral voltage between all pairs of bushings.

An alternate test is to use an alternating-current voltage of 1.5 times the rated voltage. Peak transient voltage on energization must be limited to 125 percent of the steady-state peak voltage. Breaker re-strikes on de-energizing must be prevented.

During application of test voltage listen for any indication of internal arcing. If any is heard the unit is defective.

Avoid danger to personnel during this test from possible case rupture by maintaining adequate shielding. After the test, discharge the capacitor by using a properly insulated resistor with a resistance value in ohms approximately equal to the peak voltage which was applied to the capacitor. The resistor must also have sufficient voltage and energy absorption capability. Initial discharging of the capacitor must be from a shielded location, first with the resistor, then with a final low resistance short. Use the same shorting procedure directly at the capacitor terminals.

Recheck the capacitor after the overvoltage tests and compare with the original values. Initial and final readings should not vary more than 2 percent.

4. Discharge Resistor Check: Discharge resistors are included in most high voltage capacitors to reduce the voltage from rated voltage to 50 volts in five minutes or less. The actual value of resistance may vary with different designs but a maximum value can be determined from the following formula:

$$R = \frac{300 \text{ Sec.} \times 1.1 \times \ln V \times 1.414}{C_{\text{nom}} 50}$$

R is in megohms.

C_{nom} is in microfarads.

V is the rated voltage in volts.

A resistance reading in the range of 70 to 100 percent of this value indicates the resistors are probably alright. If values lower than 70 percent are obtained, consult the manufacturer for precise limits.

For units rated 600 volts or less, replace 300 seconds in the above formula with a value of 60 seconds.

5. Leak Test: Slow leaks at room temperature are sometimes not detectable so it might be desirable to conduct a leak test at elevated temperature. If this test is to be performed, it should be done as follows:

Give the units a preliminary check by tapping the top of the capacitor case with a half-dollar or a heavy washer. A distinctly hollow sound or a sound distinctly different in comparison with other units indicate low fluid. Make this test when the units are cool.

Elevated temperature increases the internal pressure thus improving the chance of detecting leaks. The preferred method of elevating the temperature is to place the capacitor in an oven at 75 degrees Celsius for 24 hours (only effective in ambient temperatures above 20C (68F)). Leaking fluid can be more easily seen if the suspect areas are sprayed before heating with Spotcheck Developer, SKD-NF, a product of Magnaflux Corporation of Chicago, or similar product.

Particular areas to observe are bushing connections, fill plug, mounting bracket weld seams, and all case weld seams. If a leak is detected consult the manufacturer for possibility of repair.

B. Capacitor Maintenance

Before re-fusing, make a visual inspection and capacitance test. Also a check for terminal-to-terminal shorts can be performed using a medium voltage supply. A small 90 volt battery and indicating light will detect more shorted capacitors than a lower voltage.

Warning: Scrap capacitors only in strict conformance with EPA and other applicable federal, state, and local government codes and regulations. Failure to heed this warning can cause severe personal injury or death, and damage to property.

When units are beyond repair scrap in accordance with the following:

- (a) Capacitors containing polychlorinated biphenol (PCB^①) must be handled in accordance with the current requirements of the U.S. Environmental Protection Agency (EPA) and state and local government requirements.
- (b) Capacitors containing mineral oil or isopropylbiphenyl may be disposed of by incineration or other means in accordance with federal, state, and local government regulations.

In any case of scrapping, the serial number or preferably the entire nameplate should be returned to the manufacturer for field performance records.

^① This insulating fluid has been marketed under various trade names such as Inerteen or Askarel.

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Regulated Thyristor Drive Systems

Adjustable speed drive systems are used when it is necessary to closely regulate the direct-current power supply to control speeds of drive motors. These systems must slow or speed motors to meet a great variety of process requirements and instantaneous reversals in rotation or emergency stop conditions. To perform these functions the system must be coordinated, stable, and responsive to signals emanating from numerous points in the control scheme. Regulation of the system must be carefully controlled to prevent over-ride from any transient signal sources. When transients occur, they must be handled promptly by the regulators controlling the system.

Volume 2, Chapter 9 *Parallel Operation of D-C Generators and D-C Motors* provides an insight into the importance of obtaining stable output from a generator to d-c machines and why regulation is so important in a drive system. Today thyristor power supplies are the most common source of d-c voltage for regulated drives.

The thyristor power supply has largely replaced the traditional motor-generator set because it has a shorter time delay and a higher efficiency. The thyristor is also lighter and does not require a special foundation. The signal processing portion of the system uses semiconductor circuitry with frequent use of operational amplifiers. The negligible time delay and predictable performance of these devices has greatly improved the efficiency of simple systems and made possible the development of sophisticated drive systems.

13.1 Basic Theory

Figure 1 is a block diagram of a typical thyristor drive system. The thyristor power modulator takes power from the a-c line and rectifies and controls the voltage and current supplied to the motor. The gating block indicates the circuitry required for generating the gate pulses of the proper shape, phase, and sequence to control the thyristor power modulator. The signal processor combines the input reference signal and the feedback signals, and modifies them to control the gate pulses to obtain system performance of the desired accuracy, speed of response, and stability. Most drives have voltage, current, and speed feedback. Other feedback that may be involved includes position and tension.

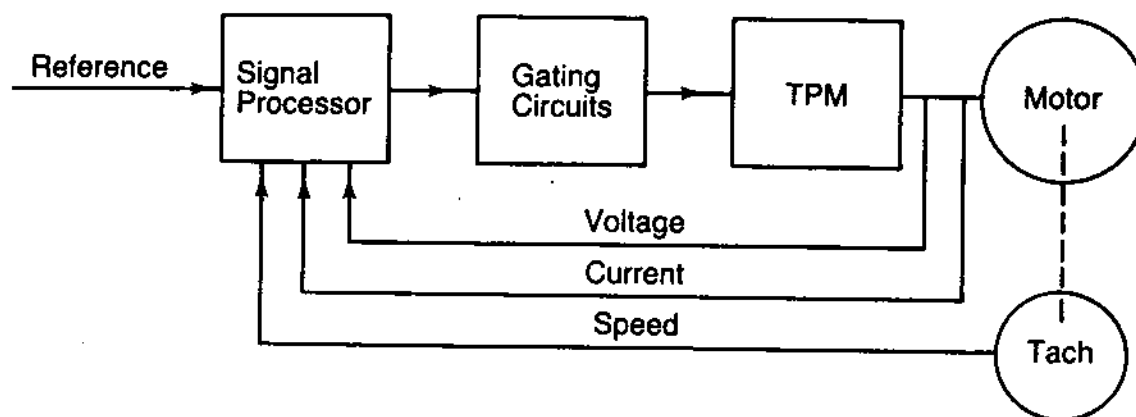


Fig. 1 – Block Diagram of a Typical Thyristor Drive System

The thyristor, often called an SCR for silicon controlled rectifier, is a semiconductor device that can block voltage in both directions but can conduct current in the forward direction when a pulse is applied to its gate. Figure 2 diagrams a thyristor in series with an a-c voltage source and a resistor load. Figure 3 shows one cycle of the supply voltage as a broken line. If a pulse is applied to the gate at angle alpha (α), the voltage on the load is represented by the solid line and is zero up to the angle of alpha. It follows the source voltage for the remainder of the positive half-cycle and is zero for the negative half-cycle. The voltage on the load can be varied from a full half-cycle to zero by varying the gate pulse angle from zero to 180 degrees. The current for a resistance load would have the same shape as the load voltage, as indicated by the shaded area in Figure 3.

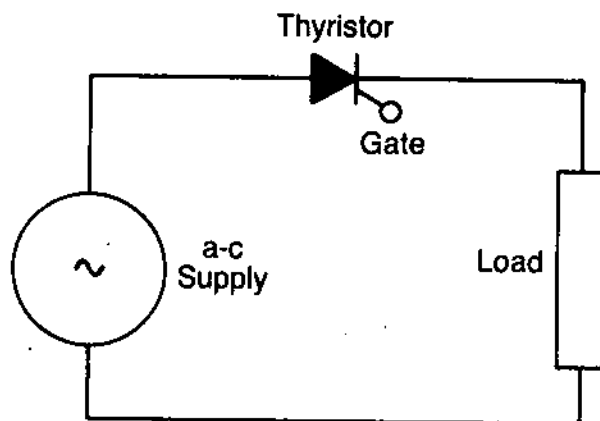


Fig. 2 – Single-Phase Half-Wave Thyristor Circuit

For an inductive load the current would build more slowly at the leading edge of the pulse and would tail off beyond 180 degrees because the current in an inductance cannot be brought to zero instantaneously. The voltage on the load would also persist into the negative half-cycle until the current is brought to zero.

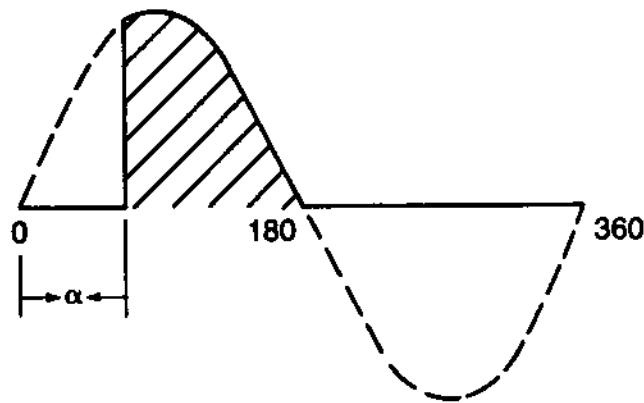


Fig. 3 – Wave Form for a Single-Phase Half-Wave Thyristor Circuit

The single phase half-wave-cycle shown in Figure 2 has some application on small loads but other, more efficient circuits are of importance for industrial drives.

13.2 Converter Circuits

Of the many power circuits that can be used, this discussion will be limited to single and three phase bridge semiconverter and three phase full-wave-bridge converter circuits.

The semiconverter can provide current and voltage in the forward direction only. The full converter can provide current in the forward direction and voltage in both directions.

A. Single Phase Semiconverters

The single phase bridge semiconverter is applied in drives up to 5 hp and as field supply for motors or generators.

Figures 4, 5, and 6 show the power circuit and typical waveforms with the thyristors being gated or turned on at 90 degrees. There are two main factors to consider which are shown in Figures 5 and 6. One factor is where the armature current is discontinuous and the other condition, Figure 6, is where the armature current is continuous.

The upper curve in these diagrams shows the a-c voltage as a broken line, the motor counter electromotive force (CEMF) as a straight broken line. 1TH, Figures 4 and 5, is gated on at 90 degrees and supplies source voltage to the motor armature through 1TH and 2D (Figure 4). The armature voltage follows the a-c voltage up to 180 degrees with the armature current increasing until the a-c voltage becomes equal to the motor CEMF then decreasing when the a-c voltage reaches zero. The armature current commutates to the free wheeling diode 3D and 1TH

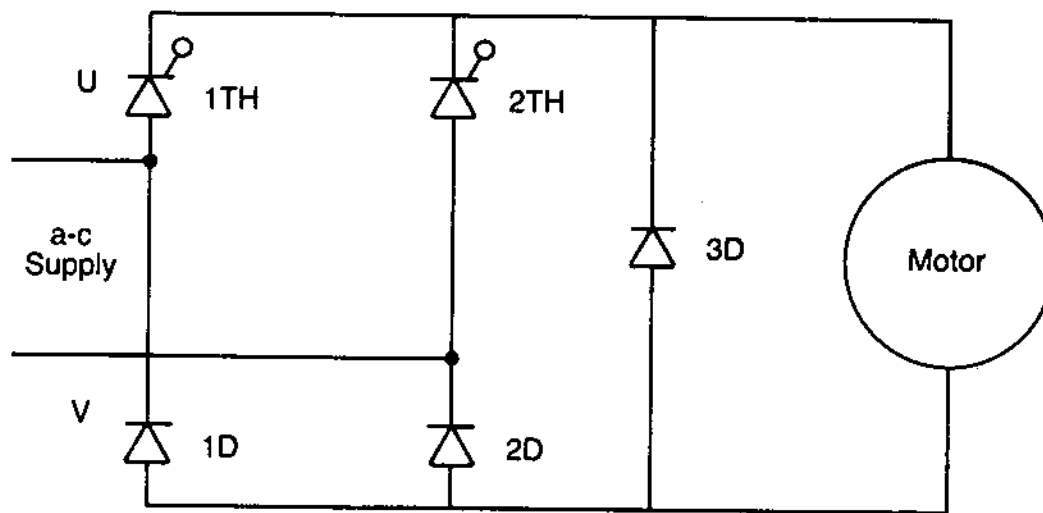


Fig. 4 - Single-Phase Bridge Semiconverter Control Scheme

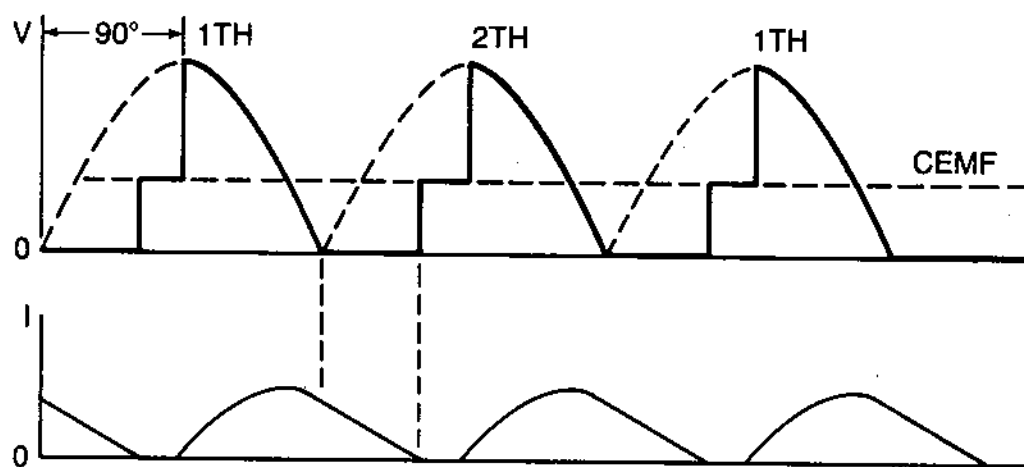


Fig. 5 - Wave Forms for Discontinuous Current (Fig. 4)

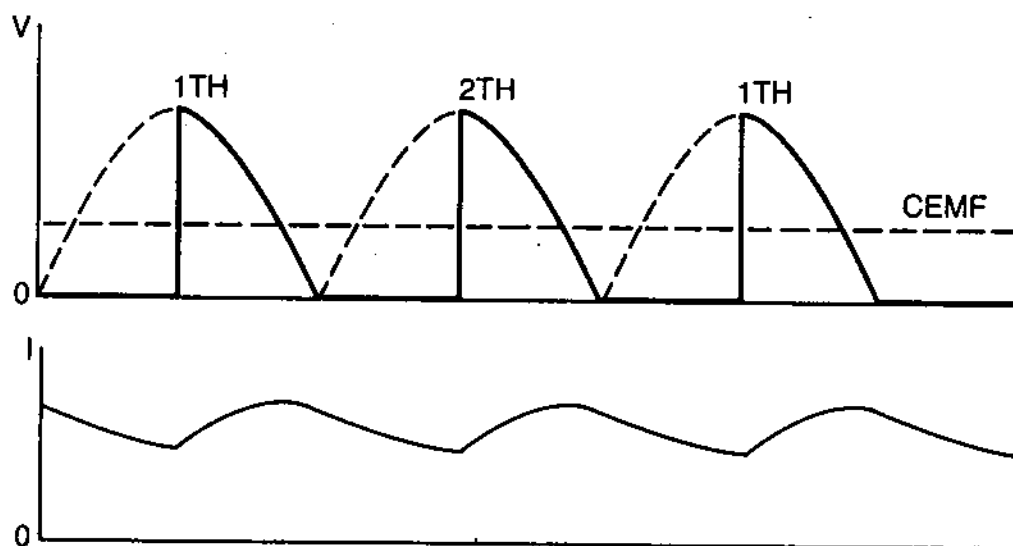


Fig. 6 - Wave Forms for Continuous Current (Fig. 4)

turns off. At this instant the armature voltage is approximately zero since the armature is short circuited by **2D** when it is conducting current. When the armature current decays to zero, **3D** blocks and the armature voltage becomes equal to the CEMF, where it remains until **2TH** is again gated on and a-c voltage is applied to the armature through **2TH** and **1D**.

For the continuous current example shown in Figure 6, the action is similar except that there is no condition (except instantaneously) when the armature voltage is equal to the CEMF. The purpose of the free wheeling diode **3D** is to assist in proper commutation of the thyristors at high angles of delay and continuous currents.

B. Three Phase Semiconverters

The three phase semiconverter is used in the 5 to 200 hp drive range. It is diagrammed in Figure 7. Three thyristors, **1TH-3TH**, and three diodes **1D-3D** form the three phase bridge and the free wheeling diode **4D** performs the function described for the single phase semiconverter.

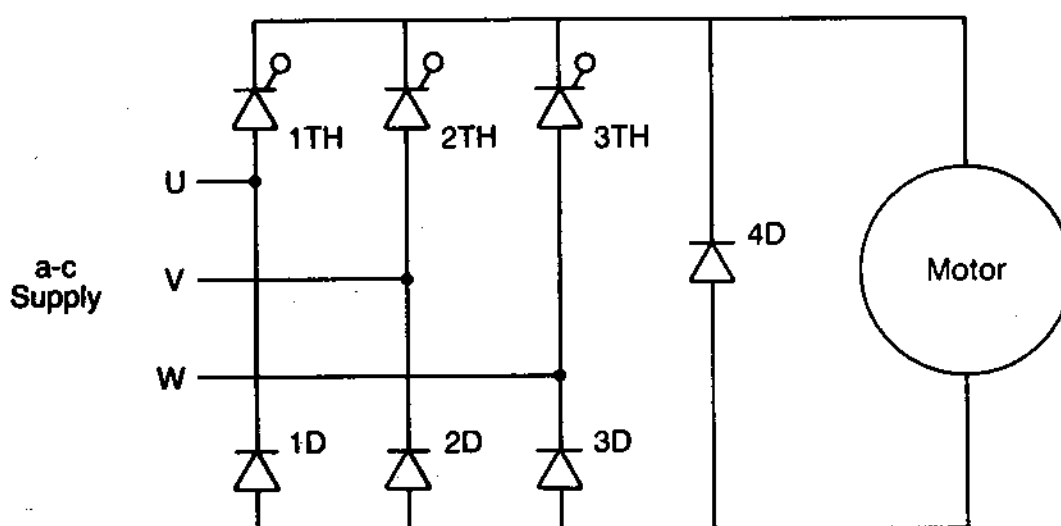


Fig. 7 - Three Phase Bridge Semiconverter Control Scheme

The upper curve in Figure 8 shows the voltage and the lower curve shows the current wave forms for a gating angle of 30 degrees. The gating angle is measured from the point where the voltage across the thyristor first becomes positive in the forward direction. This is the point at which the device would start to conduct if it were a diode instead of a thyristor.

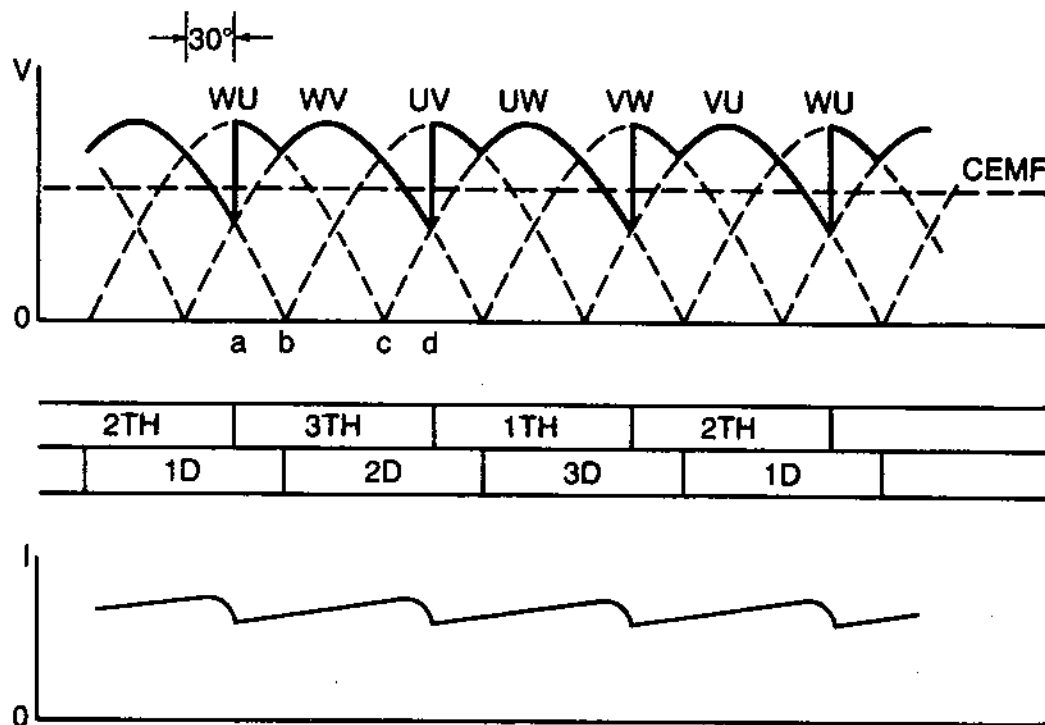


Fig. 8 – Wave Forms for Three Phase Bridge Semiconverter Control Scheme – Small Gating Angle

The broken lines represent a-c voltages in the bridge, the solid lines represent the output voltage, and the horizontal broken line represents the motor counter electromotive force.

In reading Figure 8, assume that at angle **a**, where voltage **WU** is the most positive, thyristor **3TH** is gated on. Current will then flow from **W** through **3TH**, the load **1D**, and through **U**, through the voltage source to **W**, Figure 7. At angle **b** the voltage **WV** becomes more positive than **WU** and the current commutates from diode **1D** to diode **2D**. The current path, Figure 7, is then from **W** through **3TH**, the load, then through **2D**, to **V** (the voltage source), and back to **W**. At angle **c**, **UV** becomes more positive than **WV**, **1TH** will not gate on and commutation will not take place. At angle **d**, thyristor **1TH** is gated on and current commutates from **3TH** to **1TH**. The current path is then from **U** through **1TH**, through the load, through **2D**, to **V**, then through the source to **U**. Similarly the current commutates from device to device through the remainder of the cycle. The conduction angles of the thyristors and diodes are shown below the voltage curves.

Note that for this small angle of gating the free wheeling diode **4D** does not fit into the conduction pattern. It has been assumed that the current is continuous, as shown in Figure 8.

Figure 9 shows wave forms for a large gating angle of approximately 140 degrees. This angle results in a low average output voltage and therefore low motor speed. At angle **a** assume the current is flowing in the free wheeling diode **4D** driven by the inductive effect of the motor load, and thyristor **3TH** is gated on. The voltage **WV** will be applied to the load and diode **4D** attempting to drive the current in **4D** in the reverse direction. The current in **4D** will go to zero and commute to **2D** and **3TH**. At angle **b** the voltage **WV** goes through zero and the current will commute from **2D** and **3TH** to **4D**. At angle **c** thyristor **1TH** is gated on and the current is commutated from **4D** to **1TH** and **3D**.

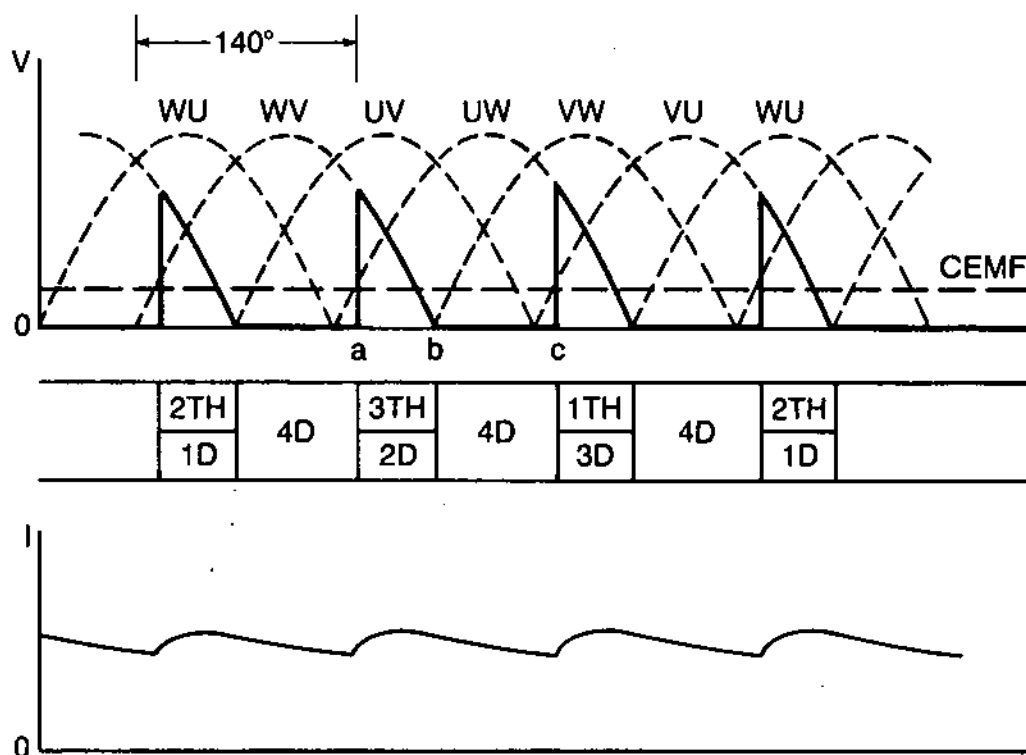


Fig. 9 – Wave Forms for Three Phase Bridge Semiconverter Control Scheme – Large Gating Angle

13.3 Three Phase Converters

The three phase converter is used for medium and large drives. A typical three phase bridge converter control scheme is diagrammed in Figure 10. This converter consists of six thyristors arranged in a three phase bridge. For large drives the bridges are paralleled to obtain necessary current rating. The basic operation can be explained by considering it as a single bridge. At angle **a**, Figures 10 and 11, assume that thyristors **3TH** and **5TH** are conducting and a gate pulse is applied to thyristors **1TH** and **5TH**. Thyristor **5TH** is already conducting and since voltage **UV** is more positive than voltage **WV**, the current will commute from **3TH** to **1TH**. At angle **b** a pulse is applied to the gates of thyristors **1TH** and **6TH** so the current will commute from **5TH** to

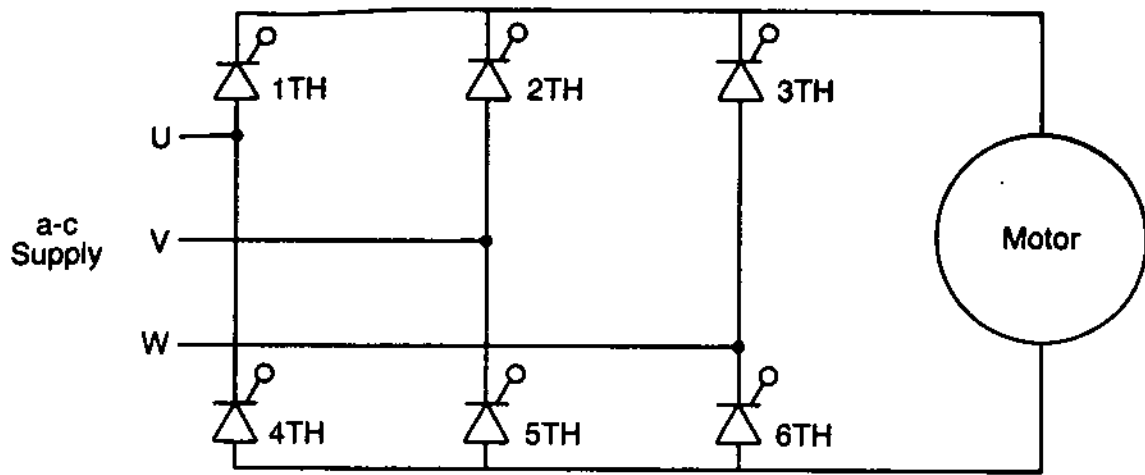


Fig. 10 – Three Phase Bridge Converter Control Scheme

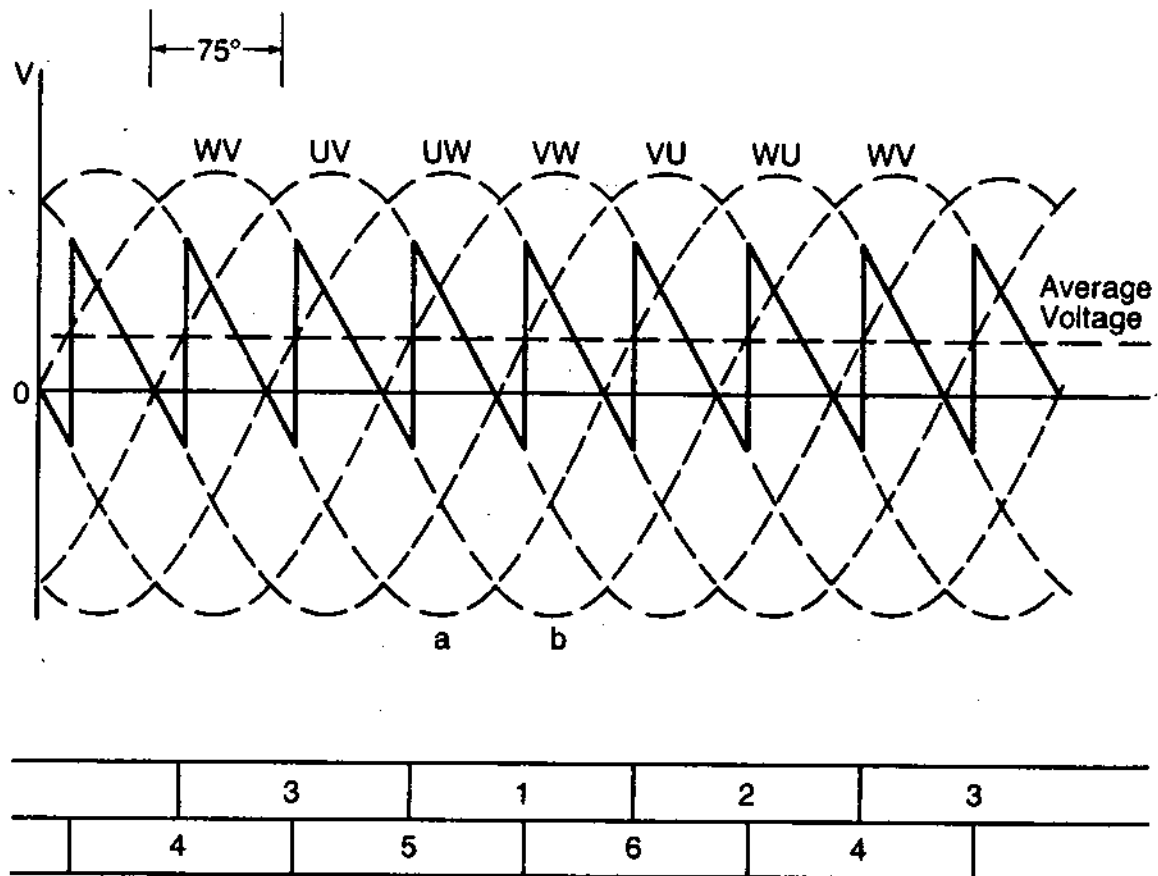


Fig. 11 – Wave Forms for Three Phase Bridge Converter Control Scheme

6TH since voltage **UW** is more positive than **UV**. The blocks below the wave forms in Figure 11 show the conducting periods for each of the thyristors which is shown at 120 degrees. The output voltage of the bridge (solid lines, Figure 11) extends both positive and negative, with the average being positive for the 75 degree gating angle. As the gating angle varies from 0 to 90 degrees and then to 180 degrees the average output voltage will vary from maximum positive, through zero to maximum negative, see Figure 12.

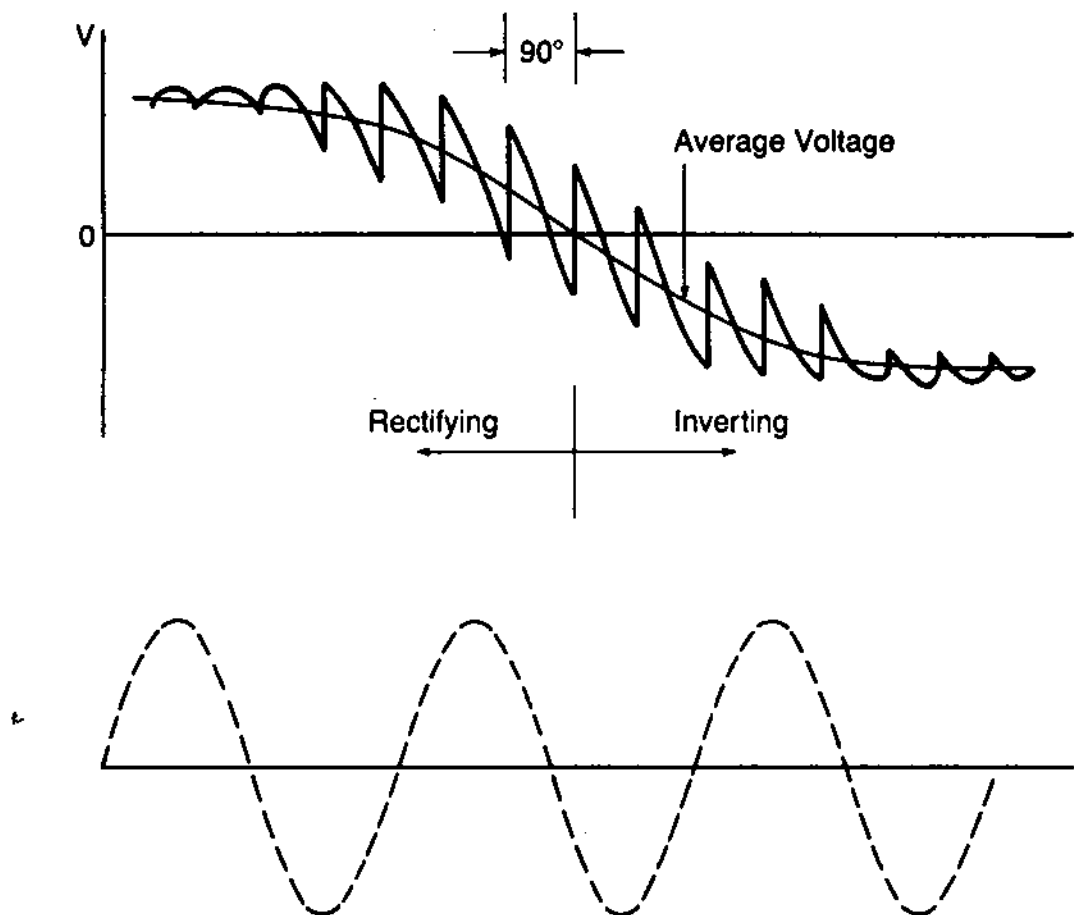


Fig. 12 – Voltage Wave Form as the Gating Angle Changes From 0 to 165 Degrees for a Three Phase Bridge Converter

When the voltage is positive, power is being delivered to the load which is called rectifying. When the output voltage is negative, power is being delivered from the load to the line and is called inverting. It is not practical to delay the gate pulses all the way to 180 degrees as commutation will fail causing an inverter fault.

A converter can provide both positive and negative voltage but can provide current only in the forward direction. For reversing drives two converters are connected back-to-back, this is called a double converter.

13.4 Quiet Wiring

Modern thyristor drives are capable of extremely high power amplifications, for example an input reference signal of 10 milliwatts can easily control a 1000 hp or 1000 kW machine. This is a power amplification of ten to the ninth power (10^9). If an extraneous noise signal is introduced into the control system, it can also be amplified and cause the system to perform in some unusual and hazardous ways. This extraneous signal is usually of a short duration occurring at somewhat

unpredicted times. It is simply called a noise, and must be eliminated. Any system, once installed and running properly, must be maintained and the electrical environment must remain clean.

Noise is transmitted from one system to another through inductive or capacitive coupling and sometimes through a high resistance short circuit.

The first step in maintaining a clean system is to see that the total instantaneous current in any cable or conduit is zero. This means that the return current path is in a conductor very close to the outgoing current. A clamp-on ammeter around the circuit should always read zero.

All phase conductors and the neutral (if used) should be in one cable, one conduit, or bundled. This applies to power levels, signal levels where twisted pair or co-axial cable may be used, and to any re-wiring, wiring changes, or maintaining or replacing cable runs.

Keeping conductors of a circuit together by twisting or cabling will reduce the net amount of signal transmitted from a power circuit to a control or computer associated circuit. If the conductors for a motor are widely separated in a cable tray they may act as the primary of a transformer. The secondary could be two loose leads from a contact to a solid-state device such as a thyristor motor control or a computer. During motor starting or high current operation, the field created by the motor leads could be transmitted and picked up by the contact circuit, possibly causing an operation not intended or expected. Minimizing of radiation noises from power circuits will make the function of noise reflection in control circuits more effective.

13.5 Shielding

Maintenance of shielding requires special care for wires and their insulation. The primary function of the shield is to intercept noise signals from one circuit before they reach another, such as between a contactor arcing and a low energy control circuit such as the input to an operational amplifier.

Shields are insulated over their entire length so any intercepted noise is contained and sent to ground.

Except for certain special co-axial cable applications, shielded conductors are usually not the signal return path. Shields are not bonding conductors. They cannot be used to electrically tie equipment together for safety reasons. Normally a shield conductor (braid or tape) cannot carry large values of current.

In maintaining the shield system:

Keep the wiring in strict accordance with the manufacturer's original design and instructions.

Do not ground the shield at both ends simultaneously;

Check for unintentional grounds such as a shield cable pinched in a conduit box, exposed braid touching a grounded surface, etc.

Make sure, when a shielded run is made up of two or more pieces of shielded cable, the shield is insulated and isolated at the joints.

Warning: De-energize all circuits before undertaking insulation testing or checking for unintentional grounds. Failure to do so can result in severe personal injury, death, or substantial damage to property.

On most de-energized systems, checking for an unintentional ground can be done quite simply by opening the common point and using a low voltage resistance tester such as an ohmmeter to check the condition of the insulation. If an unintentional ground is found, further isolation of individual cables must be made.

After the unintentional ground is found and corrected, check shielded conductor to determine if it is continuous throughout the length of the cable. Most shields cannot carry any appreciable current and an unintentional ground can allow circulating currents to flow. These circulating currents can cause noise in the signal path or burn an opening in the shield.

13.6 Operating Power Semiconductor Equipment

A. Protect Power Semiconductors from Excessive Heat.

Semiconductors are composed of materials having different rates of thermal expansion. Therefore, both short and long term temperature excursions not only impair the electrical characteristics of these devices, but also set up internal mechanical stresses at each of the material interfaces. These combined effects of high temperature excursions can ultimately lead to device malfunction and destruction. The maximum temperature limits of various materials used in semiconductors vary from 150 C for soft solder to 1300 C for silicon. Once these materials are combined into a fabricated device, however, electrical deterioration begins at lower temperatures.

For example, forward and reverse blocking capability of a junction begins to decrease and leakage currents increase when allowable maximum junction temperatures are exceeded. (These temperatures are generally between 125 C and 200 C, far below the maximum temperature limit of silicon itself.)

Periodic monitoring of ambient temperatures, cooling fan operation, cooling water temperatures, and case temperatures of the semiconductors themselves will pinpoint many malfunctions before they cause catastrophic failures. Because of the importance of preventing high temperatures from developing, this monitoring must be emphasized in the operating procedures for the equipment operator.

B. Avoid Overloading Equipment.

Avoid overloading the semiconductor, which in effect, means protect against overloading the equipment that the semiconductors are feeding and/or controlling. For example, overloading a motor operated with semiconductor controls puts a direct overload on the semiconductors. Even if this overload is only for a short time, the semiconductor's useful life can be shortened. Controls are designed to include motor overloads and the maximum values of overload should never be exceeded. Continued short term overloads above the control specifications can cause undetectable additive damage resulting in random, often unexplainable semiconductor failures.

Operator induced overload conditions that could result in excessive semiconductor currents include high on/off duty cycle or jogging for high production needs, rapid reversing, motor jam, and long acceleration time. Some mechanical problems that can cause motor overloads are high equipment temperature due to lack of cooling, wiring or bearing failure due to improper installation or maintenance, phase failure due to blown fuses or loose connections, phase imbalance, overvoltage, transient overvoltage and contaminants or dirty environment.

Table A shows various motor stress conditions and the common protection. This table can be used to determine adverse load conditions and the type of protection that should be used. In a properly designed system, overload conditions are considered and provisions are made to accommodate the overloads. The user or operator has an obligation to operate the equipment within the design ratings. The table shows the equipment user and designer methods to prevent overloading a motor, and hopefully, to avoid the situation that would cause semiconductor failure or reduce semiconductor life.

1. Protect power semiconductors from transient overloads. Silicon semiconductors are inherently long life devices if they are adequately protected against surge currents and transient voltage spikes. The protection against failure due to these phenomena are relatively simple and normally this protection is designed into the circuit. In industrial plant environments, most voltage transients in semiconductor circuits arise from three major causes:

a. Switching is the most common source of transient overloads. Whenever current is switched on or off in an inductive circuit, a transient voltage is generated at the switch terminals. Transformers and motor windings are highly inductive components, and the circuit wiring itself is inductive. Surges caused by lightning contribute to switching transients. These transients can originate in remote circuits and still feed back to the semiconductor circuit through the supply line. Protection of semiconductors from such transients is primarily a matter of attenuating the surge to a level the semiconductor can tolerate.

b. Commutation transients are associated with the reverse recovery characteristic of a rectifier junction. Since, in normal use, a semiconductor is continually switching from a conducting state to a non-conducting state, there are rapid changes of current (high di/dt). For this reason, and especially where fast switching rectifiers are used, it is imperative to keep circuit inductance at a minimum. Here again, suitable suppression networks should be designed into the circuit.

c. Regenerative surges in inductive or dynamic loads is the third major source of reverse voltage transients. Such loads include motors, lifting magnets, solenoids, relays, and many other devices involving stored inductive energy in the form of high induced voltage. Suppression of these transient voltages usually requires protective devices with high energy storage capacity.

Table A Motor Overloads and Their Effects on Semiconductors

Problem	Cause	Motor Current Variance
Overload	Operators Choice	Increases three phase current approaching 200%.
Motor Jam	Load Blockage	High operating time at locked rotor current to 600%.
High On/Off Duty Cycle	Jogging for High Production Needs	High operating time at locked rotor current to 600%.
Rapid Reversing	Production Needs	High operating time at locked rotor current to 600%.
Long Acceleration Time	High inertia slow starting loads	High operating time at locked rotor current to 600%.
High Equipment Temperature	High ambient temperatures. Lack of cooling.	No increase but can cause wiring and insulation failure.
Motor Wiring or Bearing Failure	Overcurrent, Improper Installation or Maintenance.	Locked rotor current to 600%.
Phase Failure	Blown Fuse, Loose Connection	Decrease in current until motor core reaches saturation and current increases.
Phase Unbalance	Unbalanced single phase loads on same line, poorly regulated service.	Decrease in one phase and increase in the other two phases of current.
Overvoltage	High source	Slight voltage increase decreases current. Large increase may saturate core and increase current.
Transient Overvoltage	Lightning, opening inductive switches, etc.	Slight average current increases.
Underload	Operators choice	Decrease in motor current.
Contaminants	Dirty environment	Causes corona

Semiconductor Current or Voltage Variance	Common Semiconductor Protection	Comments
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	Operation at thermal overload conditions can reduce semiconductor life. Depending on the design up to 600% increases in semiconductor currents are possible resulting in reduced life or shorted semiconductors. Surge currents can also reduce semiconductor lifetime and cause semiconductor failures. High ambient temperatures produce the same results as high currents i.e., reduced life and failed semiconductors. Never operate semiconductors without proper cooling
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload on semiconductors and motors. Design for semiconductor current overload.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload phase failure relay.	
Increases semiconductor current, eventual motor burnout can cause surge on semiconductors.	Thermal overload phase failure relay.	
Decrease or increase semiconductor current.	Overvoltage relay.	Increase of currents can cause semiconductor failure and reduced life.
High transient voltages across semiconductor when semiconductor is in the off position.	Capacitor-Resistor Networks, Voltraps, MOV, etc.	Short duration high transients can cause semiconductor failure.
Decrease in semiconductor current.	None	Light load increases semiconductor life.
Causes corona	Clean room filters	Clean equipment periodically and replace filters. Corona carbonizes dirt and causes eventual semiconductor shorts.

Some of the common devices used for transient protection are capacitors, zener diodes, free wheeling diodes, (W) Voltraps, and varistors (MOV/ZNR).

2. Protect Power Semiconductor Circuits From Current Overloads.

The power semiconductor circuit must be protected from heavy current loads caused by short circuits or other component breakdowns. Several methods are available for this type of protection.

a. Fuses – Semiconductor fuses protect against overloads and, when properly applied, remove the semiconductor from the power source when an overload occurs. However, the result is downtime and higher operating costs. Therefore, fusing is generally limited to applications where the power source can damage components before slower breakers remove the power.

b. Mechanical Breakers – Magnetically operated breakers provide an inexpensive means of limiting current. This type of breaker operates best under short circuit conditions and offers speedy, low-cost restarting and relatively fast circuit interruption.

c. Thermal Breakers – These employ heating elements to operate bimetallic contact actuators. This type of breaker offers reasonable protection for wires and good protection for components with high thermal capacity. Their ability to protect semiconductors is, however, limited.

d. Overrated Semiconductors – Semiconductors with current ratings high enough to accommodate anticipated current overloads is another method of protection. This approach allows the cost of fuses, wiring, and mounting to be put into the semiconductor. It also allows minimal protection, so safety considerations require a conventional circuit breaker to disable the circuit in extreme malfunctions.

e. Combinations – Combining circuit breakers with fuses, oversized semiconductors, or current feedback circuits are frequently applied techniques. Another approach is using special branch protection. For example, each leg of a single phase bridge might be separately protected instead of using a single fuse or breaker for the entire converter; a motor armature circuit can be protected by a breaker, while the mains are fused. This arrangement prevents overstressing a motor while the semiconductor devices are operating at high current peaks that are within fuse limits.

C. Keep Power Semiconductors Clean.

Semiconductors and semiconductor equipment must be kept clean. Why? Because on high power semiconductors, the glass or ceramic seal on the semiconductor package can be a source of trouble when dirt accumulates. Even when good engineering practices are followed in the positioning of components and support material to reduce or eliminate excess voltage stress and voltage gradients, these gradients can change with moisture, dirt, pressure, temperature and aging. With a clean system, high transients can initiate corona which will then be extinguished upon return to normal voltage. However, with any accumulation of moisture or dirt on the insulating glass or ceramic surface, the corona will remain when the voltage returns to normal, and can cause extensive damage to the circuit. Even semiconductors without a visible layer of contaminants may be covered with conductive particles that can cause corona. Therefore, periodic cleaning is advisable. The time between cleanings could be lengthened by the proper use of filters, but filters will not eliminate the need for cleaning. A good maintenance program is essential to proper operation of semiconductors.

13.7 Preventative Maintenance

The key to successful and efficient operation of high power semiconductors is a well-planned maintenance program. Routine maintenance of semiconductor equipment involves putting into actual practice good operating procedures with emphasis placed on temperature build-up, dirt accumulation, and loose mounting and/or connections. A regular schedule should be followed for checking and eliminating these conditions.

(a) Temperature build-up may be caused by excess ambient temperature, poor or blocked air circulation, failure of cooling devices, such as fans or water circulating equipment, dirty heat sinks, and air filters, or equipment overloading. Since temperature build-up is usually gradual, it should be constantly monitored with strategically placed thermocouples. A suggested method of affixing a thermocouple to a semiconductor base or heat sink is to drill a small shallow hole, fit the thermocouple into it, and then peen the surface around the hole to secure it. Equipment designed for forced air cooling or water cooling should never be energized without proper air or water flow.

(b) Dirt accumulation on the glass or ceramic surfaces of semiconductor packages must be periodically and thoroughly removed. When cleaning semiconductors, the safest cleaning method consistent with desired results should be used.

Warning: Avoid excessive contact with cleaning solvents and the breathing of their vapors. Some solvents are extremely toxic and readily absorbed into the human system. Failure to heed this warning can result in severe personal injury or death.

One of the safest methods of cleaning is by wiping with clean cloths. Often due to space limitations, the areas that need to be cleaned cannot be properly reached and, therefore, a liquid cleaner must be used. Table B lists solvents that could be used as cleaners.

The safest method of cleaning semiconductors, as shown in Table B, is to use a detergent wash and then flush with distilled water. The system must be completely dry before the reapplication of power. Regular tap water can contain many conductive impurities and should not be used as a final rinse.

Methyl, Ethyl, or Isopropyl alcohol could be used for cleaning, but they can attack sleeveings and insulations. Before using alcohol or any solvent, its use should be checked on a small sample of sleeving and insulation to determine if they are attacked. Since time of exposure to a solvent determines any adverse effects, the time of exposure during the test should be the same as the time expected during actual cleaning. Any elongation, softening or actual decomposition could eliminate the use of the solvent. A temporary softening may not be detrimental. Remember that alcohol is toxic and should be used with care.

Follow all safety precautions when using any solvents. Read the labels on all the chemicals. Do not mix solvents (or any chemicals) unless recommended by the manufacturer. The information regarding solvents, their fire, explosion, and toxicity hazards, etc., are believed to be accurate, but it cannot be guaranteed. This information is given as a general recommendation for information only.

(c) Along with scheduled periodic cleaning, a systematic checking of mounting and terminal connection tightness should be specified. If a loosely mounted device is discovered, it should be removed, both mounting surfaces thoroughly cleaned, thermal compound reapplied, and then remounted with the specified torque.

Table B Semiconductor Cleaning Solvent Characteristics

Solvent	Fire Hazard	Explosion Hazard	Toxicity Hazard	Electrically Conductive	Attacks		Precautions
					Rubber Insulation	Rubber	
Water, tap	None	None	None	Yes	None	None	Rinse with distilled water, dry thoroughly
Water, distilled	None	None	None	No	None	None	Dry thoroughly
Water/detergent	None	None	None	Yes	None	None	Rinse with distilled water, dry thoroughly
Methyl alcohol	High	High	High	No	Slight	Slight	Avoid skin contact, use ventilation
Ethyl alcohol	High	High	High	No	Slight	Slight	Can cause internal damage; ingestion can cause blindness
Isopropyl alcohol	High	High	High	No	Slight	Slight	Mix with distilled water to reduce hazards
Paint thinner (mineral spirits)	Low	Low	Low	No	Slight	Slight	Use proper ventilation; limit exposure to rubber
Acetone	High	Moderate	Low	No	Slight	Slight	Limit exposure to prevent rubber degeneration
Perchloroethylene (dry cleaning solvent)	Low	Low	Moderate	No	Slight	Slight	Use short exposure to prevent rubber damage; irritates eyes and causes headaches; heating causes fumes
Trichloroethylene	Low	Low	Moderate	No	Slight	Slight	Use adequate ventilation; limit exposure time to prevent rubber damage
Freon	Low	Low	Low	No	Slight	Slight	Use adequate ventilation; limit exposure time
Maltier XL-100	Low	Low	Low	No	Slight	Slight	Use adequate ventilation; limit exposure time
Miller Stephenson MS-180	Low	Low	Low	No	Slight	Slight	Use adequate ventilation; limit exposure time

13.8 Trouble Shooting and Servicing

Properly protected semiconductor devices incorporated in well-designed circuits should last for the life of the equipment. Semiconductors should not be a major problem for the maintenance engineer. However, experience shows that up to a 10-15% failure rate can occur during equipment lifetime, due chiefly to misuse, misapplication, or neglect of the equipment, and overloads caused by natural forces, such as lightning. Therefore, to operate efficiently, the maintenance department must have the proper tools and equipment. Most of these essential items are elementary and relatively inexpensive when compared to the wide array of measuring devices and instrumentation available for the study of power semiconductors and associated circuitry. Suggested equipment for moderate service work:

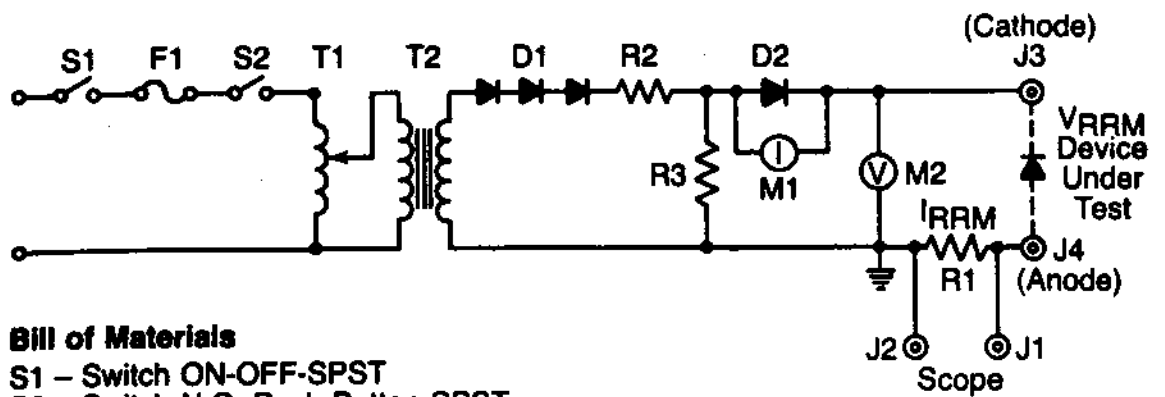
1. Volt-ohmmeter (voltmeter)
2. Clamp-on ammeter
3. Probe-type temperature indicator
4. SCR/Rectifier blocking voltage test circuit (see Figure 13)
5. Transistor blocking voltage and gain test circuits (see Figures 14 and 15)
6. Torque wrench and complete standard tool kit
7. Oscilloscope

An oscilloscope is used for viewing the current and voltage waveshapes within a semiconductor circuit. Eventually, all technicians become familiar with a "scope". It is the most important and useful tool available to the troubleshooter.

A. Safety

Safety in operating and servicing solid state equipment is especially important. Unlike mechanical equipment which has rotating parts, moving contactors, etc., there is nothing to warn one that the equipment is energized. There is also a tendency for the uninitiated to believe that voltage and current levels associated with semiconductor electronics are too low to be dangerous – *don't bet your life on it!* Obvious safety measures must be carefully observed. Most high power equipment includes built in safety interlocks to make certain that the equipment is turned off before anyone can gain access to the circuit areas.

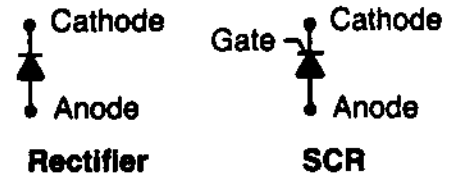
However, maintenance personnel often defeat these interlocks to simplify their service work. This is both careless and stupid. In cases when circuits must be checked while energized there are a few simple rules which could save both personal pain and equipment damage. First, if possible, always work with another person present – one who knows



Bill of Materials

S1 – Switch ON-OFF-SPST
 S2 – Switch N.O. Push Button SPST
 F1 – Fuse 1.5A. 120V
 T1 – Trans. PC8302-Variac
 T2 – Trans. T-21P89 Thordarson
 D1, D2 – Diodes
 R1 – Res. 1.0Ω Precision Non Inductive
 R2 – Res. 220 K Ω . 2 Watt Carbon
 R3 – Res. 1K Ω . 10 Watt Carbon
 J1, J3 – Banana Jack (Red) Johnson
 J2, J4 – Banana Jack (Black) Johnson
 M1 – Meter 0-5 Milliamp D.C. (2 Ω)
 M2 – Voltmeter

Symbols



Warning:

All test points, J1 to J4
 have hazardous voltages
 present during test.

Fig. 13 – SCR/Rectifier Blocking Voltage Test Circuit

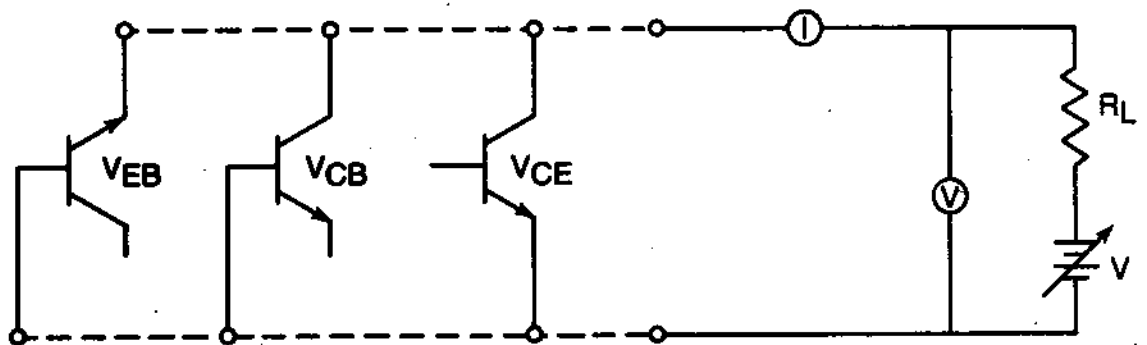


Fig. 14 – Transistor Blocking Voltage Test Circuit

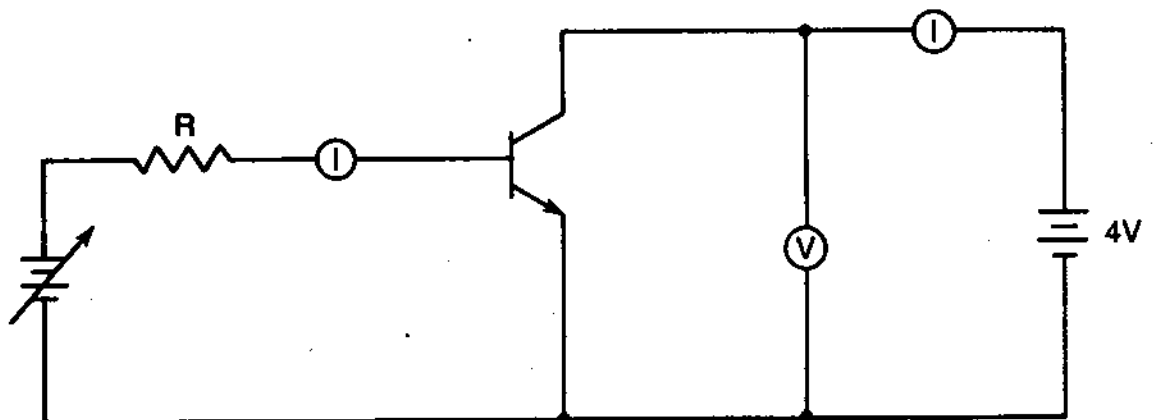


Fig. 15 – Transistor Gain Test Circuit

how to shut-down the equipment in a hurry. Second, when working around high voltages, be sure that the floor is covered with a rubber mat, and follow the good practice of working with one hand in your pocket. This sounds simple, but it could prevent one from completing a circuit through the body. Finally, always use insulated tools to avoid short circuits that could further damage electronic components. Some of the common shop practices for safety are too often overlooked or ignored. To name a few:

1. Always wear safety glasses – hot metal from a short or a soldering iron can ruin an eye as quickly as a metal chip.
2. Keep long hair contained with a cap or net.
3. Lock out the disconnect or breaker for the circuit you are about to service.
4. Check with a voltmeter to be sure the circuit is completely dead.
5. Maintain “off limit” areas for high voltage equipment. Access should be allowed only to authorized personnel.

Too many accidents are caused by carelessness or laziness. Bear in mind that it *can* happen, so *be careful*.

B. Equipment Breakdowns and Malfunctions

What should maintenance personnel look for when equipment breaks down? Are there visual signs to indicate why a semiconductor failed? As with any other type of equipment, there is much that can be learned from one's own senses and experience. With electronics, heat is still the number one symptom of impending failure. So be alert for charred or discolored components – that is a sign that too much current flows or has flowed through the component, and if it has not failed, it soon will. Although the trouble could be limited to the failed component, it is possible that some other component is at fault through failure or misadjustment. A thorough knowledge of the theory of operation of the equipment will be invaluable in tracking down *real* causes of component failure.

Voltage related failures, on the other hand, are a bit more difficult to locate because there is usually no outward sign of failure. However, this type of failure is, more often than not, catastrophic, and shorted devices result. Shorted devices are much easier found than downgrades or control malfunctions. One of the most destructive causes of failed semiconductor components is lightning storms. The electrical forces generated

by nature are enormous, so watch for equipment malfunctions during and just after an electrical storm. The maintenance engineer should also monitor closely any equipment that is pushed to its operating limit, thereby increasing the possibility of failures.

As a general procedure for checking out a suspect semiconductor, the following sequence of test checks should be performed:

- (1) Look at the suspect device(s) [with the system power OFF] using a volt-ohmmeter – check for shorts.
- (2) If no short exists, apply power (reduce power, if possible) and using a voltmeter or scope, check to see if the suspect device is blocking voltage.
- (3) If the unit is blocking voltage, the user should then check to see whether or not any current is flowing. This current flow can be measured with a clamp-on ammeter, voltmeter in conjunction with a current shunt or resistor that is in series with the suspect unit, or a scope.
- (4) Finally, the suspect unit should be checked along with the other power semiconductor components in the circuit to confirm that the devices are all operating with their maximum allowable case temperature. This maximum allowable case temperature can be determined from the manufacturer's technical data sheet by knowing the device's circuit configuration and actual current magnitude and waveform. A probe-type temperature indicator can be used for making case temperature measurements.

If the suspect device(s) fail any of the above test checks, the system power should be turned off and the suspect devices removed from the circuit for further test and evaluation. In some instances, the devices can be tested without the need of removal, test, reinstallation, and down time. However, the user should make certain that the measurement being taken is that of the device under test by disconnecting one power lead (also gate lead in the case of an SCR) for circuit isolation. Disc devices, because of their double-sided mounting, may be difficult to isolate and may have to be removed from the circuit. In this case, the disc device must be clamped with sufficient force (approximately 200 lbs.) to get a valid reading.

C. Rectifier/SCR Testing

Volt-ohmmeter – An ohmmeter can be used to check rectifier polarity or as a quick check to determine whether an SCR or rectifier (diode) has failed *open* or *short*. Note: An ohmmeter is *not* a valid tester for meas-

uring blocking voltage capability. If an SCR anode-cathode measurement shows a short in *either* direction or if the gate-cathode measurement shows a short in *both* directions, then the SCR is a short. For an SCR to be open, the anode-cathode measurement as well as the gate-cathode measurement must show an infinite resistance in *both* directions. Likewise, a rectifier must show zero resistance in both directions for a short and infinite resistance in both directions for an open. A rectifier normally shows low resistance in the forward direction and high resistance when the ohmmeter probes are reversed. Thus, the ohmmeter can be a check for rectifier polarity. An open failure on a high power SCR or rectifier is a rare event due to compression bonded encapsulation device construction.

D. SCR/Rectifier Blocking Voltage Test Circuit

The following test circuit (Figure 13) describes a simple blocking voltage tester that is capable of testing devices up to 1800 volts and can be built for about \$100.00. The safety switch S2 must be depressed to allow voltage application and the variac controls the amount of voltage to the device under test. After each device is tested, the variac setting should be returned to zero so as not to risk damaging a subsequent device under test that might have a lower voltage rating. Never exceed the device's rated voltage when testing. Since this test is conducted at room (ambient) temperature, the measured maximum allowable leakage limit should not exceed one-half the maximum junction temperature leakage current value listed on the manufacturer's technical data sheet. When testing an SCR, the gate lead must be left open. (Note: Some devices may require a gate bias termination to meet rating.) V_{RRM} (reverse voltage) is measured when SCR cathode is connected to J3 and SCR anode is connected to J4; V_{DRM} (forward voltage) is measured when SCR anode and cathode terminals are reversed. The voltage is read indirectly by M2 voltmeter ($V_{RRM} = 3.14 \times \text{DC meter reading}$). I_{RRM} or I_{DRM} leakage current is monitored directly with a scope across J2 and J1 or indirectly by M1 milliamp meter across D2 (I_{RRM} or $I_{DRM} \approx 3.14 \times \text{average leakage over full cycle meter reading}$). For rectifiers (diodes), the V_{RRM} (reverse blocking voltage) is tested the same as an SCR. Since most rectifiers are available in standard or reverse polarity, be sure to check the polarity symbol device marking to identify the anode and cathode.

E. Transistor Testing

The following simple test circuits can be used for a quick check of transistor parameters but are not recommended for classifying devices. Other, more accurate, measuring equipment that has a pulsed duty cycle should be used for incoming inspection. A good curve tracer such as the

Tektronix 576 will measure gain, currents, and voltages at a pulsed duty cycle. Other, less accurate, measuring instruments, some in kit form, can be obtained from electronic supply stores for use in troubleshooting a circuit.

Volt-ohmmeter – The only valid ohmmeter measurements on transistors are short or open determinations. A shorted transistor will show a short (resistance approaches zero) in both directions across the base-emitter, collector-emitter or collector-base terminals. This test is accomplished by removing the transistor from the circuit and first measuring the resistance in one direction and then reversing the ohmmeter probes across the terminals. A good transistor will show a low resistance (conduction) in one direction and a high resistance when the probes are reversed. If any of the three tests (i.e., collector-base, collector-emitter, or base-emitter) are faulty, then the transistor is faulty. A faulty transistor will have either a low resistance in both directions (shorted) or a high resistance (open).

Note: This ohmmeter test is correct when it indicates a shorted or open transistor, but when it shows a good transistor, it may not be correct because of the low voltages used in the ohmmeter test. Further tests must be made to determine the condition of the transistor.

1. Transistor Blocking Voltage Test Circuit – The voltage capability of a transistor is measured using the circuit in Figure 14. The transistor is connected in one of the three desired modes (i.e., V_{CE} , V_{CB} or V_{EB}). The current meter should be capable of 1 ma to 10 ma, the voltmeter and power supply to hundreds of volts and the load resistors should limit the current to about 10 ma if the transistor shorts. The voltage is set to the data sheet limits and the current is read. Any current reading within data sheet limit would indicate a good transistor. If a data sheet is not available then set V_{CE} and V_{CB} to the circuit voltage using 10 ma maximum as an acceptable current. When measuring V_{EB} , if no data sheet is available, set the voltage at 4 volts and use 10 ma as a maximum acceptable current.

2. Transistor Gain Test Circuit – Gain measurements should be made on a curve tracer or a high current pulsed test set. A d-c gain measurement can be made if precautions are taken to limit the power dissipation and a heat sink is used. The case temperature should be monitored. A resistor to drop about 2 volts is used in the base as shown in Figure 15. The base voltage is slowly increased until the desired collector current is reached. The collector and base currents are then read. The collector-emitter voltage of 4 volts is usually used. This test is a continuous power test and should be done as quickly as possible to limit internal junction temperature. The gain (h_{FE}) is calculated as follows:

$$h_{FE} = I_C/I_B$$

F. Common Causes of Power Semiconductor Failure

Most of the advice given thus far deals with the proper installation and operation of power semiconductors. However, in the event all of this advice was not followed or accidentally missed, the knowledgeable maintenance person has a good jump on discovering the reason a particular device has failed by pursuing the following checklists.

Many power semiconductor failures are the result of improper mounting and electrical application. The first step in evaluating any failure should be to assure that good engineering practices have been used in both the mechanical as well as the electrical application of the semiconductor. Faulty mechanical practices often result in eventual electrical failures.

G. Mechanical Checklist

Torque – are semiconductors torqued properly?

Flatness – are mounting surfaces flat and free of defects?

Thermal Compound – is thermal compound used properly?

Stress – is there any undue stress placed on the semiconductors?

Insulation – are the terminals or case contaminated causing electrical conductive paths?

Heat Sink – is it large enough and is it clean and efficient?

Other pertinent mechanical details.

1. *Torque* – torque wrenches must be used, and the maximum torque rating must not be exceeded. Some semiconductors can be mechanically damaged by too much torque or thermally damaged by too little.
2. *Flatness* – heat sink must be flat, free of burrs and ridges, with holes and edges chamfered. These defects could prevent the proper seating of the semiconductor, resulting in thermal or mechanical damage.
3. *Thermal Compound* – should always be used according to the manufacturer's instructions. Either too little or too much compound could result in poor thermal impedance. When applying thermal compound, be certain that the threads remain dry. Lubricated torque specs mean that the mating surfaces are lubricated. Apply thermal compound to both sides of insulating washers, when used.
4. *Stress* – semiconductor should not be used as a support for heavy electrical leads. Lead stress can cause mechanical seal cracks resulting in hermeticity problems. Mechanical stress can also be transmitted to the junction causing cracks in the elements or solders, resulting in failures.

5. *Insulation* – insulation between semiconductor terminals or terminals and case is often very small. When operating the semiconductors in moist or contaminated areas where voltage creepage can become a problem, additional protection should be used against such electrical conductive paths.

6. *Heat Sink* – should be large enough for proper heat transfer. Undersized heat sinks often cause junction temperature to exceed maximum ratings. All types of corrosion and oils should be removed with solvents or emery cloth to insure the lowest possible thermal impedance between mounting surface and heat sink.

H. Electrical Checklist

Overcurrent – is current exceeding maximum ratings?

Overvoltage – are maximum voltage ratings exceeded?

Surge Current – is there a possibility of a fault that could cause a one-time surge?

Transient Voltage – are transient suppressors used?

Power – is the semiconductor operated within rated power?

Testing – is the testing damaging the semiconductor?

Specs – is the semiconductor operated within the data sheet?

1. *Overcurrent and overvoltage* – absolute maximum ratings should never be exceeded under worst case operating conditions. For reliable operation with a minimum number of failures, current, voltage and temperature should be derated. Usually the greater the derating, the more reliable the semiconductor becomes. The semiconductor manufacturer should be contacted for assistance in derating specific semiconductors. Load, component, and environmental variations (especially temperature) should be investigated as probable causes of voltage or current problems.

2. *Surge* – surge current is a fault rating that the semiconductor may see under a fault condition. This fault could happen perhaps only once in the lifetime of the equipment. Surge currents and in-rush currents should be limited to semiconductor capability or, semiconductors with greater capability should be chosen. Since the thermal time constant of the element is small, even a very short surge current can damage a semiconductor. The surge can cause a localized (hot spot) junction temperature to be exceeded even though the case temperature is cool. These localized hot spots can result in degraded or shorted semiconductors.

3. *Transient Voltage* – should never exceed maximum rated voltages. These transients can cause a semiconductor to conduct when it should be in a nonconducting period, causing catastrophic failure. Transients

that exceed the maximum rated voltage can cause a slow downgrading of the semiconductor spec. Transient protection should be used if occasional or constant transients are suspected.

4. *Power* – check power rating for current, voltage and temperature of operation. Power, voltage and current must be derated with an increase in temperature. Never exceed junction temperature even though case temperature is within spec.

5. *Testing* – never insert or remove a semiconductor from a test circuit with the power on. Never exceed maximum ratings when testing. Always use proper, calibrated test equipment.

6. *Specification* – special characteristics of a semiconductor can be specified to reduce or avoid failures. Burn-in and other high reliability testing is available to reduce failures.

If after a thorough mechanical and electrical investigation, the user is unable to determine the cause of failure, he should contact the original equipment manufacturer for assistance. Any unusual operating or mechanical conditions found in the above investigation, along with a history of use, should be given to the manufacturer for review.

13.9 Identification and Replacement

A. Identification

Many semiconductors are identified by a JEDEC number. JEDEC numbers for rectifiers begin with a "1N" prefix (i.e. 1N4001, 1N1206A, etc.) whereas SCR's and transistors begin with a "2N" prefix (i.e. 2N681, 2N3055, etc.). A JEDEC number is an attempt by the industry (Joint Electronic Device Engineering Council) to standardize electrical and mechanical parameters so that products of one manufacturer will be interchangeable with those of another manufacturer. The user should, however, be careful when making a direct JEDEC substitution of another manufacturer because the JEDEC registered parameters do not always cover all of the critical parameters. As a result, manufacturers using completely different manufacturing processes often sell devices to meet the *same* JEDEC number. While this may not pose a problem in most general purpose and phase control applications, the user must recognize that various manufacturer's devices marked with the *same* JEDEC number can exhibit completely different secondary characteristics and safety margins. An engineer may have unknowingly designed his circuit around a particular JEDEC type number from a manufacturer with process A and a big safety factor (i.e. 6 ampere rated device that really has a 12 ampere actual capability). Everything works fine until

the user chooses a replacement JEDEC from another manufacturer . . . then the new devices keep failing in the circuit. Therefore, to be safe, all JEDEC substitutions should be evaluated thoroughly before use.

Most power semiconductors (especially those rated over the 40 to 100 ampere range) are marketed under their respective manufacturer's part number. Even though each manufacturer uses its own device nomenclature, the mechanical packages and electrical ratings are reasonably well-standardized throughout the industry. Therefore, second sourcing and device substitution is not difficult providing the user has a good cross reference guide and the technical data sheets for the devices being evaluated. There are JEDEC and alpha-numeric industry indexes published by some semiconductor manufacturers that recommend exact or suggested replacement devices. As with *ANY* cross reference guide, the user *MUST* determine the ultimate substitution acceptability by reviewing the detailed electrical and mechanical characteristic of the devices being considered. This comparison will assure that the manufacturer's suggested replacement will perform properly in the given application.

B. Replacement

Be sure to order the exact part number – if in doubt, include the *entire* device marking on your order. The most likely place to get “off the shelf” delivery of an exact replacement is directly from the equipment manufacturer. The OEM (original equipment manufacturer) normally carries an ample supply of renewal parts to service its equipment market. In the event a replacement cannot be obtained from the OEM, the user should contact a local industrial or electronic distributor that handles power semiconductors. A user should only buy a given manufacturer's type number from the manufacturer's authorized distributor outlet or directly from the manufacturer's factory. To do otherwise, the user could receive inferior and/or counterfeit devices from an unknown source. Play it safe . . . deal only with a manufacturer or an authorized distributor.

The maintenance engineer must be thoroughly familiar with equipment service manuals, with the power semiconductors and their technical data sheets, and with the various tools and instruments available for testing and replacing semiconductors. It is wise to carry spare semiconductor components in stock in case of equipment breakdown – especially for critical pieces of equipment.

Many phase control applications – i.e. welding, battery chargers, d-c motor controls, and general purpose power supplies can utilize rectifiers, SCR's and/or transistors with fairly broad parameters so long as the device selected has an adequate current and voltage rating and fits

mechanically. The user must be *extremely* careful in selecting a replacement semiconductor when general purpose or phase control devices are used in series and/or parallel combination, when fast recovery rectifiers and fast switching SCR's are used in inverters, choppers, etc. or when semiconductor devices are marked with special (non-catalog) part numbers. Specially selected, tested, and/or matched units may be required for the semiconductor to operate properly in the equipment. Failure to use the correct semiconductor device could result in device failures, equipment damage, and plant downtime.

When selecting a device for replacement, the user can always use one with a higher voltage rating provided all other device ratings are equal or better. Likewise, a higher current rated unit can be selected so long as all of the other ratings are equal or better and the mechanical package is the same. By following these guidelines, the user can often locate a suitable replacement faster, reduce spare parts inventory by standardizing on a smaller number of replacement semiconductors, and gain increased reliability with greater voltage and/or current safety factors. Of course, the additional cost for the higher rated semiconductor must be weighed against the savings in inventory reduction, fewer failures, and reduced down time.

In the absence of any other information, a good rule of thumb for specifying the proper device voltage rating (based upon the supply voltage to the semiconductor equipment) is as follows: 110v line – use a 300 volt device, 220v line – use a 600 volt device, and a 440v line – use a 1200 volt device. If in doubt about what device to use, call the semiconductor manufacturer and ask for a recommendation.

The user must realize that power semiconductors, like any other component, fail for a reason. It is acceptable to just replace a suspect semiconductor if that is all that is wrong. However, frequently a suspect semiconductor fails as a result of a current or voltage overload elsewhere in the circuit. Simply replacing the suspect semiconductor in these instances will only result in destroying more semiconductors. Therefore, always look for the *cause* of failure before replacing any devices.

When removing a defective semiconductor, care must be taken so as not to mar the mounting contact surfaces or damage adjacent components and to preserve all identifying device markings. It is wise to tag the smaller leads (i.e. gate, cathode potential, etc.) for ease of identification. The most important considerations in remounting or replacing devices are to maintain clean mounting and contact surfaces, to continue using a good thermal compound at the mounting interfaces, and to apply the specified torque.

C. Replacement Procedures

Replacement is critical. The following procedures must be followed:

Warning: Before undertaking any replacement of SCR's make sure the equipment is de-energized and will remain so during the replacement period. Failure to do so can result in severe personal injury or death and substantial damage to property.

1. Follow safety precautions.
2. Remove the device to be replaced. Make a record of all hardware (locknuts, washers, etc.) and order of assembly.
3. Remove any thermal compound from heat-sinks and other areas that will contact the device.
4. Make sure the contact surfaces are clean and flat. Noticeable scratches equal to the diameter of the device or a dimple the size of a center punch mark calls for refinishing the surface. Handle new devices with care to preserve the factory finish.
5. Clean the mating surfaces with No. 000 fine steel wool or equivalent. Use alcohol or warm soap and water with a lintless cloth to remove any residue.

Freshly cleaned aluminum begins forming an oxide in a few seconds, copper and steel take a little longer. Reassembly should begin immediately after cleaning.

6. Apply a thin film of compound (ALCOA No. 2 EJC® or equivalent) to mating surfaces, being careful to avoid threads on stud mounted devices. Rotate the device on its mating surface to spread the compound and fill any voids. This method is most applicable for aluminum heat sinks limited to 95C.

Other applications may require the use of compounds such as Dow-Corning DC-340 (a paste) or DC-200 (a liquid), both of which can be used for 150C heat sinks.

The equipment manufacturer's recommendations for compounds should be followed.

Use compounds sparingly and remove any excess from around the edges so it will not become a dirt collector which can lead to creep.

7. To transfer heat to the heat sink, each device must have proper mounting force at the mating surfaces.

With a stud mounted device this is achieved by proper torquing of the nut on the clean, dry stud. Lock nuts and other special hardware should be replaced as in the original installation. Recommended torque values should be obtained from the manufacturer's instructions.

For disc devices the mounting force is obtained from mounting clamps. In general this force is obtained by bending a piece of metal and measuring how much it is deformed.

Warning: Make sure the device clamps are in good mechanical condition. Hardware such as nuts and washers must be equal to original equipment and insulation must be intact. Failure to heed this warning can result in severe personal injury or death and substantial damage to property.

Threads must be clean, a non-seizing compound may be used and the nuts run down hand-tight, and an equal amount on each rod. Tightening should be done by taking a half-turn alternately on each nut until the manufacturer's recommended force is shown on the force indicator. Do not use a torque wrench.

All parts, upon reassembly, must fit together without forcing. Guide pins should not bottom out, there should not be gaps between mating parts.

Commutator Care and Maintenance

- Evaluation of Successful Commutation 2:14.1**
- Concentricity 2:14.2**
 - Care of Commutators 2:14.2**
 - Roughness 2:14.3**
- Grinding Commutators 2:14.4**
 - Grinding Stones 2:14.6**
 - Handstoning High Speed Commutators 2:14.6**
 - Beveling Commutator Bars 2:14.8**
 - Mica Undercutting 2:14.9**
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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Commutator Care and Maintenance

14.1 Evaluation of Successful Commutation

The success of any direct-current rotating machine is dependent on commutation. Successful commutation can be said to have been attained when neither the brushes nor the commutator is harmed in an acceptance test or in normal service, to the extent that abnormal maintenance is required. The presence of some visible sparking is not necessarily evidence of unsuccessful commutation.

Commutation evaluation is a highly subjective thing since qualified observers, using the same table of commutation numbers, may read the degree of sparking differently. Frequency of requirement for commutator maintenance can be used as a measurement of successful commutation. This evaluation must also consider other factors such as type of application, atmospheric contamination, vibration, and others. Determining acceptable intervals between need for commutator maintenance is a subjective judgment and experience is the best basis for that judgment.

A reliable evaluation can be made if the same person observes the machine at intervals and notes if the commutator surface is deteriorating, improving, or stable. A commutator that appears to be deteriorating should be judged by the length of the intervals between required grindings.

Many commutators will show some surface color variation and even patterns of light and dark bars. This condition is not in itself serious. An area of darkness is not necessarily a burn. If such an area can be brightened with a pencil eraser, and if there is not pitting, it is not a burn. Burned bars will eventually have to be ground if the burn pits the bars and grows progressively worse.

Commutator bars may have oxide films at different thickness and color which produces a pattern of bar marking. This condition is caused by the slightly differing commutation duty of each coil of a slot, because the armature coils of a slot of a d-c machine are located in a slightly different position and vary in reactance voltage of commutation. As long as the bars are not burned no corrective action is required.

Consistent inspection at regular intervals by the same person may be the best method of judging commutation performance.

One of the surest means of securing continued satisfactory operation is through maintaining the surface of the commutator in good condition. This means the commutator surface should be smooth, concentric, and properly undercut. The brush holders should be clean, the brushes of the proper grade, the correct size, and work smoothly in their holders.

Though there is a wide variance in the conditions under which d-c machines operate, there are some mechanical and electrical limits which must be maintained on all machines. These limits have been established analytically and experimentally, and verified by observation of field performance.

14.2 Concentricity

The commutator should be concentric within the following limits after grinding and polishing:

For peripheral speeds of 5000 feet per minute and over, the commutator should have a run-out or total dial indicator reading at slow roll of not more than .001 inch, the practical limit for grinding.

For peripheral speeds under 5000 rpm the run-out or total dial indicator reading should not be greater than .003 inch.

Commutator surfaces change with machine operation and higher limits may be tolerated after periods of running if commutation and brush life are satisfactory. The commutator must have no abrupt surface changes bar-to-bar. Variations from one bar to the next of as little as .0001 inch can be enough to cause improper commutation.

A. Care of Commutators

Under normal conditions commutators require little beyond frequent inspection. If a commutator appears to be in good condition it should not be worked on. Unnecessary grinding or sanding is undesirable and can invite trouble.

After a few weeks of operation a commutator should take on a uniform polished color. Such a commutator needs no attention other than to keep it clean. Oil mist and commutator compounds will gum up the surface causing a deposit of carbon and metal dust to form. Such a build-up, particularly in the undercutting may cause burning and flashing.

Caution: Do not allow oil to come into contact with the commutator mica. The oil will penetrate the mica and carbonize it, causing burnouts.

B. Roughness

The development of general unevenness, high or low bars, flat sections, or eccentricity requires immediate attention. If these conditions are not corrected they will result in poor commutation, overheating, rapid brush wear, and will greatly limit the machine's ability to handle overloads.

Commutator roughness is usually characterized by an abrupt change from bar to bar, though occasionally the commutator may become out of round. Any variation from one bar to the next, even as small as .0001 inch, may be sufficient to cause a commutator to perform badly. On high speed commutators such a roughness can cause excessive brush wear, even break brushes.

Roughness of a commutator surface can be detected by holding a pointed stick (sharpened dowelling) against the commutator surface while the machine is rotating. See Figure 1.

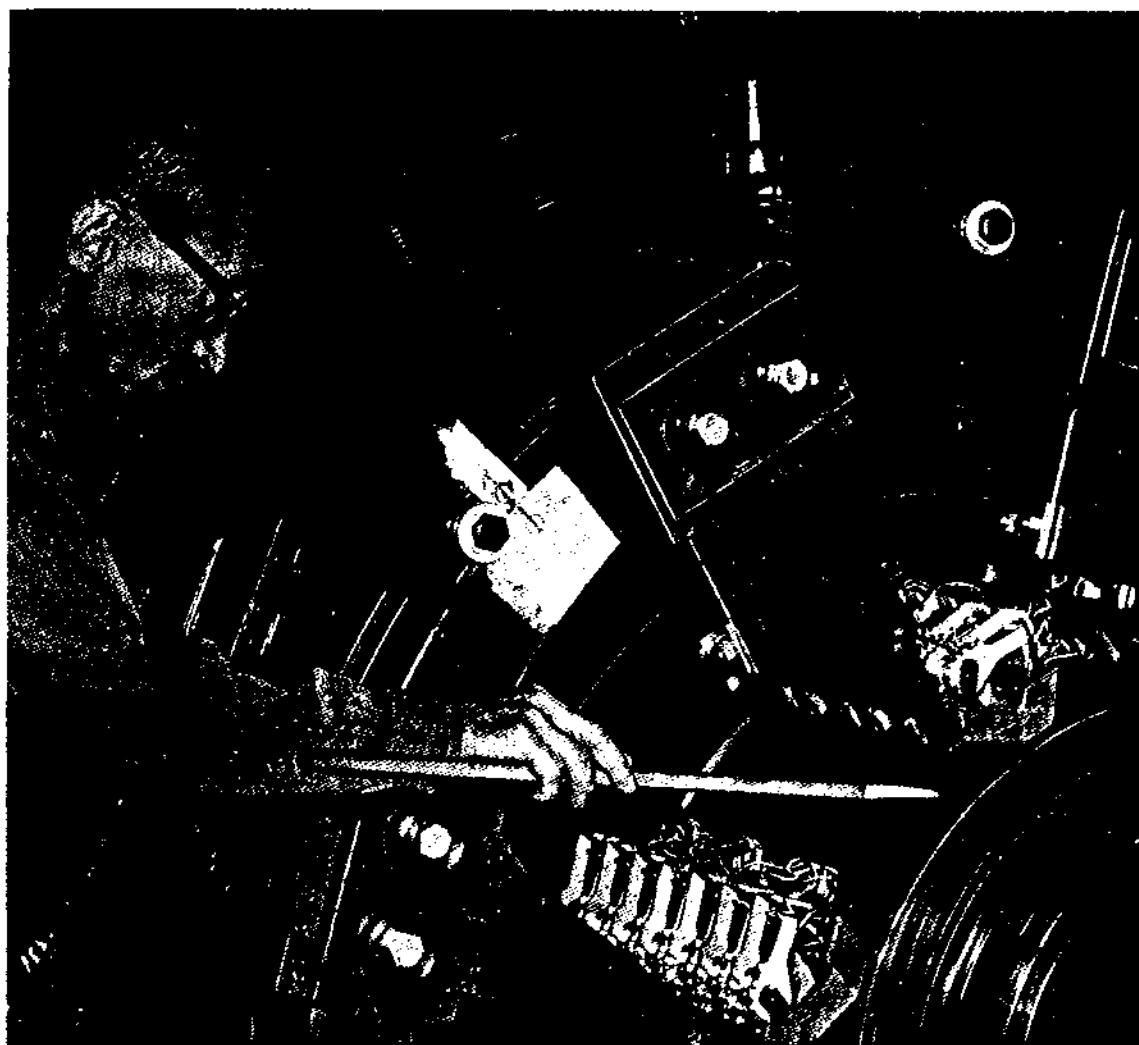


Fig. 1 – Checking for Commutator Roughness

Danger: Do not touch any metal part of the machine, stand on an insulated platform when conducting this test or any time when there is voltage on the machine. Failure to heed this warning can cause severe personal injury or death, and damage to property.

High speed commutators require a closer tolerance in concentricity than slow speed commutators. Slow speed, large diameter commutators have a low angular velocity and the brushes can follow the surface. It is poor practice to operate even very slow speed commutators with a roughness or eccentricity greater than .003 inch. Such a variation may be enough to cause side wear of the brushes. Concentricity of a commutator can be checked with a dial gauge mounted on a brush arm.

The surface of a commutator should be kept smooth. Sometimes this can be done with sandpaper.

Caution: Do not use emery or emery paper on a commutator. Emery is an electrical conductor. Abrasive particles can become embedded in the copper surfaces and in the brushes which can cause excessive sparking, burning, and wear.

Warning: Do not perform commutator work when the machine is energized. Make sure that both positive and negative lines are completely disconnected. If both sides of the circuit are not opened, contact with ground and any connected part can cause severe personal injury or death from electric shock.

Use auxiliary drives to provide rotation at rated speeds.

14.3 Grinding Commutators

All commutator grinding should be done with a grinding rig. The only time use of a handstone is permissible is when grinding 1800 or 3600 rpm exciters. At lower speeds a handstone will follow any irregularities in the surface and may actually exaggerate them.

The grinding rig is somewhat like a lathe carriage with the grinding stone held in a clamp in place of a tool post. The carriage can be moved axially and is equipped with a radial feed. A rigid support is necessary to minimize vibration of the stone. On large d-c equipment the rig may be mounted on a brush arm after removing the brushes and holders. In some instances it may be necessary to brace the brush arm to obtain maximum rigidity. It is also possible to position the grinding rig on parallels supported from the bedplate, after removing a brush arm. Refer to Figure 2.

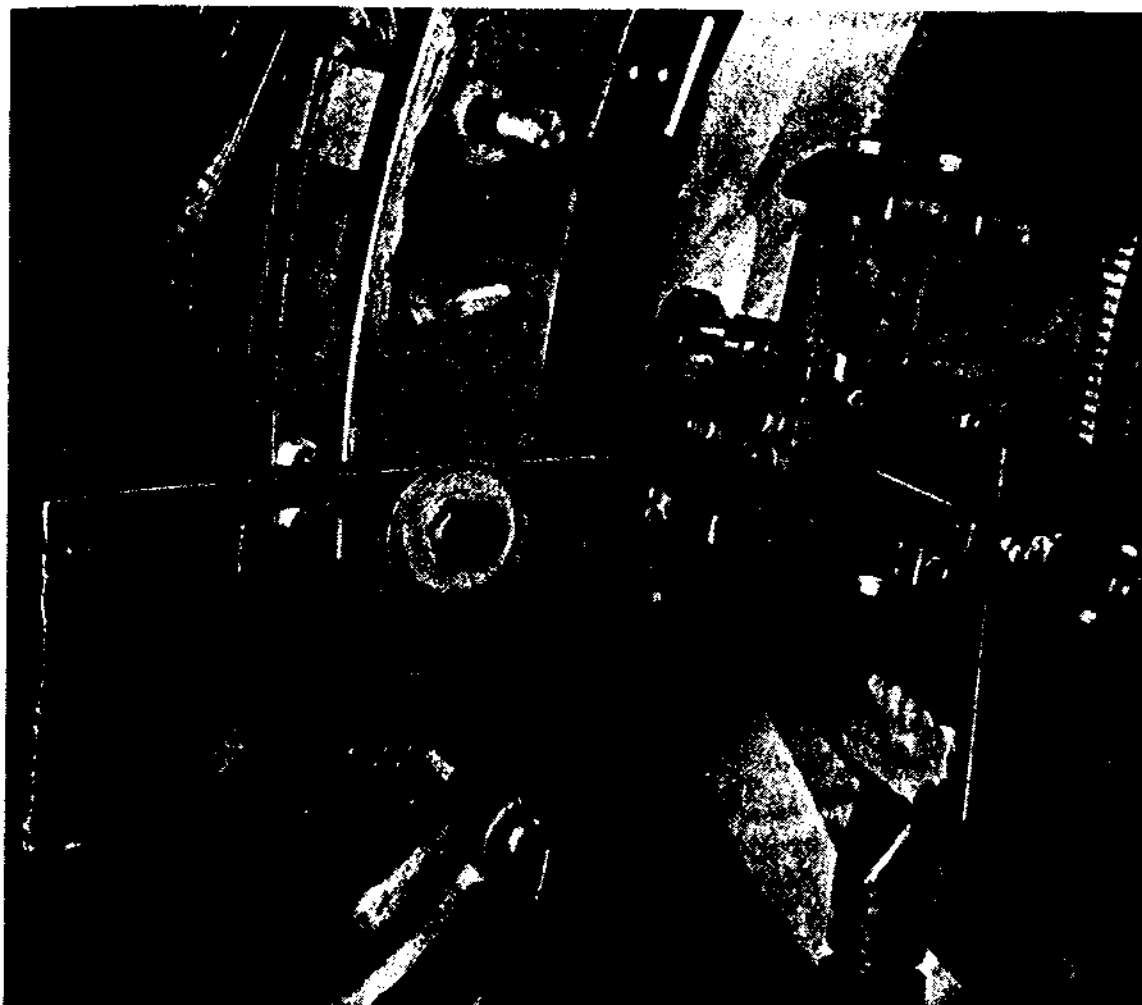


Fig. 2 – Grinding Rig in Position with a Vacuum Dust Collector

Grinding should be done with the machine running on its own bearings and at rated speed if the unit operates at 1200 rpm or less. Units with higher speeds should be ground at less than rated speed to minimize the effects of unbalance and vibration.

During grinding, care must be exercised to prevent copper and stone dust from entering the windings. The grinding rig should be equipped with a vacuum cleaner arrangement fitted over the stone to take up the dust. As a further precaution, the necks of the commutator and the front end windings should be masked by taping heavy paper over them or covering with a cloth hood securely attached.

To rotate the de-energized machine it should be belted to an auxiliary driving motor. If it is a motor-generator set, it can be run from the machine on the opposite end of the shaft. If it is impossible to grind a commutator while it is assembled in the motor or generator, the work can be done on a lathe. Proceed by making very fine cuts from the surface until it is concentric and smooth, then polish with sandpaper.

A. Grinding Stones

The stones used in grinding commutators are classified as rough, medium, and fine. The rough stone has a grit of about 80 mesh. It is to be used only when large amounts of copper must be removed. If sufficient copper must be removed to warrant its use, it may be advisable to take a cut off the surface in a lathe.

The medium stone has a grit of about 120 mesh. It is used for most grinding. The fine stone has a grit of about 200 mesh and is used only to obtain a final finish.

B. Handstoning High Speed Turbo Exciter Commutators

The relatively high peripheral speeds of turbo exciters makes it practical to handstone their commutators if the following procedures are followed exactly:

Warning: Do not perform any commutator work when there is any voltage on the machine. Make sure that both positive and negative lines are completely disconnected. Failure to heed this warning can cause severe personal injury or death, and damage to property.

1. $1\frac{1}{2}'' \times 2\frac{1}{2}'' \times 12''$ stone with a grit of 120 mesh should be used. This large mass prevents the stone from following bar-to-bar roughness. The contact tip of the stone should be ground to approximately $\frac{1}{4}''$ for best results.

2. A $\frac{1}{4}''$ thick stone may be used if the mass is increased by means of load weights as shown in Figure 3. This stone can be used to a much shorter length and does not require sharpening.

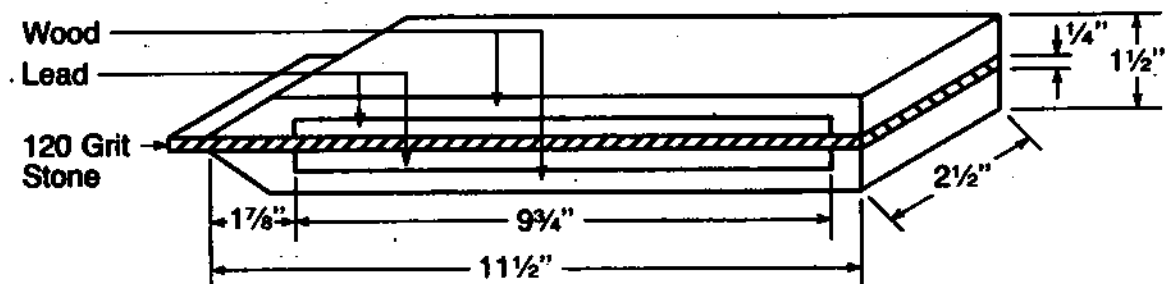


Fig. 3 - The Construction of a Handstone

3. All brushes in the track to be stoned should be lifted. Steady the stone on a brush holder as shown in Figure 4. Hold the stone firmly to prevent any chattering or vibration.

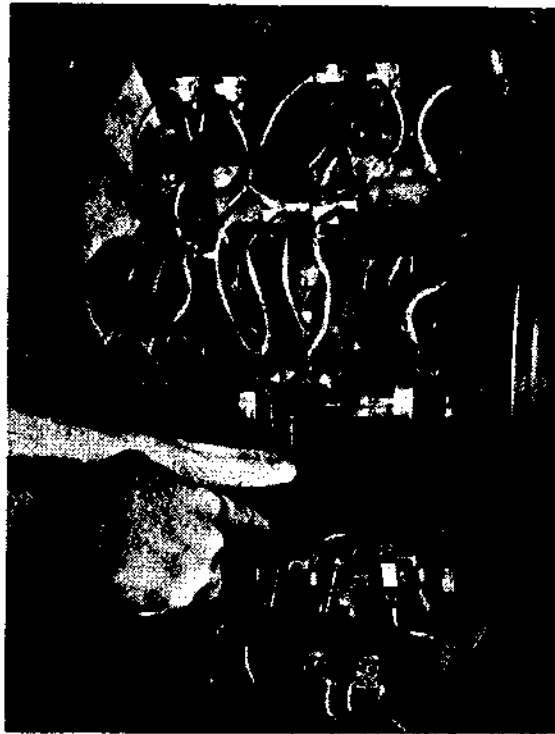


Fig. 4 – The Correct Method of Handstoning a High-Speed Commutator

4. Advance the stone so it just touches the commutator surface and hold it there until the stone wears off, then advance the stone again. Repeat this procedure until the surface feels smooth using the sharp stick test. Handstoning cannot be rushed, it takes 20 to 30 minutes per track.

5. Do not slide the stone laterally while it is in contact with the commutator surface. When the stone is to be relocated, remove the stone from contact with the surface, then relocate and repeat the grinding procedure.

Notice: Handstoning on high-speed turbo exciters is not to be confused with the cleaning operation employed on slower-speed machines in which a cleaning stone is moved back and forth across a commutator surface to remove surface film only.

6. After handstoning the surface should be polished lightly using a fine grade of sandpaper, sanding cloth, or rubber base stone. The machine should be blown out and the brushes individually cleaned. The commutator should be thoroughly inspected at the first shutdown, checking especially for high mica and the degree of bevel remaining.

Handstoning of 1800 and 3600 rpm exciters can be performed without shutdown provided there is no voltage on the machine and all brushes are lifted. The turbine will have to be operated at no load for the period of the handstoning. The machine should be carefully vacuum cleaned when the work is completed.

C. Beveling Commutator Bars

After grinding, all commutator slots should be thoroughly cleaned and the edges of the bars beveled. Beveling removes the burrs caused by the stone dragging copper over the slots, eliminates the sharp edge at the entering side of the bar under a brush, and removes any high mica that may have been missed during undercutting.

The bevel on the bars is done with a special tool and should be about $\frac{1}{32}$ chamfer at 45 degrees for bars of medium thickness. For thinner or wider bars the beveling can be adjusted proportionately. The type of beveling tool is important. The proper tool will cut a curl of copper off the commutator bar edge, giving a smooth edge that is not burred or raised by the beveling tool pressure. Figure 5 illustrates hand beveling procedure and Figure 6 illustrates two improvised beveling tools.

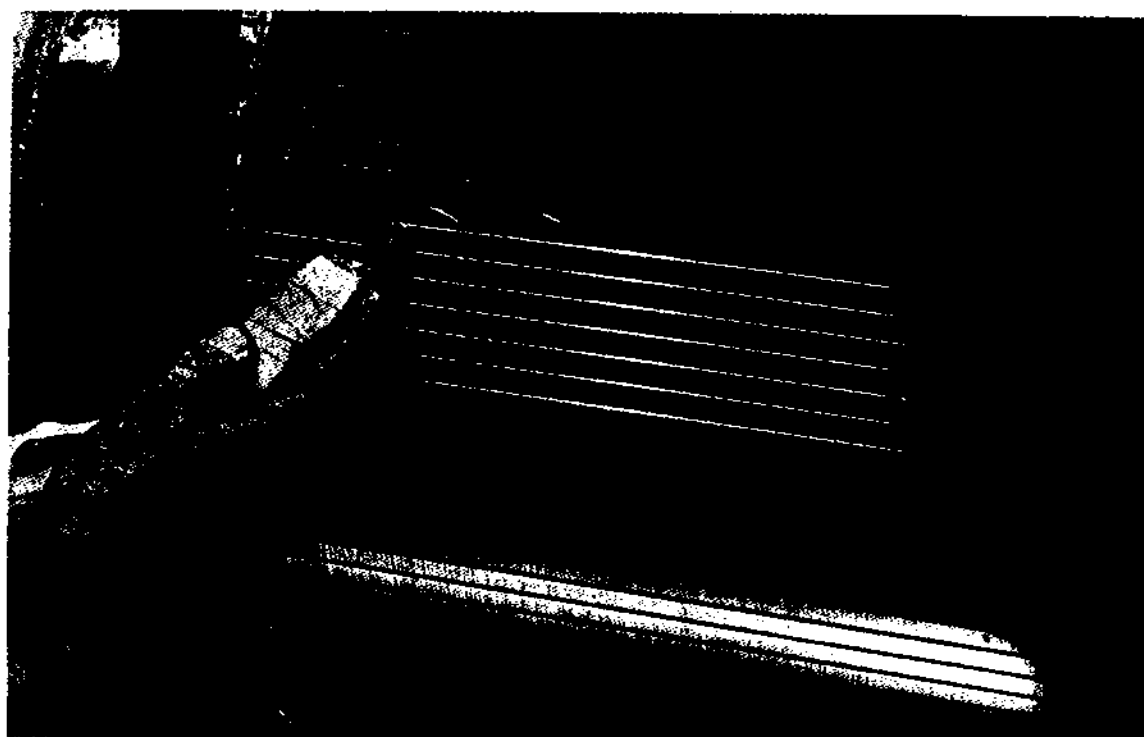


Fig. 5 – Beveling Bars by Hand

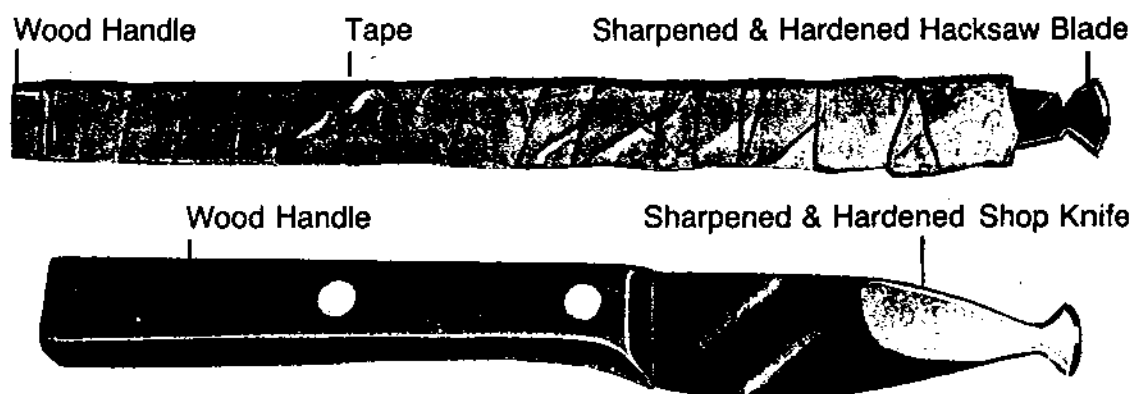


Fig. 6 – Improvised Beveling Tools

D. Mica Undercutting

All modern machines have undercut mica. The mica should always be below the bar level by $\frac{1}{16}$ inch $\pm$ $\frac{1}{64}$. If it appears that considerable copper will be removed by grinding and the mica depth will be shallow, undercutting should be done before grinding. The undercutting should be done with a small circular high-speed saw about .003 inch thicker than the nominal thickness of the mica. See Figure 7.



Fig. 7 – Mica Undercutting with a High-Speed Saw

After undercutting, a thorough inspection should be made to assure that a thin sliver of mica is not left against one side of the slot. Any such slivers must be removed by scraping with handtools. A hacksaw blade with an improvised handle makes an excellent scraper because of the serrated edge.

E. Polishing Commutators

After grinding, beveling, and undercutting, the commutator surface should be polished. This should be done with the machine rotating at rated speed using fine sandpaper or sanding cloth. After this polishing, a high gloss can be obtained by burnishing with dense felt or canvas.

Caution: Do not use any polishing compound on commutators, it may contain emery or other hard substances.

F. Precautions

All commutators are thoroughly baked and seasoned before leaving the factory and should not require any adjustment. Bolt tension is an important factor in commutator operation and is carefully adjusted with torque wrenches. Improper tightening can seriously damage the commutator.

Trouble is sometimes experienced from the break down of the mica insulation between segments. The most common cause of burn-outs is allowing the mica to become oil soaked. Burn-outs are seldom attributable to excessive voltage between bars. When burning occurs it can usually be stopped by scraping out the burned mica and filling the space with a solution of sodium silicate (water glass) or other suitable insulating cement. If this solution does not work the commutator must be rebuilt. This is a major job that must be done in an electrical repair service shop.

14.4 Brushes and Brush Holders

A. Pressures

All brush holder fingers should move freely and exert the correct pressure on each brush. Pressure should normally be 2 to 2½ pounds per square inch of cross sectional area of the brush. Finger pressure depends upon the size of the brush. These pressures are recommended for use in the absence the manufacturer's instructions:

Brush size	Pounds pressure per brush
$\frac{3}{8} \times 1\frac{3}{4}$	1.3 to 1.6
$\frac{1}{2} \times 1\frac{3}{4}$	1.8 to 2.2
$\frac{5}{8} \times 1\frac{3}{4}$	2.2 to 2.7

Recommended pressures for various applications are:

Industrial d-c machines	2 to 2½ psi
high-speed exciters	2½ to 3 psi
diesel generators	4½ to 6½ psi
axle hung traction motors	6 to 12 psi
spring suspended traction motors	5 psi
auxiliary diesel generators	2½ to 5½ psi

Figure 8 illustrates a method of measuring spring tension.

The brush shunts should be inspected to assure they are properly connected to the brush holders. There should be adequate shunt separation between brush holders and maximum clearance from all other parts of the machine. The brush should clear the commutator by $\frac{3}{32}$ to $\frac{1}{8}$ inch. Figure 9 demonstrates the procedure for spacing brush holders from the commutator surface.

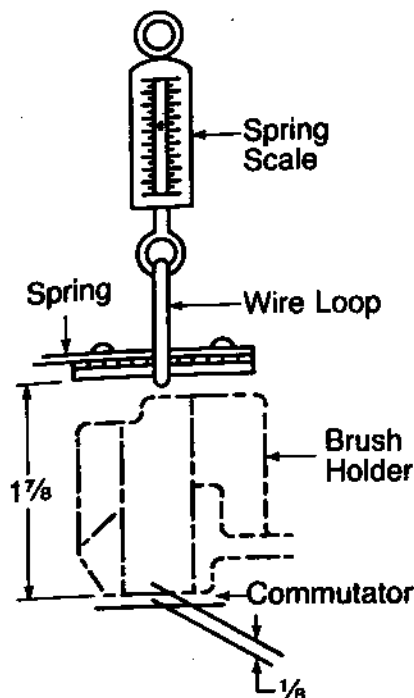


Fig. 8 – Spring Tension Measurement

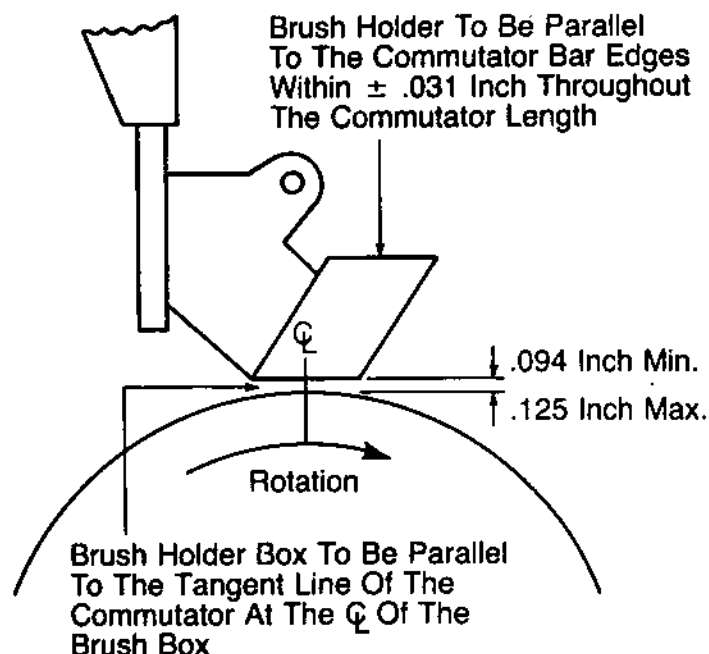


Fig. 9 – Spacing the Brush Holder from the Commutator Surface

B. Pressure Springs

Brush pressure springs should be set at the manufacturer's recommended values and all should be set as uniformly as possible. Uniform spring pressures assure that all brushes will take an equal share of the load.

In measuring pressure the tension should be determined just as the brush being measured touches the commutator. The measuring pull on the spring should be exerted in the exact opposite direction from the brush motion to assure that the tension measured corresponds exactly with the pressure on the brushing operation. Dividing the tension in pounds by the cross sectional area of the brush in square inches gives the brush pressure per square inch. In figuring the pounds per square inch of brush pressure of an inclined, reaction, type brush, the area of a cross section of the brush should be used, not the area of the brush face. The machine manufacturer's recommended pressures should be followed. These pressures may vary with the design and application of the machine.

C. Brush and Brush Holder Tolerances

Brush holders should have sufficient clearance to permit brushes to move freely in the box. The standard tolerance for brush thickness is $+.000 - .004$ inch; for brush width it is $+.000 - .004$ for brushes under $\frac{3}{4}$ inch wide, and for brushes over $\frac{3}{4}$ inch wide it is $+.000 - .015$ inch. The average industrial type brush holder has a tolerance of $+.003$ to $+.006$ inch on thickness and $+.002$ to $+.010$ inch on the width dimension and $-.000$ on both dimensions.

With these tolerances even a small amount of dirt or carbon dust can cause the brushes to stick in the holders. The machine must be kept clean and must be blown out at regular intervals. If brushes feel tight in the holders, even though they have been cleaned, the holders should be checked to determine if they have warped out of shape. Warping sometimes happens when a machine has been overheated or sustained a heavy overload flash. A steel block machined to brush dimensions ($+.001$ inch) can be forced through the brush box opening which will sometimes restore the original shape. Remove the box from the machine to work on it as some filing may be necessary. Avoid filing so much as to weaken the box. When re-installing protect the commutator, it is easily damaged.

Caution: Do not drop or rest tools or parts on the commutator, do not stand on the commutator, the surface is easily damaged and repair is a major undertaking.

D. Care of Brushes

Properly positioned brushes under proper pressure should be frequently inspected. See Figure 10. These checks should be made:

Brushes not sticking in holders.

Pig-tail shunts properly attached to brushes and holders.

Correct tension is being maintained as the brushes wear.

Brushes in need of replacement. Brushes should be replaced before they reach their limit of travel and break contact with the commutator or damage the commutator surface with an exposed metal shunt clip.

Remove any free copper picked up and lodged in the face of the brush.

When a new brush is installed it must be fully radiused, seated, and free in the brush holder. Sanding-in is always necessary to insure full contact with the commutator.

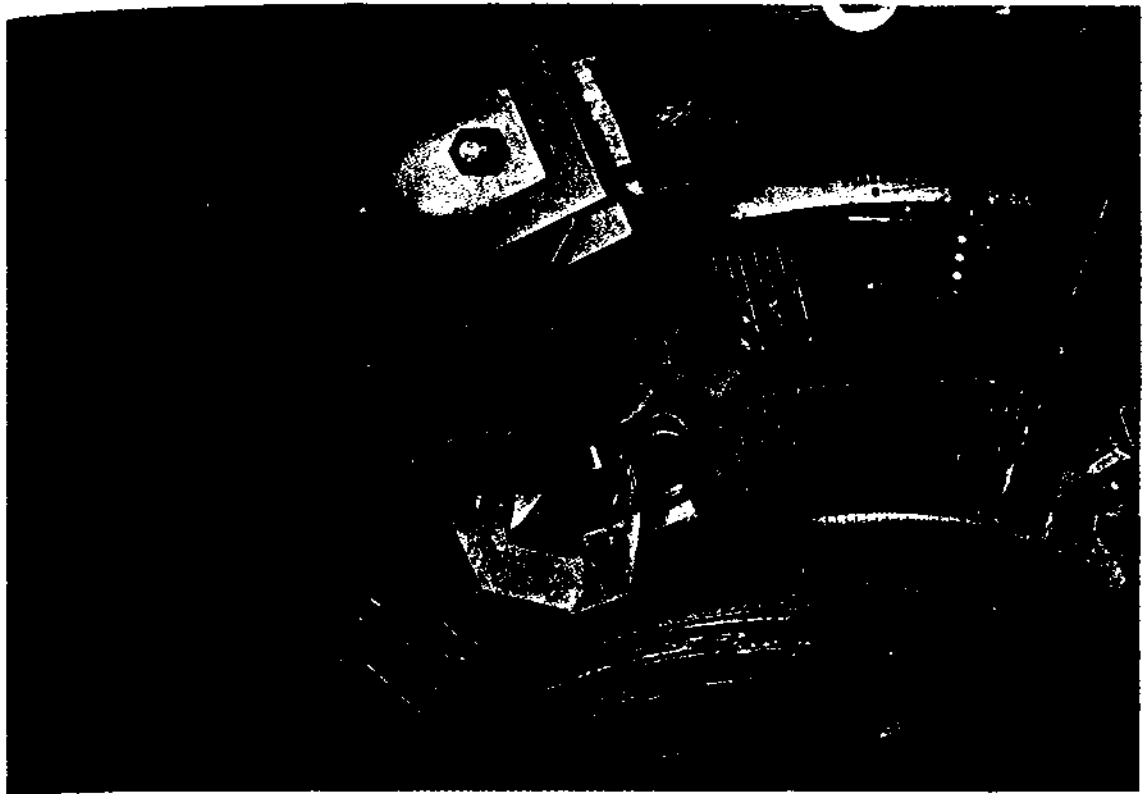


Fig. 10 – Checking Brushes and Shunts

E. Seating Brushes

All brushes should be fitted to the commutator and make good contact over their entire bearing surface. Contouring is done after the brush holders have been adjusted and the brushes fitted, following this procedure:

Fit the brushes in each holder separately. Place a piece of sandpaper face up under the brush, then pull the sandpaper in the direction of commutator rotation while pressing the brush firmly against the commutator. Pull down, not up; keep the smooth side of the sandpaper as close to the commutator surface as possible to avoid rounding the edges of the brush. The abrasive side of the sandpaper will cut the brush in the direction of normal rotation. Lift the brush each time the sandpaper is drawn back so cutting occurs only in the direction of rotation. Refer to Figure 11.

Caution: Do not use emery cloth or emery paper to seat brushes. Particles will become lodged in the brush surface and a continued abrasive action on both brush and commutator surface will result.

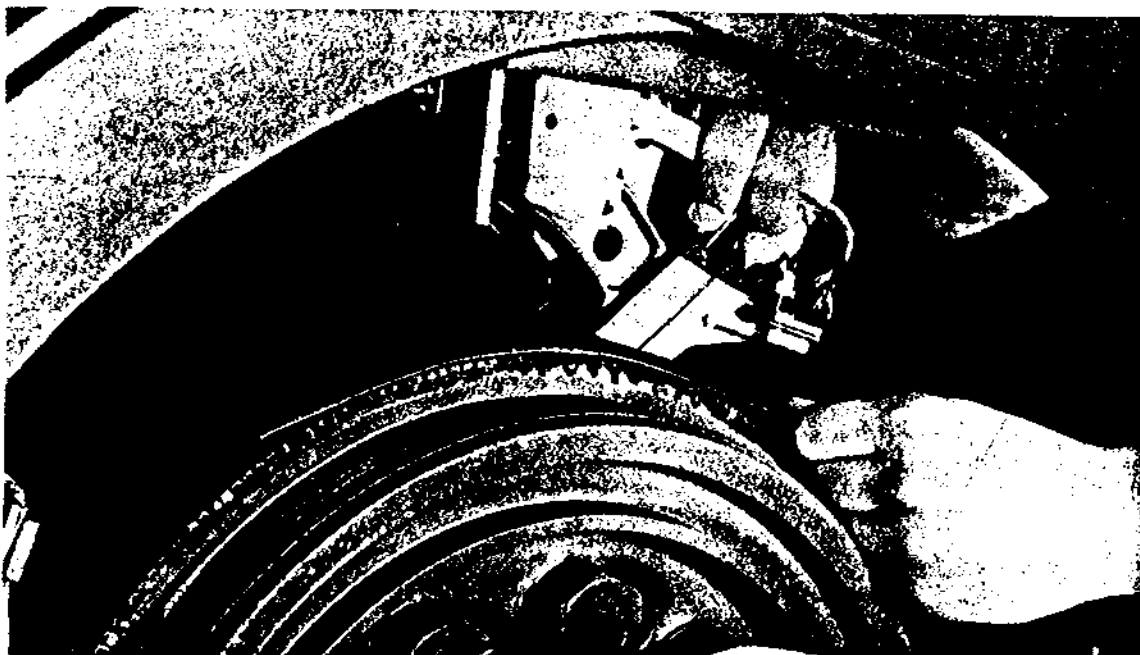


Fig. 11 – The Method for Seating Brushes

F. Factors Affecting Commutation

Good maintenance is essential for satisfactory commutation, long brush life, and commutator condition. There are a number of other factors which may contribute to poor commutation. The following can serve as a guide in solving commutation problems but is not the ultimate answer to all commutation troubles.

1. Excessive Brush Movement

Brush movement results from one or a combination of the following conditions:

- a.** Variations in the commutator surface, high bars, high mica, out of round commutator, smutted bars, non-uniform film, or any other condition which will change the symmetry of the commutator.
- b.** Incorrect pressure spring setting, weak or broken pressure springs, worn or bent pressure fingers.
- c.** Improper brush holder positioning with respect to the commutator surface, distorted brush holders, or loose brush shunts and terminals.
- d.** Lengthy periods of no-load or light-load running, prolonged operation at elevated temperatures.

The type of movement from any of the first three conditions usually produces a relatively large amplitude vibration of the brushes at low moderate frequency.

2. Brush Chattering

Brush chattering is one of the most destructive conditions and requires immediate correction. Brush chatter is caused by high friction between the commutator and the brush causing high frequency brush movement. This is injurious to the brush, the commutator, and results in poor commutation.

One of the most common causes of brush chatter is the commutator surface film produced by light-load or no-load running for a prolonged period. The brush friction curve shown in Figure 12 illustrates the change in the coefficient of friction between brush and commutator relative to brush temperature. From this curve it can be seen that the desirable operating temperature is about 80C plus or minus 10C.

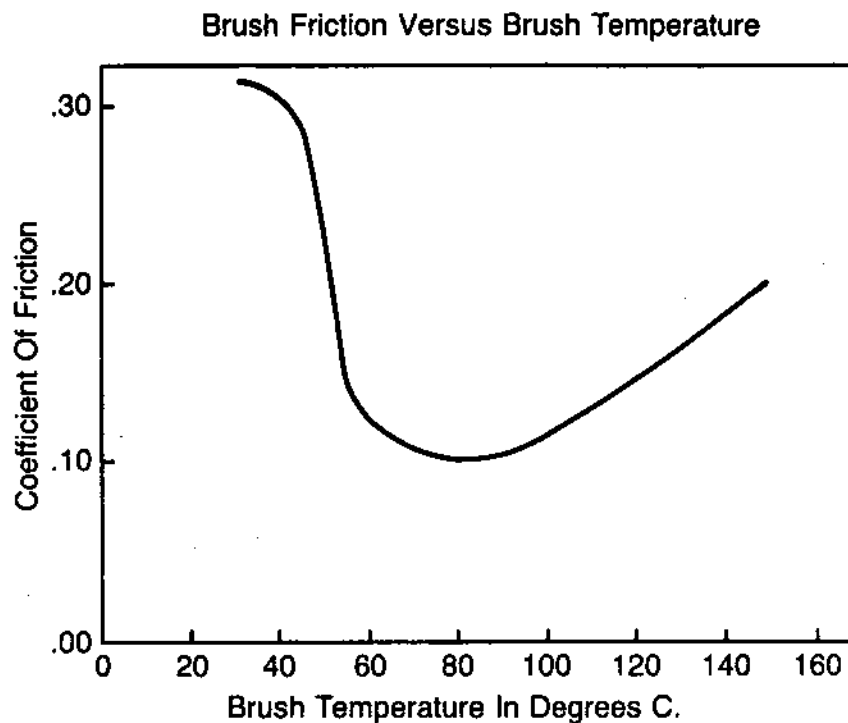


Fig. 12 – A Typical Brush Friction Curve

Brushes which operate with current densities below 30 amperes per square inch will in time develop a highly polished glaze on the commutator. This film increases the brush friction and causes it to chatter. Chatter has many negative effects, it causes:

Poor commutation.

Chipping and breaking of brushes. Figure 13.

Noisy operation, a high frequency sound.



**Fig. 13 - Brush Chipping and Fractures
Should be Investigated for
Cause**

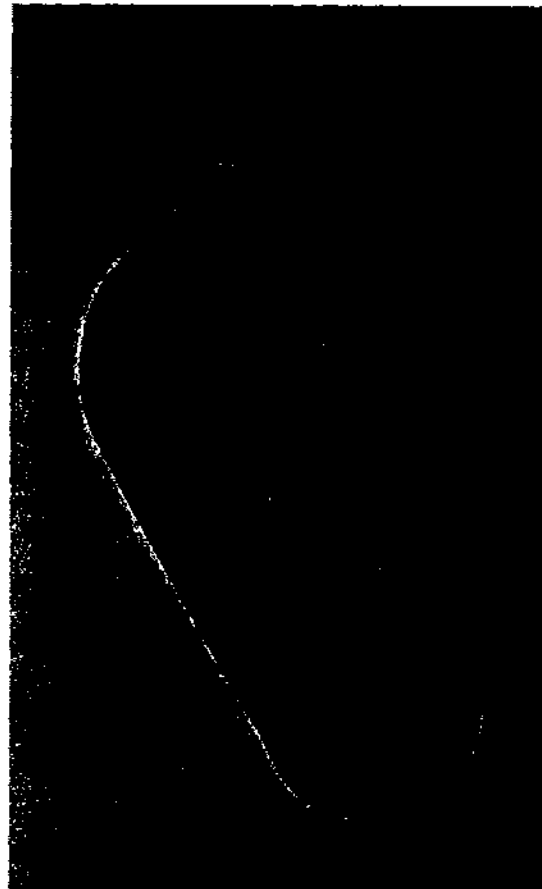


**Fig. 14 - A Prolonged Chatter Condition
Can Wear Brush Fingers**

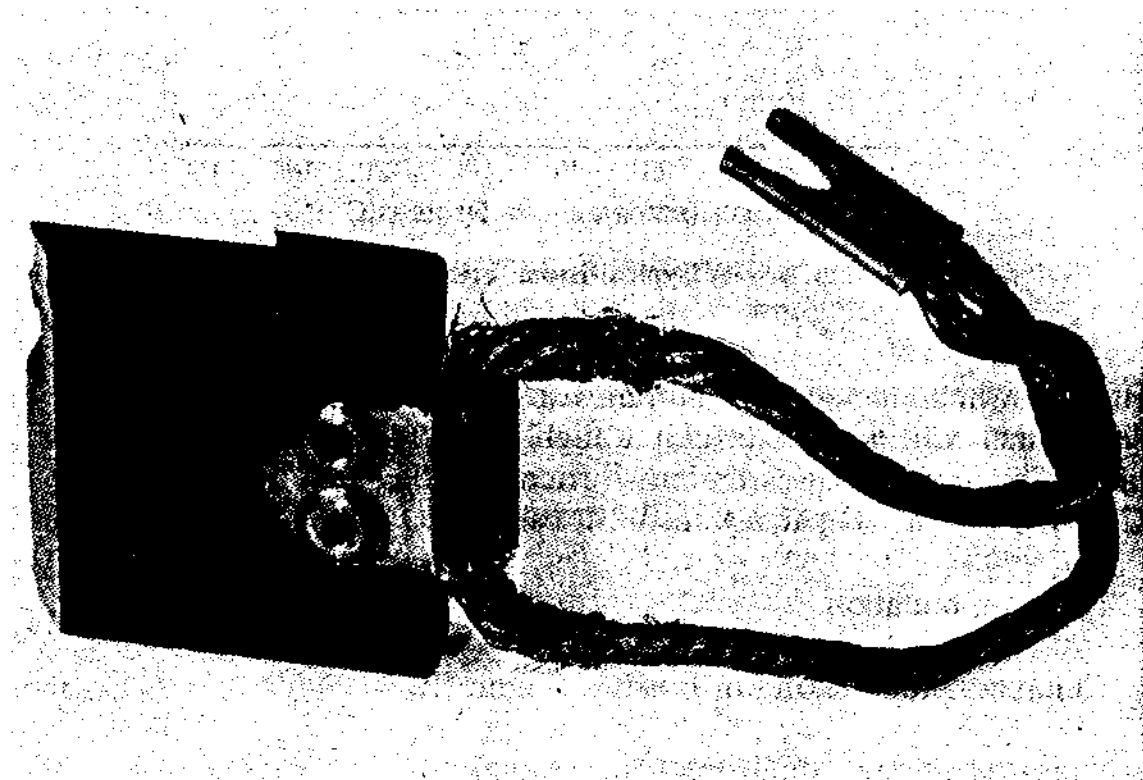


Fig. 15 - Chatter Can Totally Destroy Brushes and Shunts

Wearing of brush holder fingers. Figure 14.

Fraying and breaking of brush shunts. Figure 15.

Grooving in the brush by the finger.

Threading of the commutator. (See 14.4, F. 5 below).

Shorting between commutator bars by copper slivers hammered loose by the chattering brush.

Brush chatter can be corrected in two ways. The best solution is to increase the brush current density to a value of 35 to 60 amperes per square inch. Brushes can be lifted uniformly to produce this desired current density. Occasional peaks on the brushes should not exceed approximately 125 amperes per square inch or about 100 amperes per square inch for frequently applied loads. The proper approach is to study the application and lift enough brushes to get the desired current density for the major portion of the operating time.

Example: Raise one complete track of brushes around the commutator at a time. This is important, the number of brushes should always be symmetrical. Maintain the same number of brushes on each arm and an equal number of + and - brushes in each track at all times.

The other solution to brush chatter is to keep removing commutator film before it becomes objectionable. This can be done by removing the glaze from the commutator after prolonged periods of light-load operation by using a rubber banded stone on the commutator surface. The film formation can be retarded by using a grade of brush with some cleaning action or by uniformly adding some cleaner brushes across the commutator.

3. *Brush Chipping or Breaking*

The most common cause of brush chipping or breaking may be chatter, but other causes may be too light or too heavy spring pressure, high mica, poor fit of brush in holder, or severe shock or vibration in the vicinity of the machine. The correct tolerances and pressures for brushes, brush holders, and springs must be maintained to prevent chipping and breaking of the brushes.

4. *Sparking*

Satisfactory commutation is evaluated by largely subjective judgment. To make the assessment of commutation more objective the following rating table may be used as a guide.

Description of visible commutation	Rating		
	A	B	C
Black - No visible sparking	1	1	1
Few intermittent fine sparks	2	1¼	- 1⅛
Continuous fine sparking over ¼ brush width	3	..	1¼
Continuous fine sparking over ¼ brush width plus intermittent heavy sparking	..	..	- 1¼ to + 1¼
Continuous sparking over ½ brush width	..	1½	1½
Continuous fine sparking over most of the brush width	..	2	- 2
Continuous fine sparking over most of the brush width plus heavy sparking over ½ of brush	4	..	2
Continuous heavy sparking	..	3	+ 2
Continuous heavy sparking plus streamers	..	..	+ 2(3)
Continuous heavy sparking plus blue arcing	5	..	+ 2
Continuous heavy sparking plus glowing across brush width	6	4	+ 2(4)

In Rating C fine pinpoint sparking is designated -, intense sparking +, and neither extreme no symbol. (3) designates streamers, (4) refers to glowing spots.

The most common causes of sparking are:

Machine overloaded.

Rough commutator with high bars, flat spots, or rough bar edges at the mica undercutting.

High bar mica.

Dirty, oily, or worn out commutator.

Brushes not set exactly on factory test position.

Brushes not equally spaced around the commutator.

Brush holders too high above the commutator.

Brushes sticking in holder or at limit of travel.

Brushes not properly seated on commutator.

Insufficient pressure on brushes.

Unequal pressure on brushes.

Brushes of unsuitable grade.

Brush faces burned.

Brush vibration.

Incorrect brush angle.

Non-uniformity of main or commutating pole gaps.

Incorrect commutating pole field air gap.

Open circuit or loose connection in armature. This condition is indicated by a bright spark which appears to pass completely around the commutator. Inspection should be made for indications of burning at the point of open circuit.

If a lead from the armature winding to the commutator becomes loose or broken, it will draw a bright spark as the break passes through the brush position. The location is easy to detect because the commutator will show signs of pitting on either side of the disconnected bar.

If sparking occurs that cannot be accounted for by overloads, service conditions, wrong adjustments, or mechanical problems, the manufacturer should be consulted to help determine the cause and recommend corrective action.

5. Streaking or Threading of the Commutator

When there is a breakdown of the film on the commutator surface an area of lower resistance is created. The area of lower resistance tends to spread around the surface of the commutator and eventually the copper bars start to wear creating streaks and threads.

This breakdown of the film can be caused by the build-up of a too heavy film on the commutator surface, usually due to atmospheric conditions. Since film is not a good conductor, the film must breakdown to permit current to pass between the commutator and the brush. This breakdown will start in one spot but gradually develops into a streak or a thread all around the commutator.

Threading and grooving can also be caused by particles of copper imbedded in the brush face. These particles cut the commutator film. Since copper-to-copper contact drop is relatively low, these areas on the commutator surface carry more than their share of current which further aggravates the condition.

The tendency for one brush or group of brushes to carry a disproportionate share of the load is another cause of streaking and threading. Streaking in particular can be attributed to this selective action.

To prevent threading and streaking due to selective action it is necessary to check the terminal connections, spring pressure, shunt to brush connections, brush freedom in the brush holders, spacing, brush contact with the commutator, and symmetry. Any factor which will make the electrical resistance in one path different from other parallel paths in a machine will cause selective action. Mixing several different brush grades in on one machine or improper staggering will often cause selective action.

Threading is not caused by a brush that is too hard. One ingredient in a brush that may contribute to threading is the ash content. Ash particles in a brush can be extremely hard. The brush or even the brush grade should be changed to one without these hard ash particles or the threading will continue.

6. Flashing

Flashing or bucking are terms commonly used to indicate arcing between adjacent brush holder arms or between brush holder arm and the armature. This condition is generally caused by excessive voltage or abnormally low surface resistance on the commutator between brush holders of opposite polarity. Any condition tending to produce poor commutation increases the danger of flashing. Other possible causes may be:

Rough or dirty commutator.

Water on the commutator from an overhead leak such as steam or water pipes, roof, etc.

Short circuits on the line producing excessive overloads.

If elimination of these causes does not stop the flashing, the condition is usually due to causes external to the machine. The cause must be located and eliminated or the machine will be severely damaged.

G. Effect of Setting Brushes Off Neutral

Industrial type d-c machines are usually designed so the brush location relative to the main and commutating-field poles can be easily shifted circumferentially. This shifting is done to obtain the most favorable commutation and performance under actual load conditions.

When brushes are moved in a direction opposite to the direction of rotation on a generator, it becomes overcompounded and the effective compensation from the commutating poles is reduced. Moving the brushes in the direction of rotation under compounds and over compensates it. On a d-c motor the effects are the reverse of this.

Locating brushes off kick neutral is also done to obtain voltage or speed regulation curves that more closely approach straight lines.

Shifting should never be done to the extent that commutation is impaired.

If a machine is of the reversing type, the brushes are normally pre-set at a position called running neutral. This is the location that gives similar performance in either direction of rotation.

1. Mechanical Redetermination of Factory Brush Position

If the brush position has been disturbed due to repairs, the brushes must be returned to their original factory setting. There is a mechanical method for checking the factory brush position called tramming.

Notice: This method may not be valid if a spare or replacement armature is installed or if the commutator of the original armature has been replaced, since the commutator bars and armature slots may not line up the same as the original armature.

Tramming Procedure:

Using the two center punch marks inside the circle on the front edge of the frame as centers, scribe two arcs to intersect on the front end of the commutator bars near the commutator surface, see Figure 16. Draw through this intersection a radial line to the commutator surface. The point of intersection of this radial line with the commutator surface is the correct factory location for the center of the brush arc on the commutator. Due to the angularity of brush contact with the commutator surface, the midpoint of the brush arc does not coincide with the centerline of the brush. The midpoint of the arc periphery of brush contact must be selected.

Notice: When brushes are staggered circumferentially, the midpoint of the effective arc must be used.

This point is the factory brush position, it may or may not be the electrical neutral position.

Small and medium sized machines are shipped with the brushes in place, pre-adjusted to factory test standards for good commutation and other operating characteristics.

On new installations another method is available to locate brush position, provided the brush holder brackets have not been disturbed from their original position on the rocker ring and armatures have not been interchanged.

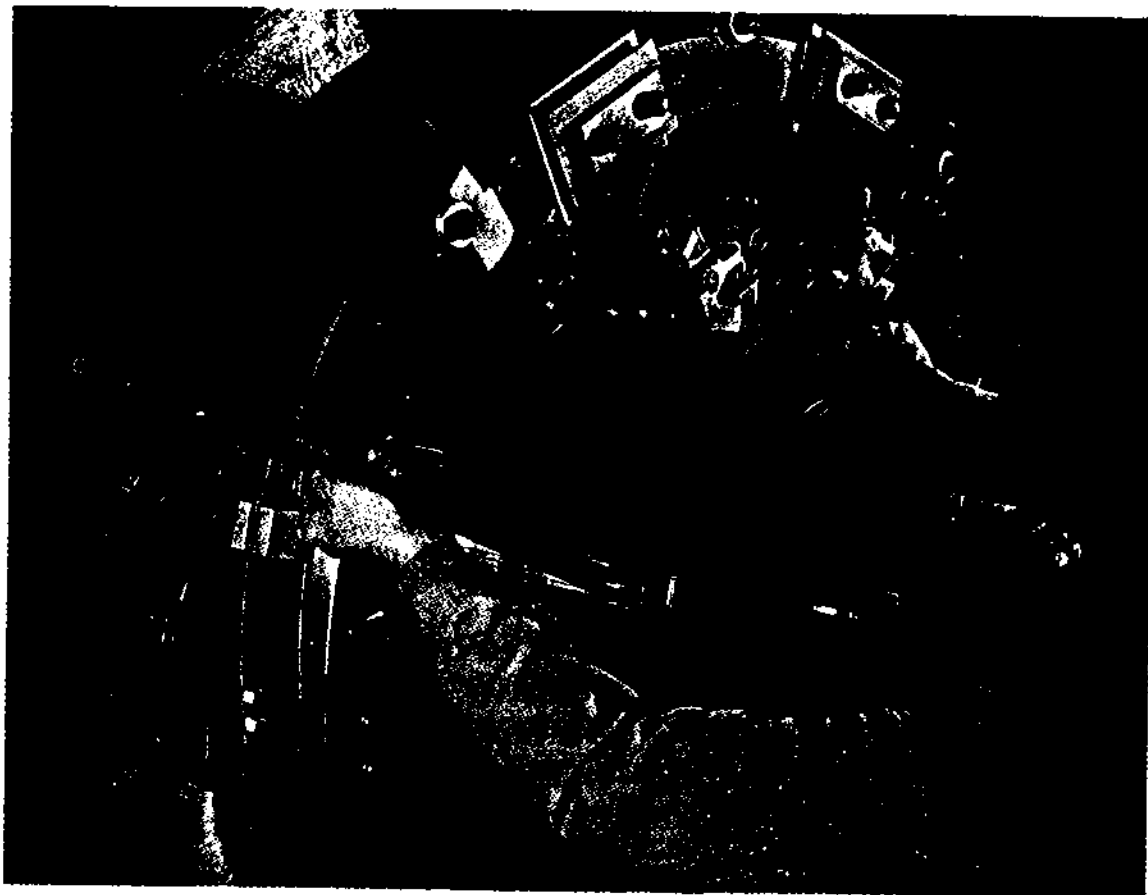


Fig. 16 – Tram Method for Relocating Mechanical Neutral Setting

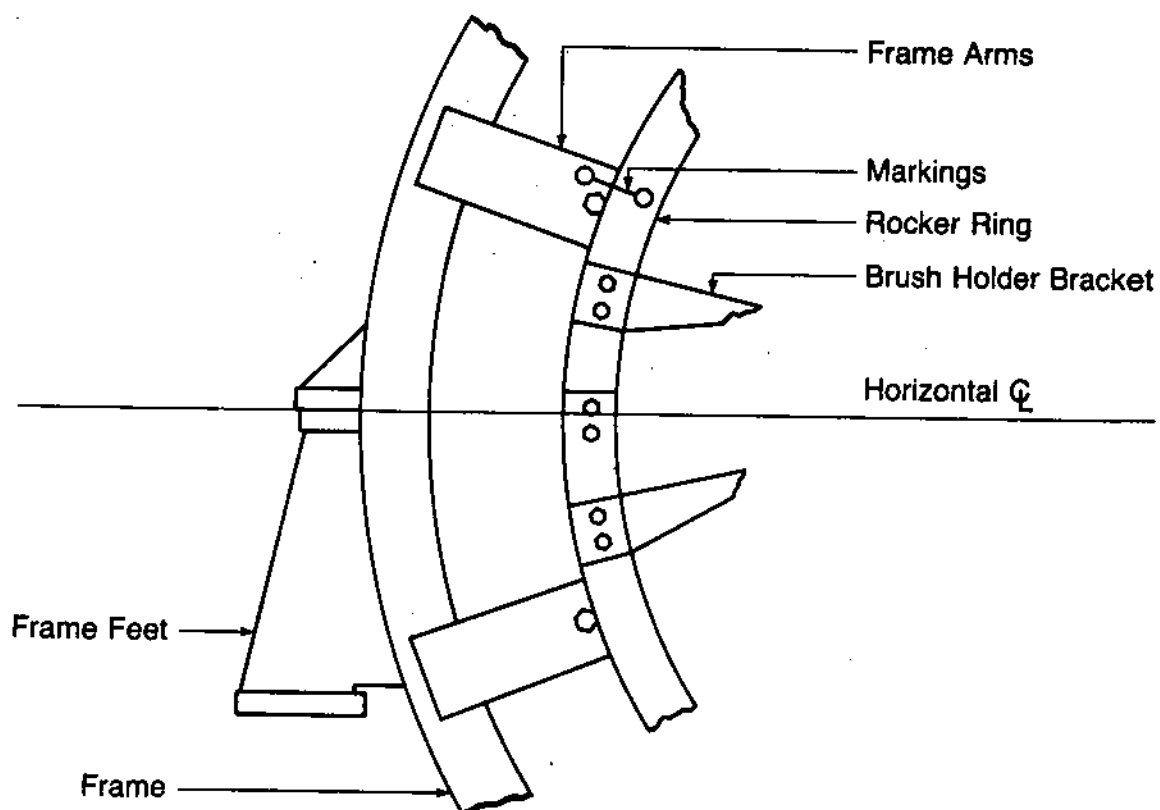


Fig. 17 – Method of Locating Brush Position by Rocker Ring and Frame Arm Markings on Standard Machines

Located on the left side of the machine, at or just above the horizontal centerline, there is a chisel mark on the frame and rocker ring. Aligning these chisel marks relocates the correct brush position. These index marks are usually indentified by a center punch indentation with a circle around it located at the outer end of each chisel mark. See Figure 17.

If the brush holder brackets have been moved on the rocker ring, it is necessary to relocate the brush position by tramming.

The chisel marks locating correct brush position on a reversing mill type motor are placed as shown in Figure 17. Here the rocker ring base, rocker ring arms, and rocker ring are an integral part of the rocker ring assembly.

2. The D-C Kick Method of Determining Neutral

If it is necessary to locate the electrical neutral on a d-c machine after installation, it may be located using the electrical kick method. With the machine at standstill, all brushes should be raised and the number of electrical bars counted. In a few high-current, low-voltage machines there are two commutator bars joined together by the commutator risers or necks to form one electrical bar. Each such pair should be counted as one electrical bar. On other machines the total number of bars on the commutator is the number of electrical bars.

To determine if there are two mechanical bars for every electrical bar, several test readings should be taken. For example; if the readings between bars 1 and 22 and between 1 and 21 and 1 and 23 are all different, it indicates that there is only one mechanical bar for each electrical bar. If any two of these readings are the same, it is an indication that there are two mechanical bars for each electrical bar.

Once the number of electrical bars is established the kick method can be used.

a. Machines With an Even Number of Bars

If the number of bars is evenly divisible by the number of poles, the number of bars per pole, or throw should be determined. The following is an example: If the machine has 160 bars and eight poles the throw would be bar 1 to bar 21. Using a d-c volt meter, preferably one with .5, 1.5, and 15-volt scales, place the voltmeter points on bars 1 and 21 in the approximate neutral zone, see Figure 18. Separately excite the shunt field from a d-c source through a quick-break switch. Insert enough external resistance in the excitation circuit to keep the field current low at the beginning. Use only enough field current to produce a good deflection on the low scale of the voltmeter. The kick voltage is read as the quick break switch is opened. On the first trial begin with

the 15-volt scale and change to the lower scales only when it is established that the voltage is within their respective ranges.

Caution: Before the switch is opened for each reading, wait long enough for the induced voltage caused by closing the circuit to decay.

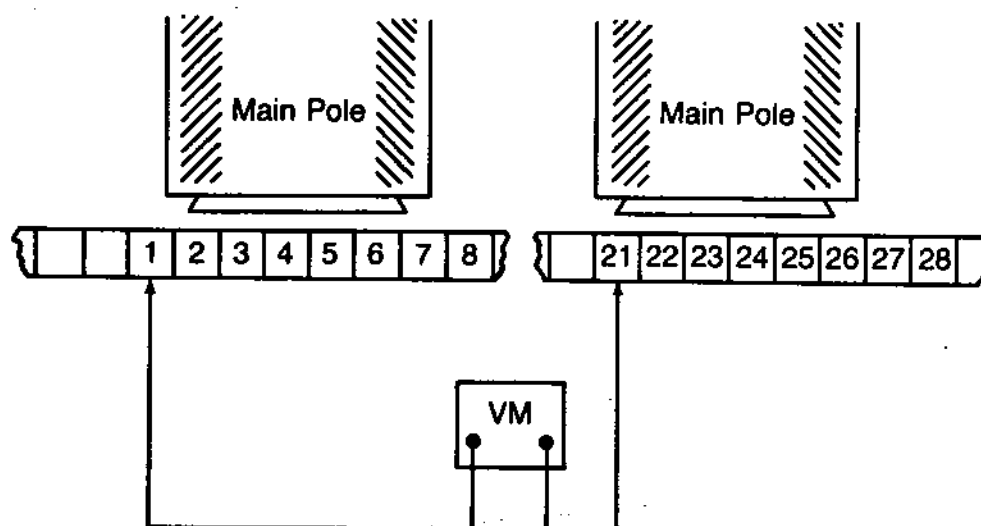


Fig. 18 – Bar-to-Bar Method of Reading Induced Armature Voltages

After a satisfactory value of field current is found, move the voltmeter points to bars 2 and 22. Again read the deflection as the field is opened. If possible, rotate the armature in either direction and repeat the operations until the two readings are equal but opposite. This would indicate that the correct neutral is exactly on the mica between bars 1 and 2 or between bars 21 and 22.

Next, shift the rocker ring so the center line of the brush arc is over the correct neutral point. If the machine has double brush holders, be sure the center of the total brush arc is placed on the neutral. On machines with brushes staggered circumferentially, locate the midpoint of the total brush arc on the neutral mark. The midpoint is halfway between the front of the leading brush holder to the rear of the lagging brush holder.

Notice: Location of the rocker ring on the electrical neutral does not mean the final brush position has been located. The original factory brush position must be established relative to the electrical neutral and the rocker ring shifted properly in the prescribed direction.

Calculation or plotting a curve may be used when the armature cannot be moved, if the number of bars is evenly divisible by the number of poles. See Figure 19.

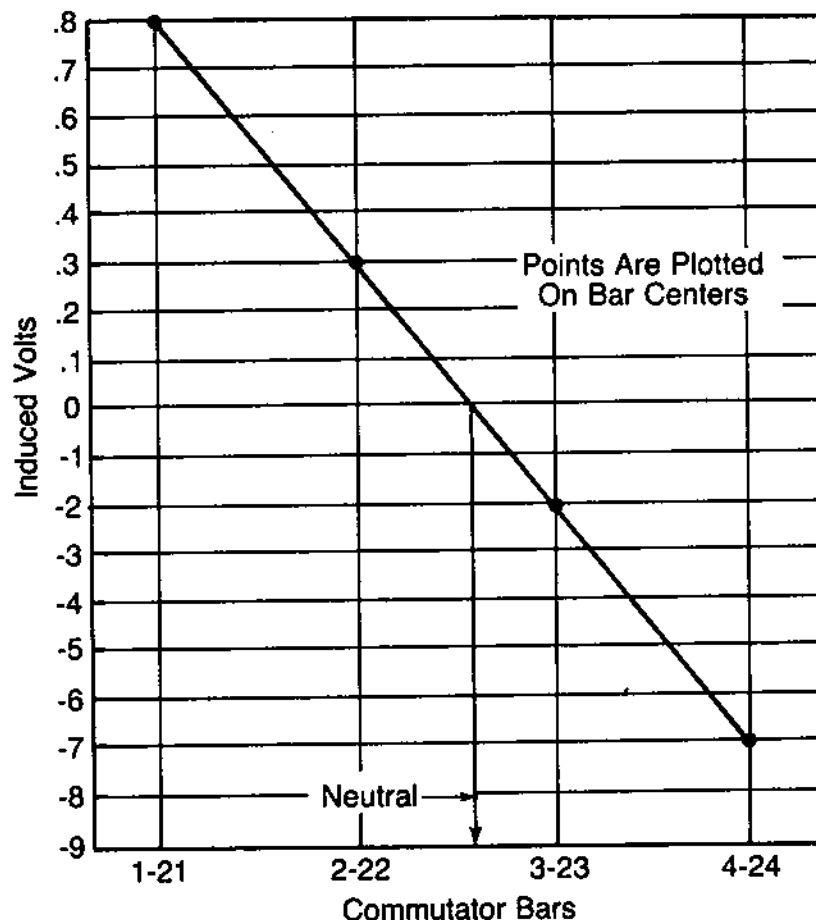


Fig. 19 – Curve Method of Determining Neutral on D-C Armatures With an Even Number of Bars

When a satisfactory value of field current is found, as described above, read the induced voltages between bars 1 and 21, 2 and 22, and 3 and 23, etc., until a point is reached at which the polarity of the induced voltages reverses. Two readings on either side of this reversing point should be recorded. Plot a curve using these four readings as ordinates and the numbers of the commutator bars as abscissae, using the first number in each pair. The bar number indicates the center line of the end of the bar. Determine the exact point of reversal from the plot and mark that position on the commutator. This point is the correct neutral. Shift the rocker ring so the center of the brush arc is set over this point.

If the points plotted from the readings do not fall on a straight line, there is probably another field on the main pole that is short circuited at its terminals. This condition usually causes the points to plot on an S curve rather than a straight line. If this condition is encountered, the additional field should be opened at its terminals. A wire-wound series field excited by the IR drop across the commutating and compensating windings is common in large machines. Just one brush that has not been raised will also result in erratic readings.

b. Machines with an Odd Number of Bars

If the number of commutator bars is not evenly divisible by the number of poles, for instance, 164 bars and 8 poles, which is $20\frac{1}{2}$ bars per pole, proceed as in the method for an even number of poles, above, except read the voltage with the voltmeter points on bars 1 and 21 in the approximate neutral position. Then move the voltmeter points to bars 1 and 22 and read again. If possible rotate the armature slightly until the two readings are equal but opposite in polarity. This indicates the correct neutral is exactly on the centerline of bar 1 and on the mica between bars 21 and 22. The rocker ring should be shifted until the brush surfaces are centered over this position.

If the armature cannot be rotated and the number of bars is not evenly divisible by the number of poles (machines with an odd number of bars) proceed as with a machine with an even number of bars except read voltages between bars 1 and 21, 2 and 22, and 3 and 23, etc., until a point of reversal is reached. Then repeat the readings using bars 1 and 22, 2 and 23, 3 and 24, etc. Record two readings on either side of the polarity reversal point for both sets of readings. Plot each set of four readings as described above, see Figure 20. The neutral point, graphically determined, is the midpoint between the two points of reversal. If adjustment is necessary, mark the commutator and shift the rocker ring in the indicated direction.

The curve method can be used for any fractional number of bars per pole. For 165 bars and 8 poles, there are $20\frac{5}{8}$ bars per pole. Readings obtained from bars 1 and 21, 2 and 22, etc., when plotted result in a line $\frac{5}{8}$ of a bar under full pitch; and readings from bars 1 and 22, 2 and 23, etc., result in a line $\frac{3}{8}$ of a bar over full pitch. The neutral point thus determined is $\frac{5}{8}$ of the distance from line marked bars 1 and 21, etc. toward line marked bars 1 and 22 etc. at the two points of reversal.

3. The A-C Method of Determining Neutral

An easier and more accurate method of determining neutral involves exciting the shunt field with 60 Hz a-c voltage instead of low voltage direct current. The shunt field may be excited continuously from either 110 or 220-volts from any convenient a-c outlet. The current is limited by the normally high a-c impedance of the winding. The voltage induced in the armature can be accurately measured with a low reading (200 mV or 2.5 V) digital voltmeter. Readings are taken in the same manner as described for the d-c kick method (2. above). The curve method is used to determine the polarity reversal points. These points taken after the polarity reversal point has been established, should be plotted as negative to assure that they fall in straight line.

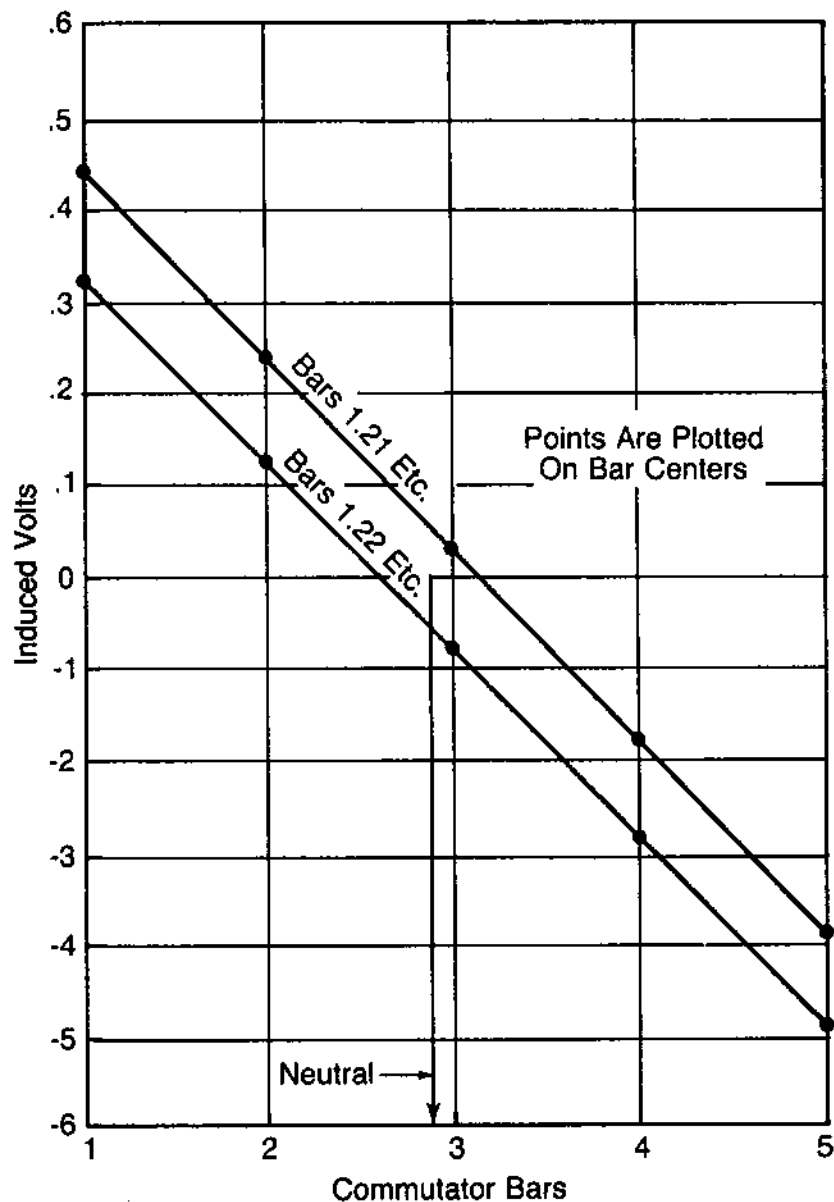


Fig. 20 – Curve Method of Determining Neutral on D-C Armatures With an Odd Number of Bars

4. Spacing Brushes

Having located the centerline position of one row of brushes, the other brushes should be equally spaced around the commutator, using the first row as a reference. The brush spacing should be accurate, within $\pm \frac{1}{32}$ inch. One way to obtain accurate spacing is to use a narrow strip of paper (calculator tape if convenient) cut to the exact length of the circumference of the commutator. This tape measure can be marked at equal intervals corresponding to the number of brush arms. When this tape is stretched around the commutator with one mark located under the center of the first row of brushes, all other rows can be located at a mark. See Figure 21.

The method is more accurate than spacing based on counting equal numbers of commutator bars because it does not depend on exactly equal spacing of the bars. The bar spacing method can be used as a rough check.

If any brush arms have been removed or changed, verify that the brushes are parallel to the commutator bars ($\pm 1/32$ inch back to front).

5. *Staggering Brushes Axially*

Brushes are staggered at the factory to promote even wear of the commutator. Staggering is done in pairs of brush arms, not alternate arms. One positive set of brushes with an adjacent negative set, is offset to the right or left of another pair of positive and negative brush arms by $3/16$ inch or more. Brushes on the third arm line up with the first arm; the fourth with the second, etc. See Figure 22. If the brush holder supports are ever removed from the rocker ring, they should be reassembled so the correct staggering is retained.

6. *Staggering Brushes Circumferentially*

On some machines the brushes are staggered circumferentially by placing spacers between the brush holder and the brush holder bracket. Spacers are generally put on alternate brush holders and located on the same brush track on each arm. See Figure 23.

7. *Staggering to Improve Commutation*

Staggering can improve commutation. By increasing the time of commutation it reduces the reactance voltage. At the trailing edge of the brushes where the bar leaves the brush, the cross section of brush in contact with the bar is reduced. This gives higher resistance which promotes good commutation. If rough or out of round commutator conditions exist, the staggered brushes give the effect of a wider brush and all brushes on any one arm will not be affected simultaneously. There will be some brush contact on all brush arms at any instant.

There is a normal difference in appearance of commutator film on brush tracks under staggered brushes and non-staggered brushes. This is due to the difference in angle between the staggered and non-staggered brush and the commutating conditions are not exactly the same. The condition is normal and not detrimental.

To place a machine in service with staggered brushes, follow procedures outlined in 14.4, G.1 – *Mechanical Redetermination of Factory Brush Position*.



Fig. 21 – Centering Brushes Using the Calculator Tape Method

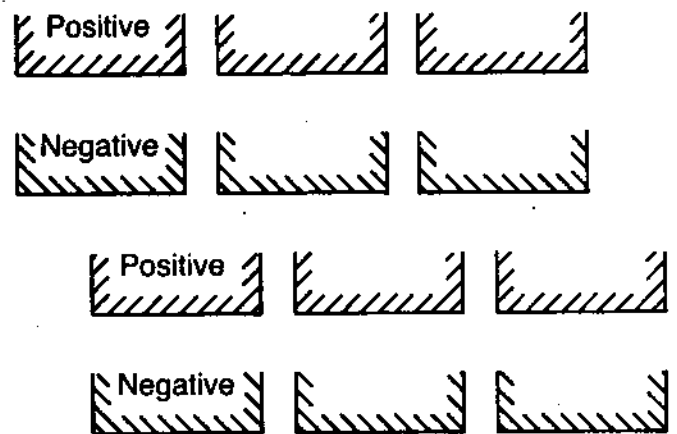


Fig. 22 – A Staggered Brush Relationship to Improve Commutation

Note: Spacer Is Used To Offset One Row Of Brushes

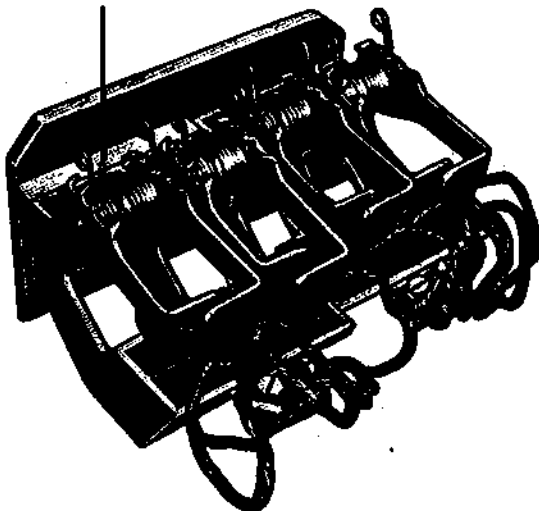


Fig. 23 – Physically Staggered Brush Box Assembly

H. Brush Wear

Brushes wear both electrically and mechanically and the two functions have a complex relationship. Brush life is most assured when the load on the brush is about 55 to 60 amps/sq. in. Lightly loaded brushes increase friction, chatter, and vibration which shorten brush life.

When a machine first goes into service, brush life is frequently short. This shortened life is frequently due to dust from recent construction and installation activities which is stirred up when the machine is started. A machine put into service in a new building will initially experience short brush life, but the condition is temporary and will gradually improve.

The conditions, both mechanical and electrical, that adversely affect commutation, increase brush wear. Correcting these unsatisfactory conditions will go far in improving brush wear.

The question of brush wear presents a problem in economics. The objective of long brush life must not be attained at the expense of severe commutator wear or unsatisfactory commutation.

I. Brush Composition and Application

Electrical designers carefully select the proper brush grade to meet the requirements for each machine. The application and operating conditions of a machine may require a departure from the specified brush grade. The five common types of brushes each have characteristics which make them especially suitable for certain types of application.

1. *Electrographitic Material*

Electrographitic brush material meets the requirements of high speed d-c machines. These machines have exacting requirement for commutating ability and long brush life.

Basic electrographitic materials are lampblack, cokes, pitches, and tars. These amorphous carbons are mixed, calcined, screened, and blended. They are molded into plates, baked, and graphitized. The graphitizing process involves subjecting the material to intense heat in specially constructed electric ovens. A change from amorphous carbon to graphite takes place in the furnace.

2. *Carbon Material*

The term Carbon Brush, when used in the electrical industry, means a specific type of brush. It is composed chiefly of amorphous carbons such as lampblacks, pitches, and tars.

Carbon brush material is usually very hard, but can carry only moderate currents so is used usually on low speed applications.

3. Carbon Graphite Material

Carbon graphite materials are a mix of amorphous carbons and natural graphites. The brushes made from this material are generally stronger than electrographitic brushes and have a more definite cleaning action. There is a limit to the speeds at which these brushes can be operated and the current carrying capacity is not as high as most electrographitic brushes. For applications where mechanical strength and adverse atmospheric conditions are a factor, brushes made of carbon graphite material are highly suitable.

4. Natural Graphite Material

Natural graphite brush materials consist of graphite mined from natural deposits. It is bonded with tar, pitch, or resin binder, molded into plates and heated to the curing temperature of the bonding material.

Brushes made of natural graphite have a very low coefficient of friction and a very definite cleaning action due to the ash content which is a part of natural graphite. Some natural graphite materials are laminated in structure and the resistance across the laminations is from five to eight times the resistance measured parallel to the laminations. This characteristic is effective in reducing short circuit currents in the face of the brush. For this reason natural graphite brushes are very suitable for machines with high commutating voltage.

5. Metal-Graphite Material

Metal graphite brushes are made from metal powders, natural graphite, and resins. The metals most commonly used are copper and silver in percentages varying from 10 to 95 percent by weight. Low metal content brushes are mixed using resin as a bonding agent. Medium metal content brushes are bonded by the sintering action of the metal, or by addition of a resin binder. High metal content brushes rely solely on the sintering action of the metal for bonding.

Control of particle size and shape of the metal powder is a critical factor in the manufacture of metal-graphite brushes. These brushes are used in applications where exceptionally high current capacity is required, where the contact drop must be minimal, and where machine voltages are low.

J. Brush Application

(Quoted with permission from *Carbon Brushes—The Physics and Chemistry of Sliding Contacts*, written by Erle I. Shobert, II Vice-President-Technology, Stakpole Carbon Company. Copyright Chemical Publishing Co. All rights reserved.)

1. *D-C Motors and Generators-Up to 250 HP*

Brush applications in motors and generators up to 250 hp are similar to those for the larger machines. These differ in specific instances in that there are many special machines that tend to exceed the design limitations of the machines as well as the brushes. The number of machines in service in this area is considerably greater than in that of the larger machines and, although the percentage of brush problems is probably much less, their absolute number is greater because of the variety of operating circumstances and the extension of machine technology into more difficult areas. Some of the problems are the following:

Machine-tool drives must work over wide ranges of speed and load, and thus require proper commutation over wide limits. The brushes are operated to the limit of their commutating ability and sometimes beyond it for short periods. Earthmoving machines and electric shovels not only must work at extremes of speed and load, but they are also subject to vibration and dust. Dynamometers for testing internal combustion engines must operate under a wide range of speed, including very high speed and load, and are subject to the vibration and atmospheres generated by this equipment.

The same maintenance procedures are desirable for this smaller equipment as would be suitable for the larger equipment while smaller machines, because of their large number and occasional inaccessibility, are more often neglected. As a result, best over-all results are achieved with a brush which has a wide range of commutating ability.

2. *D-C Motors and Generators 250 HP and Larger*

The area of large motors and generators is differentiated from others because most of the designs are developed to more specific parameters, the machines have been checked out by extensive manufacturers' tests before shipment, and the installations are usually so large that considerable engineering effort has gone into their design. In general, there is less machine and brush trouble in this area than in any other area of brush application. When machines are put into operation with suitable maintenance procedures for lubrication, cleaning, and brush changes, satisfactory operation can be expected and is achieved for years. The longest brush life reported is from a machine in this category on which brushes last for three to four years of almost continuous operation.

The brush problems that do appear occasionally in this area are usually concerned with operating circumstances and with the surrounding atmospheres. These two can sometimes combine to cause brush problems. More brush problems are caused by running at light load than perhaps by any other single factor. Brush surface can increase through accurate "seating-in"; the friction force increases and high friction can

result. Current tends to disturb this seating, and loaded machines do not usually have this problem. The change in friction with temperature is also a factor. Many installations are over-powered, and both motors and generators can then run under light loads for long periods. In some plants it is not economical to shut down the generators during slack periods and they can run overnight or over weekends with light loads. The solution to this problem is to take off some of the brushes and to use carbon brush materials that are low in friction but have good life.

Brush problems also can appear in these machines if maintenance procedures are poor, or if certain industrial atmospheres are present. Excessive oil, due either to leaks in oil seals or to oil mist in the atmosphere, is one of the worst offenders. Unusual amounts of dust in the air can cause difficulties such as film stripping and copper dragging. Low moisture can cause increased wear in the winter. Proper oiling and cleaning, the addition of moisture to the air in winter, and ventilation suitable for human habitation, are usually all that are required for continued satisfactory operation.

3. Machines Operating in Contaminated Atmospheres

The effects of different chemical atmospheres on brush operation have been discussed. As the usual effects observed in this area involve over-filming of the commutators with subsequent film stripping and high wear when the film becomes unstable, the problem is to provide brush materials that prevent the build-up of excessive films. This can be accomplished by several different types of material.

For the large, high-speed machines, an electrographitic material containing an abrasive is used. Because good commutating ability is required over the wide ranges of speed and load that occur in reversing-mill motors and in the larger paper mill machines, an electrographite brush grade is most suitable for these applications.

For lower-speed machines, such as the motors of run-out tables in rolling mills, a carbon-graphite grade is found to be suitable. For the extremes of atmospheric conditions found in steel mills and paper mills, more cleaning action or abrasive effect is required and, a resin-bonded material is used for this reason.

Marine applications present a special group of problems because of the salt water mist that is always present unless elaborate precautions are taken to eliminate it. All types of machines are involved, from large power equipment on the piers and in submarines to small lift and control motors. Brushes may stand for days on the same spot on a commutator or collector. Electrolytic effects will cause picturing or marking on

the collector in which a replica of the brush face is etched into the collector surface. Brushes with considerable amounts of abrasive will be able to remove the contamination and operate properly.

Brush holders must be made of naval bronze or stainless steel to prevent any corrosion between brush holder and brush which can cause the brushes to stick in the holders. Shunts must sometimes be covered with plastic sleeves to prevent their being corroded.

When we say *abrasive materials* in the brushes for these special industrial and chemical atmospheres, we do not mean materials that wear rapidly themselves or cause excessive collector wear. In general, the wear on collector and brush is higher with the abrasives; but under the same circumstances these rates of wear are much lower with the abrasive than without it. Even in very severe service, the wear rates can approach those obtained in normal atmospheres, particularly on machines in contaminated atmospheres. Proper maintenance is important, lubrication procedures, cleaning, and ventilation are even more important than in normal atmospheres.

4. Turbine-Generator Ring Applications

On large turbine-generators, the excitation current of the rotor must be carried through rings on the shaft. Currents up to 3500 amperes are common. Because of the high stresses and high speeds, high carbon tool steel alloys are used for the rings. The problem then becomes one of having many brushes in parallel on steel rings. Because the changing of brushes requires shutting down a machine, brush life is most important. As the machines are enclosed, the brush dust generated by even normal wear is undesirable. The brushes represent only a very small fraction of the cost of such machines, but they become a very important factor in maintenance.

It has been necessary to develop brush materials that run with very little selective action, with stable contact drop and low friction to keep the temperatures down, and with long life when operating on steel rings at speeds up to 14,000 feet per minute. Brush wear on steel is usually higher than on copper, but suitable materials have been made that will operate for periods of six months to one and one-half years without change of brushes.

5. A-C Motor Rings

Where armature excitation is required for a-c motors, the problem is similar to that of the large turbine-generators, except that copper-alloy rings can be used. The currents and speeds are lower. Wherever possible, metal-graphite brushes are used to keep the electrical losses to the minimum. In some industrial atmospheres, where cleaning action is required, an electrographitic grade may be necessary.

A-c motors usually require less maintenance than d-c machines and, as a result, the rings are often neglected. Again, excessive oil should be avoided, and proper ventilation is always desirable. Long shutdown periods during which the rings are stationary in moist atmospheres can lead to etching or marking of the rings, which may or may not clear up on subsequent operation.

6. *Machines Designed for Special Purposes*

a. Elevator Generators:

These machines represent a separate category because of their special operating circumstances. They must be able to handle the full loads imposed upon them during the rush hours, but may then run idle or with only intermittent loading for a large part of the day. At night, they must continue to run at practically no load, unless protected by controls. In hotels and apartment buildings, the generators may be placed near living quarters, so that silent operation is required.

Quite special materials have been developed for this application. Grades have been developed that can live with the no-load running for long periods without increasing in friction, and one that can handle the "rush hour loads" without difficulty.

b. Low-Voltage Generators:

There is a range of low-voltage d-c generators (12-50 volts) that calls for special brush materials because of efficiency requirements as well as commutation. An electrographitic material, with particularly low and stable contact drop, has been most successful in this type of application. Machines of this type include welders, battery-powered trucks, and hoists. As the problems here are related to the specific applications, they often involve dust, vibration, contaminating atmospheres, and, in general, all the circumstances that can contribute to brush problems. Wide variations in loading and stall conditions can cause commutator distress. A grade with a certain amount of cleaning action that can overcome most of these difficulties should be used. Selective action between brushes on a given brush arm, as well as between two or more machines operated in parallel, is kept under control by the brush material.

c. Plating Generators:

Depending upon the circuits and the systems, plating generators may operate from about 6 volts up to 30 volts. Although rectifiers are being utilized in many of the new installations, many plating generators are still in service and will continue to be until they either wear out or become obsolete.

Machines of this kind are designed to provide the maximum current and efficiency at the voltage required. Voltage is usually adjusted by field control. As voltages are low, commutation as such is usually good, but circulating currents in the armature between brush arms can sometimes cause over-loading because the resistance of the circuits is so low. Such effects can cause commutator bar marking and brush face marking; these can be avoided with the use of brushes of higher resistance and better commutating characteristics.

The surrounding atmosphere is usually corrosive and if the machines are not properly ventilated, they are exposed to fumes from the plating baths. Selective action is often a problem, and one path or track on the commutator will break down while the others still retain high resistance. A metal graphite brush grade has been found suitable for many plating generator installations. Some modifications of this grade (to lower or higher resistance) are sometimes required for special circumstances. Similar brush materials are used to carry current to the rolls in pickling operations. Here, and in some plating operations, it has been found desirable to cover the brush shunts with a plastic coating to prevent corrosion and disintegration.

d. Regulating and Control Devices

Machines such as Amplidynes and Rototrols are essentially amplifiers in which a small current applied to the machine controls and regulates a larger current which can be used for power purposes. Since brushes are involved in the control circuits, the magnitude of the brush drop can affect the position as well as the rate at which control takes place. In these applications, it is necessary that the brush materials have a uniform and consistent contact drop that is as nearly independent of the actual value of current as possible.

Brushes on some machines operate in positions on the commutator that would correspond to the center of the main field, where the voltage between bars is high. Brushes made from resin bonded graphite are widely used in this application. When such machines are subject to atmospheric changes, reacting gases or oil vapors, the voltage drop can be altered and the accuracy of the control will change. Maintenance must therefore be consistent and ventilation adequate to prevent both over-filming and under-filming.

14.5 Etching of Commutator Bars

A phenomenon sometimes seen on slip ring and commutator machines is the appearance on the commutator or ring surface of a dark or etched area. It looks like a silhouette of the brush face complete even to the chamfers on the corners of the brush.

This condition usually develops when the machine is not running. Carbon in the presence of some mild acid, plus moisture and the unavoidable contaminants in the air can set up a battery action on copper bars and bronze or steel rings. Electrolysis takes place and etches the surface of the ring or commutator. When the machine is again put into service the etched areas present a poor brush riding condition. This results in sparking which aggravates the condition.

To prevent electrolytic action paper should be inserted between the brush and commutator or rings when the machine is shut down. An alternate preventive measure is to place a space heater or incandescent lamp near the brushes which will prevent condensation and the formation of acids.

A similar appearing condition can be caused when the machine is running. The cause is the actual burning of the bar or ring under the brush due to high current starting surge or to load current surges during operation.

14.6 Commutator Bar Marking

There are a number of markings that develop on the commutators of d-c machines.

1. *Coils per slot*

One type of marking coincides with the number of coils per slot. The marking consists of a dark commutator bar followed by a specific number of lighter bars in a pattern that is repeated around the commutator. There may be one to six armature coils per slot so the dark bar plus the light bars would total two to six depending on the winding.

The commutating pole tip and air gap flux is designed and adjusted to give the best average commutation based on the number of electrical coils in an armature slot. One coil will not have as much commutation margin as the other coils in the same armature slot due to its position in the slot. The bar connected to this coil will be the first to mark when something upsets the commutation. The cause may be incorrect brush grade, brush riding, rough commutator surface, wrong brush position, or incorrect brush spacing.

2. *Armature Equalizer Connections*

Another type of marking coincides with the armature coils that are connected to the armature equalizer connections. These bars will sometimes mark if the commutation is upset by vibration, magnetic dis-symmetry, circulating currents in the brushes, improper brush position, or other factors.

3. *Vibration*

Vibration can cause bar marking similar to that described above, however there may be no regular pattern. It is possible to encounter certain modes of vibration causing repetitive movement between the commutator and brushes. In some instances the marking will be in the form of the brush face even including the chamfered corners.

4. *Open Armature Coil*

An open armature coil or commutator riser will cause severe burning and eventual destruction of one bar and possible markings at pole pitch spacing. All the maintenance practices which contribute to the symmetry of commutator conditions and brush riding ability are needed to prevent pattern formation.

5. *Brush Grades*

Brushes should be selected that give wide black band performance. Some conditions which seem to hasten the progress of pattern formation are attributable to incorrect brush grades as well as to vibration, dirt on the commutator surface, high mica, contaminated atmosphere, oil or oil vapor.

Commutator bar marking is a symptom of some other more serious problem. The cause should be found and corrected as soon as possible to prevent serious damage.

14.7 Commutator Films

The most desirable commutator film should be evenly colored between light brown and dark brown, not highly glazed or extremely dull.

Undesirable films caused by adverse atmospheric conditions are usually dark brown, black, or gray. When the cause of an undesirable film is the atmosphere, the discoloration appears also on the copper not in the brush paths.

The level of contamination of the atmosphere need not be high to produce injurious films on commutators. Conditions which cannot be detected without sensitive instruments can cause undesirable film to form. For instance, 3 parts of sulphur in a million parts of air is sufficient to cause heavy formation of undesirable film.

If adverse atmospheric conditions cannot be controlled it is necessary to use a brush grade with enough cleaning action to prevent formation of heavy film. Some kinds of brushes with film forming properties may develop a satisfactory film of copper oxide before an obnoxious film can be established.

Commutator condition is so important that a set of standards has been developed for rating commutators and evaluating brush performance.

14.8 Visual Commutator Classifications

Class

- A-0 *Newly ground commutator* or a good commutator without any characteristic identification.
- A-1 *Pattern, light to medium*: variation in color of alternate commutator bars, usually in regular sequence and in well defined groups of 3, 4, or 5, depending on the arrangement of the coil sides with respect to the slots on the machine under observation. To be permissible under Class A, the bars must be well polished. Light to medium refers to the contrast between the lightest and darkest bars; light, hardly perceptible; medium, well defined.
- A-2 *Light smut*, confined to bar edges: a dull feathery smear confined to the bar edge (not over $\frac{1}{4}$ width of the bar) on no more than a third of the bars visible between any two brush holders, or not more than two bars, visible between two brush holders, with $\frac{1}{2}$ the bar width smutted. If the smear is erased, it should show no pitting etching of the exposed copper.
- A-3 *Light to medium streaking*: parallel stripes of varying shades of color encircling the commutator or one or more brush tracks. Light to medium refers to the degree of contrast between streaks; light—hardly perceptible; medium, well defined. Streaks must be polished to be permissible under Class A.
- A-4 *Medium to high polish*: the normal condition when brushes are operating satisfactorily. The degree of polish is determined by the sharpness of the reflection of the brush holders on the commutator. With medium polish, the reflection of the brush holders can be readily distinguished, but the outlines are not sharp. With medium-high polish, the outlines of the reflections are sharper, but details are somewhat fuzzy. With high polish, the reflections are a sharp, mirror image of the brush holders. The direct reflection of a strong, sharply focused flashlight is almost blinding from a highly polished commutator.
- A-5 *Light tracking*: a brush track having a lighter or darker shade of film from that of the adjacent tracks. The tracking is classified as light if the contrast in shading is barely perceptible.

A-6 *Very light bar edge burning*: a faint indication of roughness at the top of the slot that could either be the start of bar edge burning, or tool marks from undercutting or bar edge deburring. This defect is permitted in Class A because it may or may not be bar edge burning, but is listed as such to caution observers on future inspections to be on the lookout for possible bar edge burnings.

A-7 *Very light copper drag, no recent flashover marks*: this defect is more prevalent on main generators than on traction motors. It is defined as occasional minute projections of copper beyond the bar edge. If they can be seen only by very close examination and there is no evidence of recent flashover marks, the defect is permissible under Class A.

B-1 *Heavy pattern*: This is the same as light to medium pattern except in degree of contrast between the light and dark bars. In heavy pattern, which is usually regular, the darkest bars are definitely dark in shade, sometimes black, and the lightest bars are definitely light in shade.

B-2 *Medium smut*: same as light smut, but more extensive. If most of the bars visible between any two brush holders have bar edge smut, or if more than one bar within the same area is covered over 50 to 100% bar width, the smutting is classified as medium smut.

B-3 *Heavy streaking*: same as light to medium streaking except in degree of contrast between the streaks. In heavy streaking, the darker streaks are in very sharp contrast with the lighter streaks, and the streaking is usually coarser than light to medium streaking.

B-4 *Heavy tracking*: same as light tracking except for a sharp contrast in shading or color between the tracks.

B-5 *Light bar edge burning*: unmistakable burning confined to the bar edge. When burned, the bar edge will be rough and beaded with definite evidence of fused copper. A burned bar edge may be hidden by smut, so if it is suspected, the smut should be removed with an eraser, which will reveal the burn if it exists. Whenever there is medium to heavy smutting, there should be a check made for bar edge burning.

B-6 *Light copper drag with no evidence of recent flashover*: in light copper drag, as distinguished from very light copper drag, the copper projections are readily visible without close scrutiny of the commutator.

B-7 *Light ridging:* A thin raised line between brush paths which can just be felt, but can barely be seen.

C-1 *Heavy, dull, regular pattern:* a heavy pattern on which one or more bars in each group has a dull, smutted surface.

C-2 *Heavy smut:* smutting extending over the entire bar width in groups of two or more bars.

C-3 *Dull polish:* entire, visible area of commutator lacks any reflective properties. In some cases the condition is caused by contamination in which case it is usually temporary. If caused by poor brush performance, the condition is permanent and will eventually develop into bar burning.

C-4 *Heavy bar edge or light bar face burning:* these two terms are really synonymous. When light bar edge burning progresses to the point that it puts a definite bevel on the bar edge, it is designated as heavy bar edge or light bar face burning.

D-1 *Bar face burning:* when bar edge burning develops to the point that it extends any perceptible distance into the bar face, beyond a level on the bar edge, it is bar face burning. When this happens, it will soon progress to a full bar width and from there extend to adjacent bars. Once the stage of true bar face burning is reached, the commutator should be resurfaced, either by grinding or remachining, depending upon the severity of the burn.

D-2 *Copper drag accompanied by evidence of heavy or repeated flashovers:* flashovers may be caused by many factors other than copper drag; but copper drag, if extensive enough, can be a cause. If copper projections are easily visible on the bar edges, and there is evidence of heavy or repeated flashover, in all probability the flashovers are caused by copper dragging. The commutator should be classed as "D" and scheduled for prompt reconditioning.

14.9 Copper Picking

Sometimes copper particles are transferred from commutator surfaces or slip rings to the surface of the brushes where they become imbedded. This is called picking and once started it is usually progressive to the point of impairing commutation and current collection.

When copper transfers to the brush face the contact drop is decreased, eventually to the point that commutation is impossible. The abrasive effect of the copper particles in the brush surface against the ring or the

commutator causes threading or grooving by breaking down the commutator film, as described in 14.4, F.5 *Streaking or Threading of the Commutator* above.

To prevent picking it is necessary to maintain proper bar edge beveling. The machine should be blown out clean after working on the commutator and brush seating stones should be used sparingly. Once picking has started it is necessary to sand the brush faces to remove the imbedded copper particles.

Electric Brakes

Torque Rating 2:15.1

Braking Capacity 2:15.1

Time Rating 2:15.2

Direct-Current Magnetic Brakes 2:15.2

Alternating-Current Magnetic Shoe Brakes 2:15.5

Maintenance and Troubleshooting 2:15.5

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Electric Brakes

The construction and function of brakes places a high importance on frequent inspection and careful maintenance. Mechanical wear is a normal expectation since brakes are composed of a linkage of moving parts and friction members.

Caution: Do not neglect inspection of brakes or inspect carelessly. Electric brakes are used to hold a load and retard or stop rotation. Neglect or careless inspection and maintenance could result in danger to life and damage to property.

All bearings and pins should be kept lubricated and all nuts and locking devices should be periodically inspected to insure that the brake is in proper operating condition.

Representative types of brakes will be covered here. The manufacturers instructions should be consulted for specific installation, adjustment, and maintenance information.

15.1 Torque Rating

The torque rating of the brake is usually selected at least equal to the full-load torque of the motor. There are cases in which this value should be exceeded, where it is necessary to stop the machine very quickly or to provide adequate margin of safety. The full-load torque of the motor is calculated as follows:

$$\text{Torque in lb ft} = \frac{\text{Motor rated hp} \times 5250}{\text{Speed at full load in rpm}}$$

15.2 Braking Capacity

For loads of high inertia or where electric motor braking is not provided, the braking capacity should be checked. The necessary braking capacity is calculated as follows:

$$\text{Hp sec. per min.} = \frac{\text{Total } WR^2 \times (\text{max. motor rpm})^2 \times \text{No. operations per min.}}{3,220,000}$$

This is based on heat dissipating capacity due to the volume of material in the brake wheel, the surface area, etc. If exceeded, abnormal lining wear and over-heating of the brake wheel may result. Since physical dimensions of the brake wheel for direct-current operated brakes are set by the AISE, the heat capacity of a particular brake frame will be essentially the same, regardless of manufacturer.

15.3 Time Rating

Time rating of brakes is controlled by the amount of heating produced in the brake coil. The brake time rating is usually made at least equal to the motor time rating, since the brake is energized as long as the motor is energized.

Continuous rated brakes are applied where conditions of intermittent duty rating, as explained below, cannot be met. Also continuous rated brakes should be applied when any doubt exists that the intermittent duty rating will be exceeded.

Intermittent duty shunt-wound d-c brakes should not be energized for more than one-half of an on-off cycle with continuous application of normal voltage not exceeding one hour. The same intermittent duty time applies for a-c brake coils and thruster brakes. Since d-c series brake coils are only applied with series-wound motors, which are usually applied either on a one-half hour or one hour basis, the brake coil time rating is again made at least equal to the motor time rating. Disc brakes are usually applied on the basis of continuous duty.

15.4 Direct-Current Magnetic Brakes

D-c magnetic brakes are designed for heavy duty steel mill and crane service, but may be used on any application requiring rapid stopping, such as on hoists, conveyors, screwdowns, and ore bridges. Brakes are usually floor mounted with the wheel mounted on the shaft extension of the motor, but may be mounted directly on the motor frame by means of an optional brake adapter.

Static rectifier operated brakes are employed where operation of a direct-current brake is desired from an alternating-current supply. The rectifier unit is mounted externally from the brake. To prevent recirculating current and resulting slow setting time of the brake, the current must be interrupted at the brake coil.

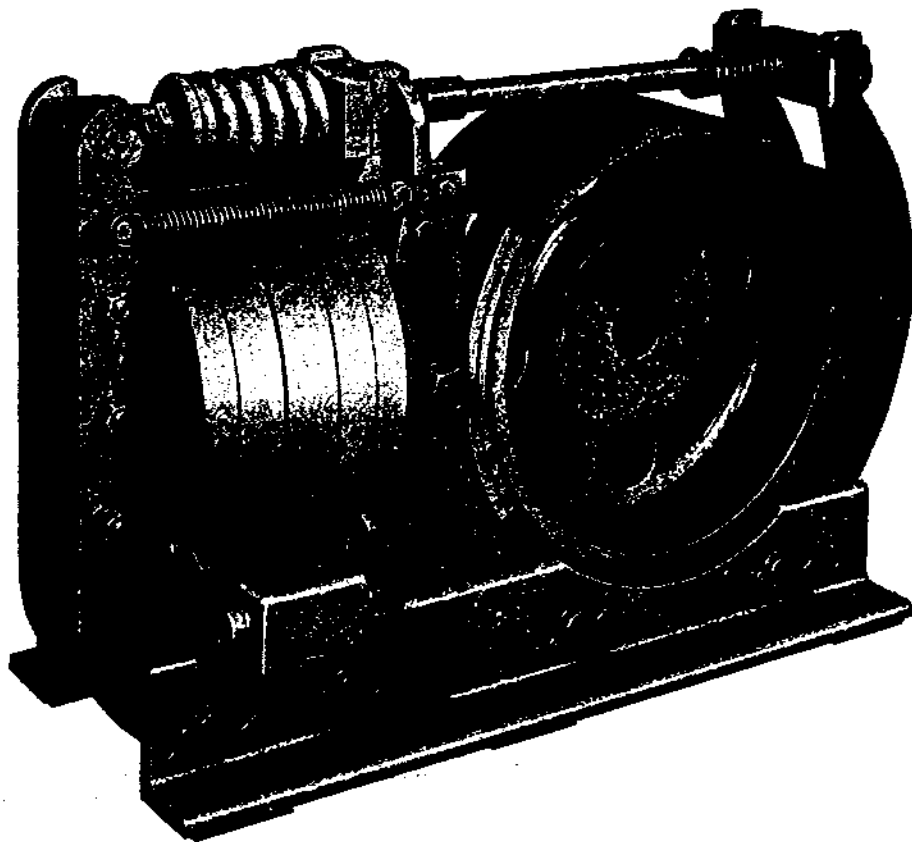


Fig. 1 - Typical Direct-Current Magnetic Brake

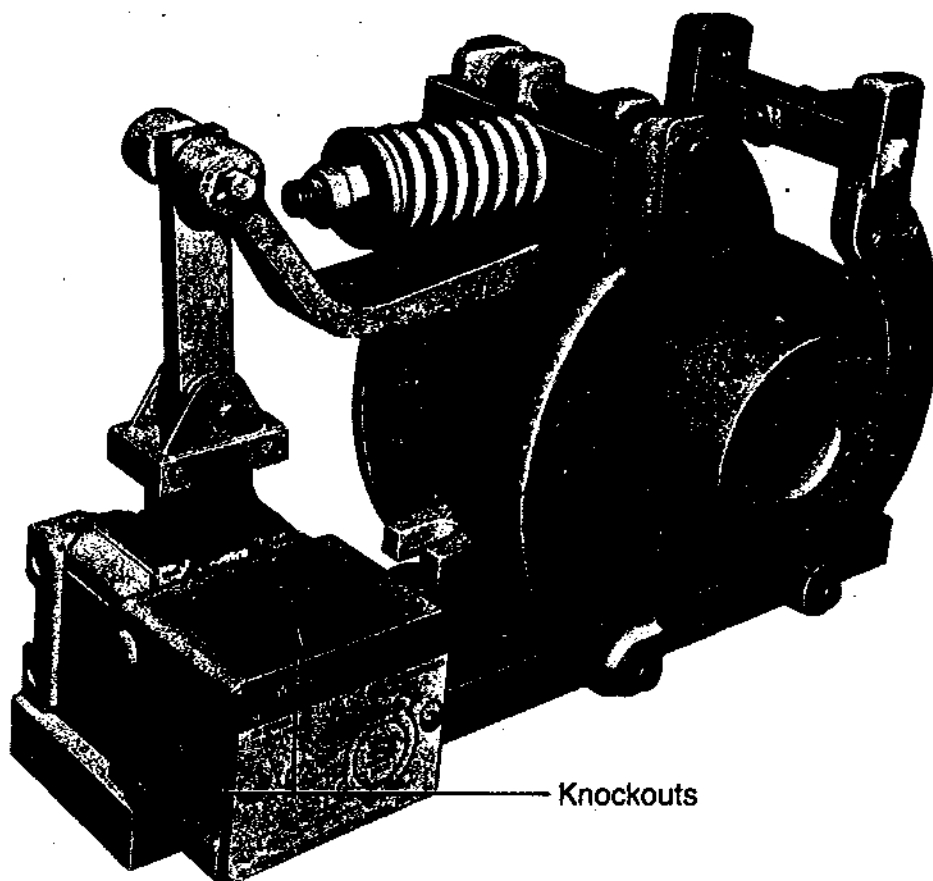


Fig. 2 - Typical Alternating Current Magnetic Brake

Table 1 - AISE Standard No. 11
Torque Ratings for Brakes used with Mill Motors

Brake Wheel Dia. Ins. Hr.	Maximum Torque in Lbs-Ft.			
	Series Brake ½ Hr.	1 Hr.	Shunt Brake ½ Hr.	8 Hr.
8	100	65	100	75
10	200	130	200	150
13	550	365	550	400
16	1000	650	1000	750
19	2000	1300	2000	1500
23	4000	2600	4000	3000
30	9000	6000	9000	6750

General

Direct-current magnetic brakes have a d-c clapper type magnet and are so designed that when the magnet is energized the shoes will clear the wheel. When de-energized the shoes are pressed against the wheel by the force of a compression spring. The force of the compression spring produces equal pressure of the shoes against the wheel and movement of the magnet results in equal movement of the shoes. Construction allows full accessibility of all parts for visual inspection and maintenance.

For optimum operation brakes should be adjusted to normal magnet travel as often as a reasonable maintenance schedule will allow. Minimum travel will result in fastest, quietest operation with the least shock and bearing wear. Readjustment for lining wear will automatically return the compression to its original setting.

Shunt Coil Operation

Shunt brakes are usually supplied with low voltage coils for speedy action unless otherwise specified, and it is necessary to have resistance in series with the coil.

Series Coil Operation

Series brakes are operated with coils connected directly in the motor circuit.

Failure to Operate

A brake may fail to release for any of the following reasons:

- a. Lead wire to operating coil disconnected.

- b. Voltage below normal.
- c. Brake not properly adjusted. Lining may be worn causing magnet air gap to open to the point where the magnet acts sluggishly or not at all.
- d. Coils may be defective. Check coil resistance.

15.5 Alternating-Current Magnetic Shoe Brakes

A-c, spring-set, shoe-type brakes are designed for demanding industrial braking service on such applications as cranes, hoists, conveyors, and machine tools. They are designed with power failure protection so in the event of power failure the brake automatically spring sets. In normal operation release is effected by a solenoid.

Adjustment

Brake life may be extended appreciably by holding solenoid to the minimum required for a free wheel. Where practical, it is best to readjust brakes frequently even if the marker has not reached the readjust indicator. Wear of solenoid and linkage is accelerated by increased travel. This is true of any type of magnetic brake regardless of manufacturer.

Alternating-current shoe brakes are used with an a-c power supply and are furnished with shunt-wound single-phase coils.

Hydraulic Operated Brakes

Hydraulic operated brakes operate on an a-c power supply and are applicable where high torque is required with cushioned setting and releasing and/or adjustable time delay in setting. Hydraulic operated brakes are operated with three-phase a-c power applied to the hydraulic motor.

Disc Brakes

Disc type brakes are available for both a-c and d-c power supply and are only supplied with shunt coils. These brakes are most often motor mounted.

15.6 Maintenance and Troubleshooting

Extremely loud chattering noise may indicate improper mating of magnet and armature faces or a broken shading coil.

A few drops of oil occasionally at bearing points will keep the bearings free to turn.

The releasing force on shoe and disc brakes is a coil supplying sufficient pull to overcome the preset spring tension. The amount of spring tension, hence brake torque, that the coil force can overcome is limited by the heating of the coil. The amount of force that a coil can produce is a direct function of the ampere turns in the coil. The intermittent torque rating of a brake is considerably higher than the continuous torque rating, because more current is passed through the coil for a shorter time. Since the coil heating increases with current, only name-plate rated voltage should be applied to the coil.

Direct-Current Shunt Brakes are designed for one-hour or eight-hour operation as established by A.I.S.E. Standardization Committee. These brakes are supplied with Class B insulation, and are designed to release at 80 percent of full-line voltage and set when voltage drops to approximately 20 percent of full-line voltage with coils at standard operating temperatures.

A low-voltage coil and a series resistor are used to provide fast operation on shunt-wound brakes.

Direct-Current Series Brakes will release on 40 percent of full-load motor current and remain released on 10 percent of full-load motor current with the coil at operating temperatures. This condition applies to torque ratings for 1 hour or ½ hour duty which corresponds with the motor ratings. When series-wound brakes are applied to continuous duty motors and so rated, these brakes will release at 80 percent of full-load motor currents and remain released on 20 percent or less of full-load motor current.

Brakes with series coils are applied with series motors wherever possible for d-c application because of the quick action and the safety factor obtained by always having sufficient current on the motor to hold the load when the brake is released. Quick action is inherent with series brakes as the current build up time, hence release time, is not greatly impeded by the coil inductance. Also the setting time is fast because of quick current decay.

Disc Brake Coils will operate at a minimum of 85 percent line voltage with an a-c coil and 80 percent line voltage with a d-c coil. All coils are wound for full voltage. All coil maintenance necessary on shoe type brakes applies equally to disc brakes.

A-c Brake Coils are designed to operate at a minimum of 85 percent line voltage. The shunt coils are supplied with full-line voltage as shown in Figure 3.

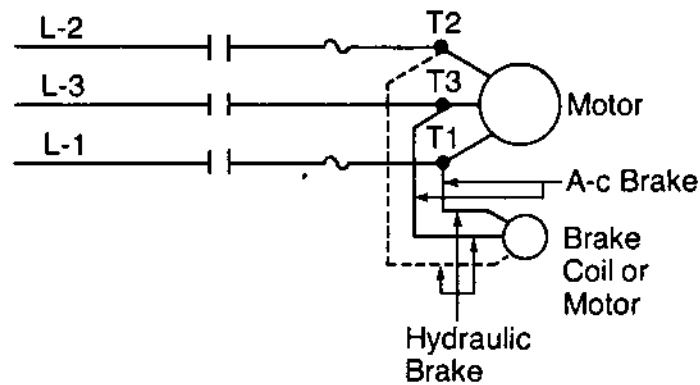


Fig. 3 – Schematic for an A-C Brake or an Hydraulic Brake

A-c magnetic brakes are extremely fast in releasing and setting as current build up and decay is almost instantaneous. For this reason, no time-decreasing features are necessary, also full-line voltage can be used.

The maximum initial current that flows the instant an a-c brake coil is energized is many times the amount of current flowing when the brake is fully released, because of lost impedance when an air gap is present with the plunger out of the coil. More initial current will flow as the air gap increases. Therefore, it is extremely important that the plunger travel be kept close to its nameplate travel or coil failure will result from overheating. Intermittent duty is equivalent to half time on and half time off with continuous application of voltage not exceeding one hour.

The clapper and plunger should be fully seated. If it is not properly seated, the air gap present will cause a large current to flow and coil failure will result from overheating.

The hydraulic brake thruster is a device for obtaining straight line motion with constant pressure thrust, in one direction, from an electric motor drive. The motor is usually the three-phase squirrel cage type, connected as shown in Figure 3, and will operate the brake satisfactorily at 85 percent voltage. No regard to rotation need be given as the hydraulic operator functions correctly with either rotation.

The oil is an important maintenance factor as the force is transmitted by it. Correct level must be maintained for the brake to release properly. Fill the tank until the oil starts to flow out of the oil level hole. When initially filling the tank, make sure that no air is trapped below the piston or in the pump by moving the piston up and down several times. If air was trapped, it will be necessary to add more oil.

Consideration must be given to the ambient operating temperature as oil thickens at low temperatures. Thick oil causes overheating of the motor and sluggish operation. The oil for the hydraulic cylinder is a special grade, little affected by extreme changes in temperature. Temperature range is -40°F to $+150^{\circ}\text{F}$ (-40°C to $+65.56^{\circ}\text{C}$). Push rod seals are an item subject to wear. These seals are provided to act as oil wipers on the push rods and to prevent dirt from entering the oil tank.

A time delay feature in setting is usually supplied on thrustors, and can be adjusted to provide a delay up to five seconds. Changing the setting time does not affect the releasing time. On hydraulic operators having the adjustment screw and nut on the outside of the tank cover, arrows indicate the direction of rotation for the desired time.

Spring Compression of a brake is directly proportional to the amount of torque that a brake can produce. The amount of spring compression for rated brake torque is given on the brake nameplate. The speed of travel of the plunger on a solenoid brake depends on the retarding action of the spring. For this reason, spring compression should never be reduced to the extent that the speed of the plunger becomes excessive and hits into the stationary magnet seat with such force that damage to the plunger or magnet develops.

For this reason it is specified that on all brakes the spring compression shall not be reduced more than approximately 50 percent of the nameplate rating. Special brake coils for the magnetic brakes or special spring ratios may be required when the torque is reduced to such values.

The necessity for reducing spring tension usually arises when an oversized brake has been applied for greater braking capacity. If the oversized brake was set for rated torque the load would then be retarded too quickly.

Caution: Do not increase spring tension to produce brake torque. This would result in rapid destruction to the brake lining and wheel. Also the brake will fail to release if the spring compression is increased appreciably beyond the nameplate value.

Faulty alignment on all solenoid brakes will cause the plunger to ride against the stationary sides. This would produce excessive friction resulting in failure of the brake to pull-in.

A-c brake plungers and stationary magnets are constructed of laminated steel to reduce heating. The laminations sometimes become burred, due to plunger operation, which results in excessive brake humming caused by normal magnetic reversals. Should this occur the plunger and stationary magnet faces should be filed, so that a good seat is obtained.

To reduce magnetic humming on a-c solenoid brakes, a single turn of metal (shading coil) is pressed into the plunger or stationary magnet face. Should the shading coil become loose or broken, excessive noise and heating will develop. It will then be necessary to repair the shading coil, or replace the plunger or magnet if the shading coil cannot be repaired.

Brake Shoes of most shoe brakes are the same construction. A single pivot bolt holds each shoe to its respective brake arm, which permits a certain amount of up or down misalignment. A sufficient amount of friction should be present in the pivot pins when the nut is tightened to maintain alignment after the brake is released in order to prevent dragging of the shoe tips.

Normal lining wear gradually throws the brake out of adjustment by causing the plunger travel to increase and the length of compressed spring to increase. If the brake is not readjusted the magnet will ultimately fail to release the brake shoes or brake slippage may develop.

To readjust brake for lining wear on all brakes, it is only necessary to restore the plunger travel to its specified value. By doing this, the spring compression is simultaneously returned to its original setting.

The brake shoe lining should be replaced when wear approaches the point that the lining rivets may come in contact with the brake shoe wheel. If the same type of lining is not installed that was previously used, it may be found necessary to readjust the spring where critical braking is required. This would be required due to the different braking quality of the new type lining.

When relining shoes, it is important to have the back of the new lining held evenly against the brake shoe, otherwise the lining will drag against the wheel when the brake is adjusted for normal shoe clearance. The rivets should be properly recessed in the lining and securely fastened to eliminate lining movement. After relining, the brake should be readjusted for proper plunger travel and shoe clearance. Spring setting should also be checked as a precautionary measure.

A certain amount of imperfect fit on the wheel usually results when a brake has been relined. For this reason wear will be more rapid until the lining "wears in."

Disc Brake friction lining is of the moulded type. The linings are the rotating portions of the brake, and pressure is applied to both faces by a smooth finished cast iron pressure plate.

Brake Wheels on a properly applied and adjusted brake will not exceed a temperature of 200C. If the temperature exceeds this value, due to retarding a load or rubbing due to improper adjustment, expansion of the wheel will take up shoe clearance and result in rapid destruction of the lining. Adjustment of the brake should be checked. If heating persists after the brake has been readjusted, the indications are that the duty cycle is too severe, and that a larger size brake is necessary. If a larger brake is necessary, consideration must be given to the necessary torque so that the proper magnet coil or thrustor and/or its linkage can be properly selected.

All brake wheels are machined completely for balance. If any portion of the brake wheel becomes broken off, vibrations may develop which would contribute to failure of the motor. Therefore, any wheel damage should be immediately repaired or the wheel replaced.

The brake wheel should never be rotated beyond its safe operating speed. If this is done rapid destruction to the lining will occur, or even more serious, the wheel may fly apart due to the increased centrifugal force.

Disc brakes have a stationary pressure plate that is pressed against the rotating lining by the spring. Overheating of the plate can develop and be corrected in the same manner as explained for brake wheels.

Brake wheels should be kept free of oil, water, or dirt. Oil causes slipping of the brake. Water will cause rusting of the brake wheel with the result of rapid lining wear. Also water would produce swelling of the brake lining resulting in decrease in shoe clearance and rapid retardation of a load. Dust, because of its abrasive nature, would cause rapid wear of the brake lining.

Bearings and pins should be kept lubricated. Judgment should be used as to quantity and how frequently. Excessive oiling accumulates dust, which because of its abrasive character causes excessive wear.

Due to normal wear, worn brake bearings will result in reduced shoe clearance for the same amount of plunger travel. When the wear

becomes excessive so that the stroke has to be appreciably increased in order to free the shoes from wheel, new pins and bushings should be installed.

Manual Release Levers are available with all types of shoe brakes and permit releasing the brake by hand.

Brake Enclosures should be used where conditions might allow water, oil, or dust to come in contact with the brake. Water or oil on the brake wheel might produce a certain amount of brake slippage that would be undesirable, also water would cause damage to the electrical equipment. Where dust of an abrasive nature is present rapid destruction of the brake wheel and linings would occur. Weatherproof enclosures are a ventilated enclosure to protect the brake from dripping or splashing liquids. This would include indoor service where oil or water might come in contact with an unprotected brake or outdoor service to protect the brake from rain, snow, or ice. Water and dust-tight gasketed construction provides protection from great quantities of water or dust that would penetrate the ventilation openings of a weatherproof enclosure. When using this type enclosure, consideration must be given to the dissipation of heat generated by the wheel because of its completely enclosed construction. It is therefore necessary to check the duty cycle with the manufacturer when ordering. All water-tight and dust-tight enclosures are provided with drain plugs to allow for draining the enclosure of condensed moisture. These should be periodically checked. Frequency of draining will depend on operating conditions.

Industrial Gearing

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Industrial Gearing

Most industrial gear units are relatively simple devices with only a few moving parts. The simplest type uses two shafts, a pinion, a gear and four bearings. These components are assembled into a precision machined housing which positions the shaft and pinion and fixes their axis of rotation; it also serves as an oil reservoir. This assembly need only be bolted to a rigid mounting and coupled to a motor and the driven apparatus to perform its intended function. Shaft alignment, however, is very important; misalignment can induce unnatural stresses and cause excessive wear, noisy operation, overheating, and ultimate failure.

Maintenance, unless otherwise specified for a particular type of gear unit, normally consists of routine periodic oil changes, the washing and cleaning of breather devices, and exterior wiping of the gear case to prevent a buildup of dirt or other contaminants, and checks for seal leaks. Heavy deposits can create a thermal insulating coating on the outside of the case and prevent ambient cooling.

Some gear units have auxiliary equipment for heat extraction when normal convection cooling is not adequate. Frequently used auxiliary cooling devices are direct coupled fans on shaft extensions or, oil pump heat exchanger units which circulate and cool the oil in the gear unit. Their use depends entirely on the amount of heat to be removed and environmental temperatures. Fans are not recommended for dust laden atmospheres. For these applications, water to oil heat exchangers must be used unless water is scarce, or totally unavailable.

Maintenance personnel should inspect for oil leaks, signs of overheating and loosening of hardware. Mounting bolts and coupling set screws should be checked whenever a shutdown opportunity presents itself. If gearing is applied where there is considerable vibration from coupling or associated equipment, a more frequent maintenance schedule should be established. This is recommended because of the need to maintain alignment and tightness of assembly hardware and gear unit couplings.

As a simple precaution, records on maintenance and performance should be maintained. A good history of performance and maintenance data is a valuable asset in appraising the condition of gear unit and determining the course of action if it is giving trouble. It is not always how a unit is

operating, but how long it has been operating without maintenance or change of oil that is important.

When communicating with the supplier or manufacturer regarding operating or maintenance problems with a gear unit, complete information must be given. This should include full nameplate information, length of service, type of application, nature of trouble, and any accessory or auxiliary devices installed on it. There could be such things as an integral oil pump and heat exchanger, a separate motor driven oil pump, or a tachometer generator coupled to the gear unit which could be important in diagnosing trouble and recommending corrective measures.

Always consult the manufacturer's installation, operating, and maintenance instructions before working on a gear unit.

16.1 Construction of Gear Units

A. Gearmotors

Gearmotors consist of the gear unit and the driving motor mounted together by the manufacturer.

The integral gearmotor shown in Figure 1 is made up of an electric motor flange mounted to the gear housing.

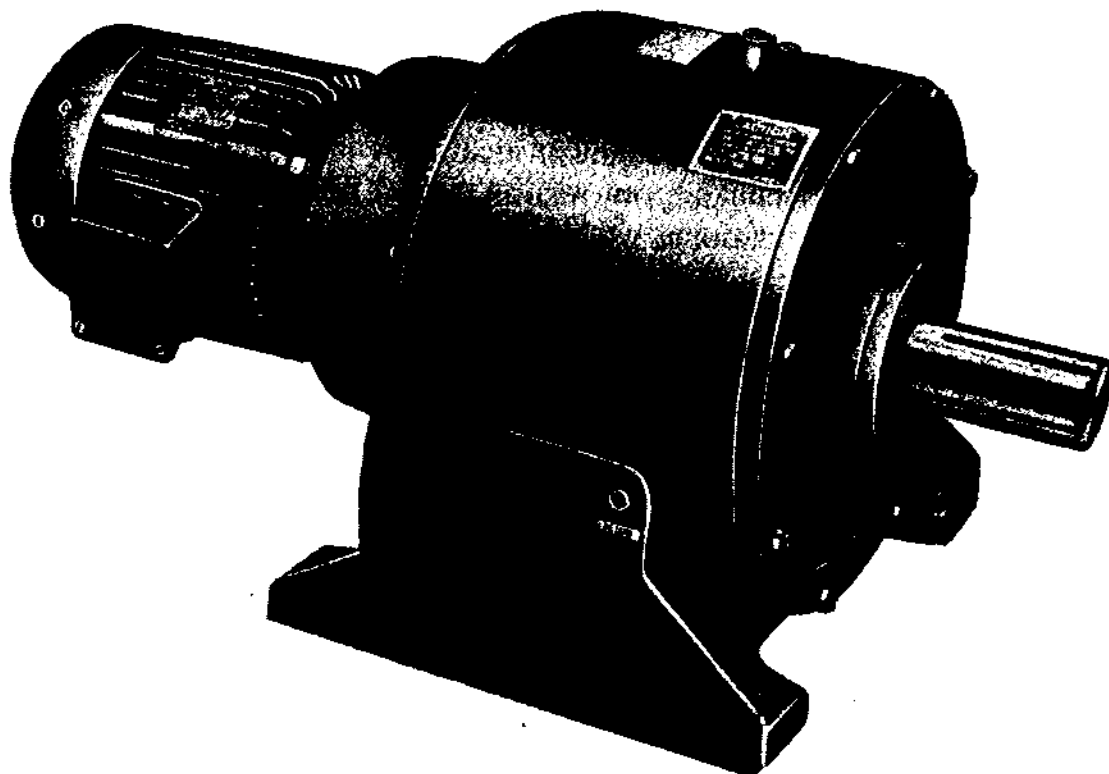


Fig. 1 – Integral Gearmotor with Motor is Flange-Mounted on the Gear Housing

Another type of gearmotor is shown in Figure 2. In this design, the motor is mounted on a base which is in turn mounted on the gear housing.

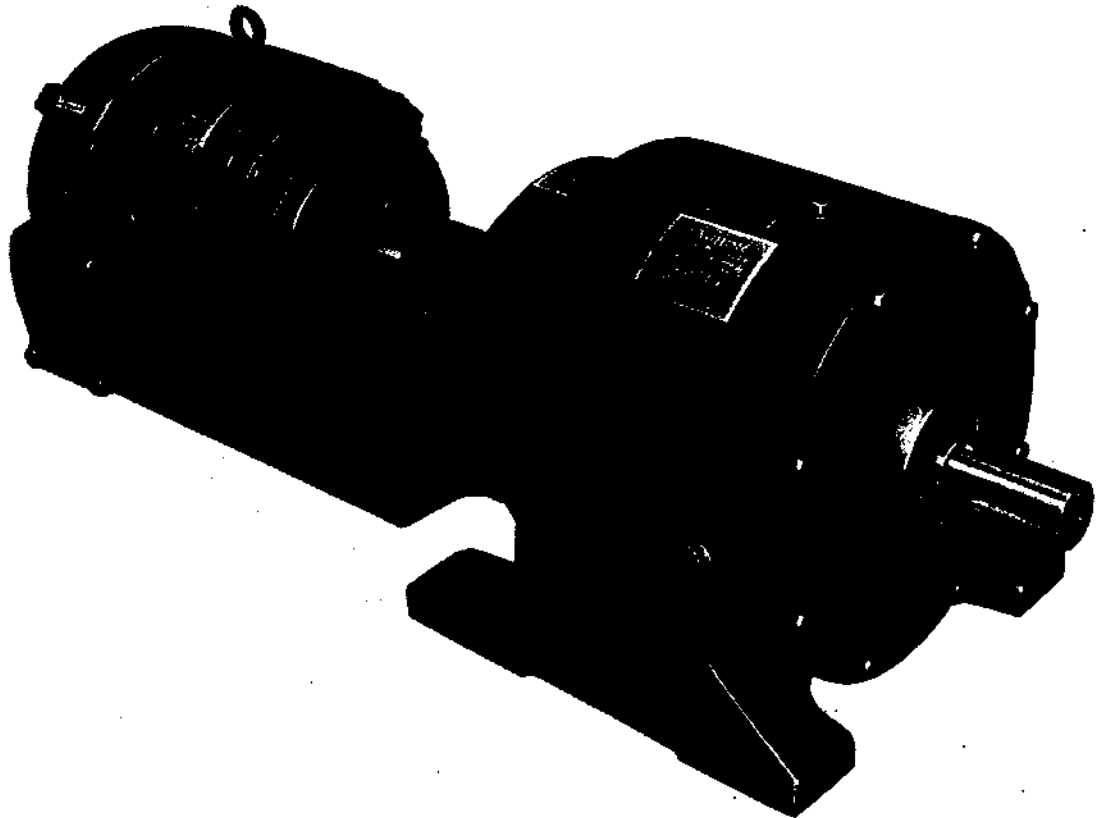


Fig. 2 – Gearmotor with Motor Mounted on a Base which is Mounted on the Gear Housing

The integral type gearmotor requires no motor alignment as the motor is matched to the gear unit and permanently aligned by the manufacturer.

The gearmotor designed for use with the integral mounted motor does require shaft alignment. Gearmotors are not normally supplied in ratings above 125 horsepower with speed reductions from 420 to 1.5 rpm.

Except for the mounting method, the construction of these machines is the same. Figure 3 shows the construction and components of a typical gearmotor. The internal components are identified as follows:

1. A combination oil filler-breather plug is located on top of the unit to facilitate oil changing, ventilate the unit, and maintain a low profile in height.
2. Single row tapered roller bearings.

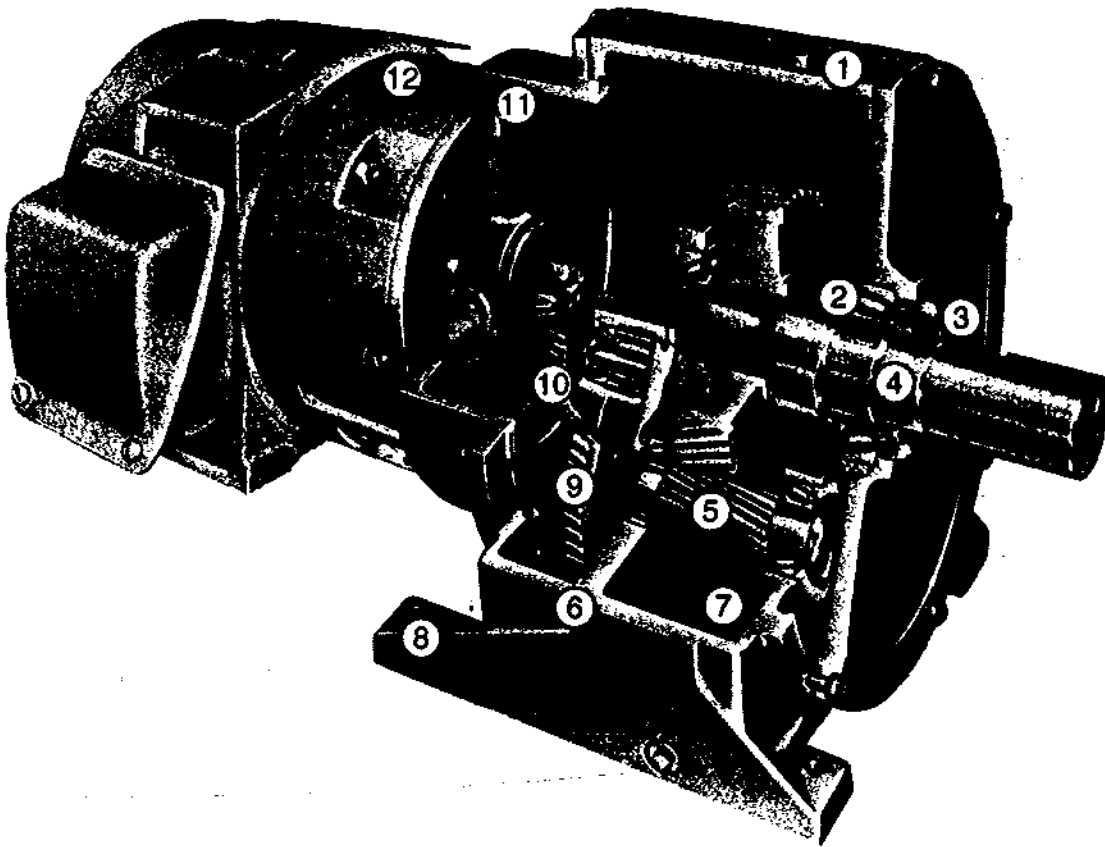


Fig. 3 – Gearmotor Cutaway View

3. Dual lip seals retain oil in the unit and protect against entry of contaminants.
4. The output shaft is usually of alloy steel. It is supported on a wide bearing span to assure ample overhung load capacity.
5. Helical gears permit more than one tooth face to carry the load and progressively transmit load from tooth to tooth.
6. The housing is a one piece casting with integrally cast and precision machined bearing supports to guarantee proper internal alignment of components.
7. The oil reservoir with its splash system provides positive lubrication of all gears and bearings.
8. The mounting feet are integrally cast and later machined to precise tolerances.
9. All gears and pinions are made from the same high quality alloy steel. They are precision machined, then heat treated as a final operation.

10. The high speed gear and pinion are mounted on splined shafts. Splines are cold rolled and precision ground to assure concentricity of the gear and pinion with the shaft.
11. The motor is normally a standard 1750 rpm unit built to industry standards and pretested before assembly to the gear unit. Motor change out does not require disassembly of the gear unit.
12. On integral type gearmotors, the motor flange, with its rabbet fit, provides accurate, built-in alignment for coupling of the motor and gear. Positive alignment throughout is necessary to obtain maximum gear life with minimum maintenance requirements.

B. Speed Reducers

The speed reducer is a self contained gear drive. The input shaft can be connected to the driver by means of pulleys, sheaves, sprocket and chain drive, or direct coupling.

Figure 4 illustrates a typical speed reducer.

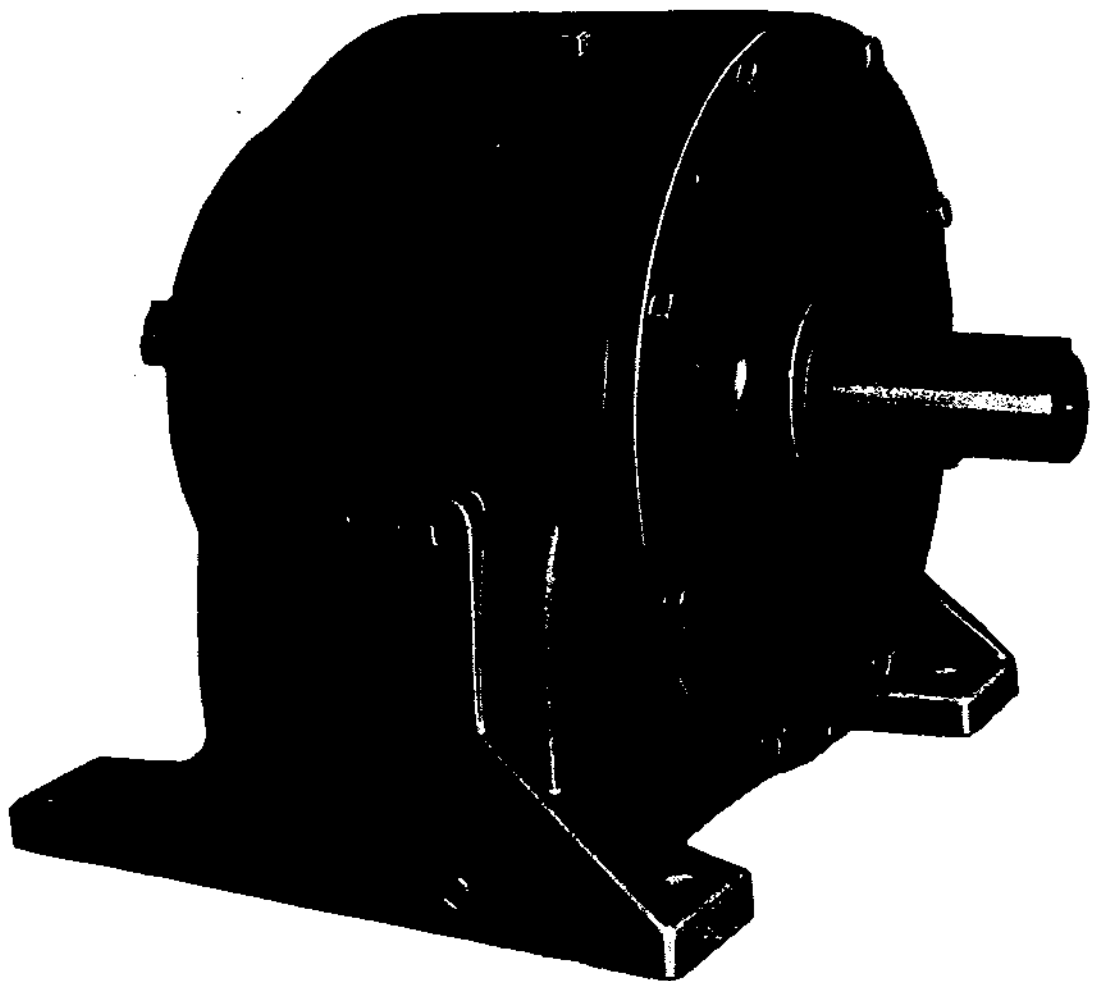


Fig. 4 – Typical Speed Reducer

There are some mounting restrictions for speed reducers. Mounting positions are shown in Figure 5 and restrictions on angularity are shown in Figure 6. Other mountings are available but special seals or lubrication devices may be required.

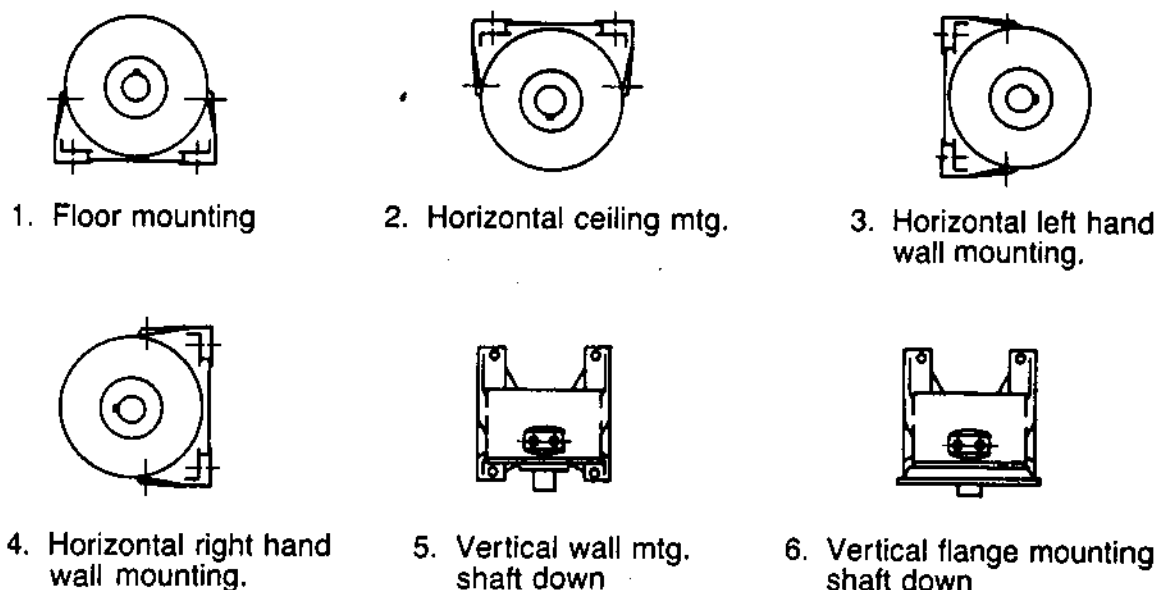


Fig. 5 – Speed Reducer Mounting Positions
(Views 1 through 4 are from the Output End)

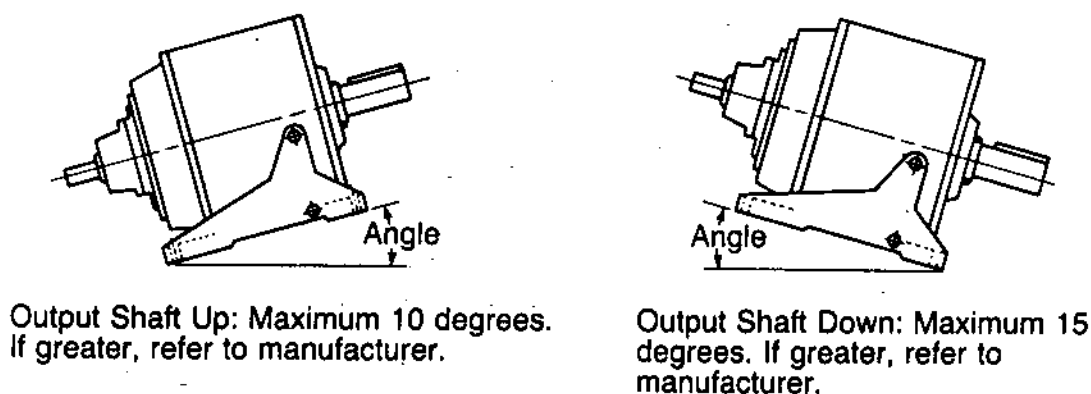


Fig. 6 – Restrictions on Angularity for Inclined and Declined Mounting

C. Parallel Shaft Speed Reducers

Heavy duty applications calling for higher horsepower ratings require parallel shaft speed reducers. These are the heavy duty units commonly used in mills, foundries, mines, quarries, and tipples. They are also used in elevator and moving stairway applications.

The drive power for parallel speed reducers may be turbines, internal combustion engines, or most commonly, electric drive motors.

Figure 7 illustrates a typical parallel shaft speed reducer and Figure 8 shows the same unit with the cover removed.

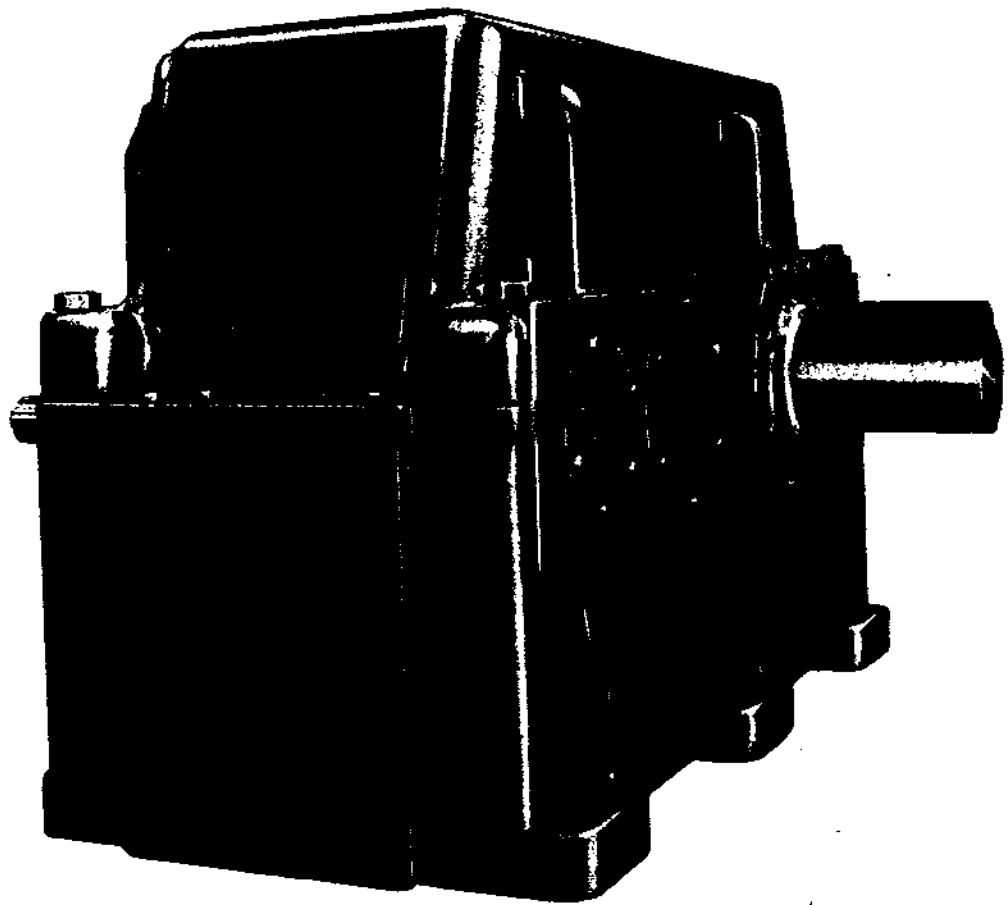


Fig. 7 - Typical Parallel Shaft Speed Reducer

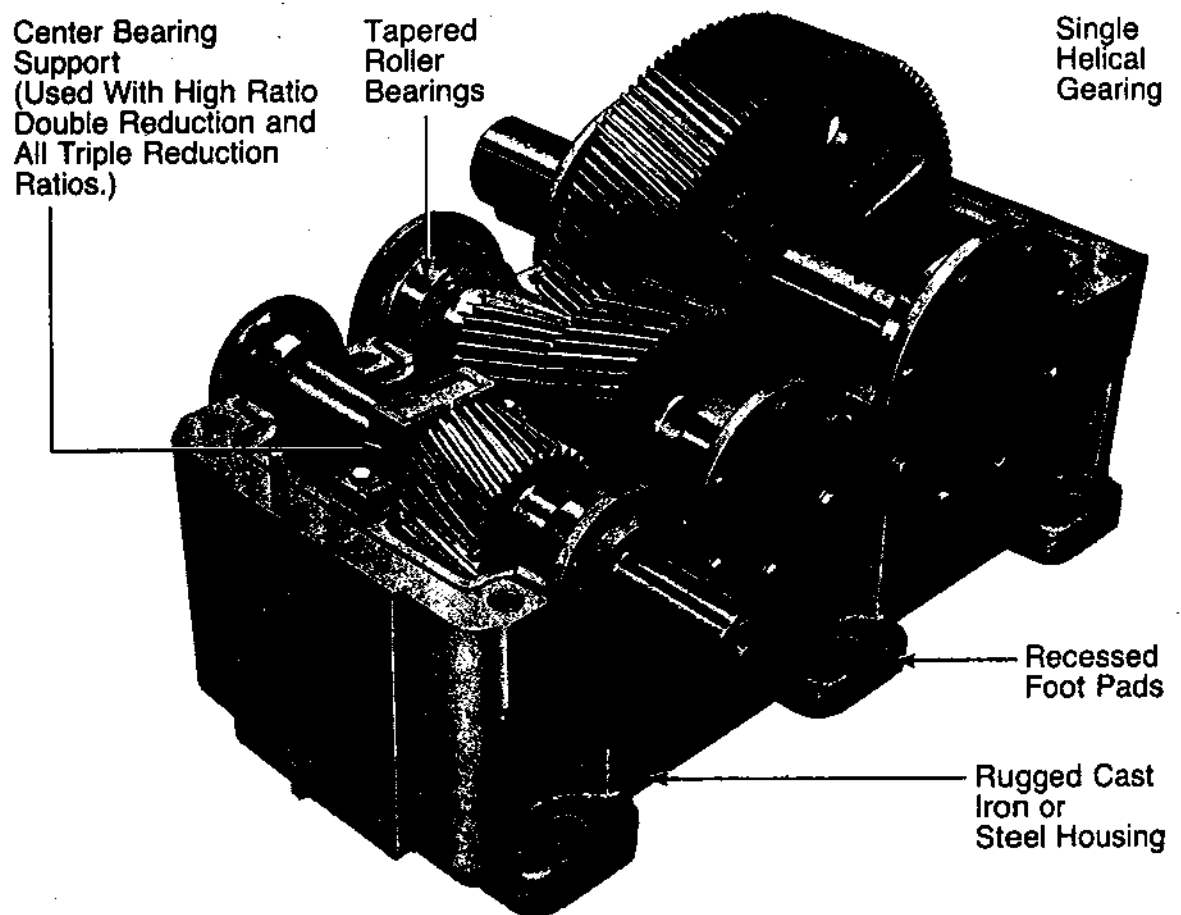


Fig. 8 - Parallel Shaft Speed Reducer with Cover Removed

Great care is taken by the manufacturer to assure that the speed reducer is in perfect alignment and without flaw when it is shipped.

Familiarity with the manufacturer's instructions is important. Critical information regarding start-up is included. The gear unit has no oil in it when shipped. Before operating the unit, it is the responsibility of the user to fill it to the proper level with high quality oil of the type recommended in the instructions. The wrong type of oil can provide inadequate lubrication and may cause foaming, which is undesirable.

Operating problems can be avoided by following the manufacturer's recommendations. Condition of the gear reducer should be checked after two or three weeks of operation. At this time, the condition of the gears should be determined. Misalignment of the unit on its bedplate or to coupled apparatus soon shows up. Occasionally, the factory alignment has changed due to either rough handling during installation or in transit. Changes in internal alignment show up as excessive tooth wear and, if not corrected, result in gear trouble. Foreign matter in the oil, chips or cuttings, will also mark the gear teeth or crack them.

Improper alignment on the bedplate or to mating couplings on either the input or output shafts, transmits stresses to bearings and, in turn, to the gear teeth. Unless these conditions are detected early, the gear unit can rapidly wear out. It can become excessively noisy and soon requires maintenance. Good alignment is important at all times and should be checked at regular intervals on rotating apparatus. Gear units subjected to shock loading or that operate under vibrating loads or mounting conditions can easily develop misalignment when the hold down bolts work loose. Unless otherwise specified by the manufacturer, a good practice is to change oil every six months or 2500 to 3000 hours. The original filling should be drained, filtered and replaced within one months time of operation.

16.2 Types of Gears

Single helical gears are used in main gear trains. Helical teeth are cut on an angle and are usually designed to mate on parallel axes; though they can be cut to mate on intersecting axes. A pair of unmounted single helical cut gears is illustrated in Figure 9. The inclined tooth construction of this gear achieves an effect of an infinite number of small thinly stacked spurgears slightly displaced and progressively transmitting load from tooth to tooth. This effect reduces the momentary accelerations and shocks that create noise in simple spur gears. Because there is always tooth contact at the pitch line of several teeth on a helical gear train, helical gearing transmits motion at an essentially constant angular velocity. Higher pitch line velocities and rpm are also possible with helical gears than with spur gears; 9000 rpm or higher are not uncommon.

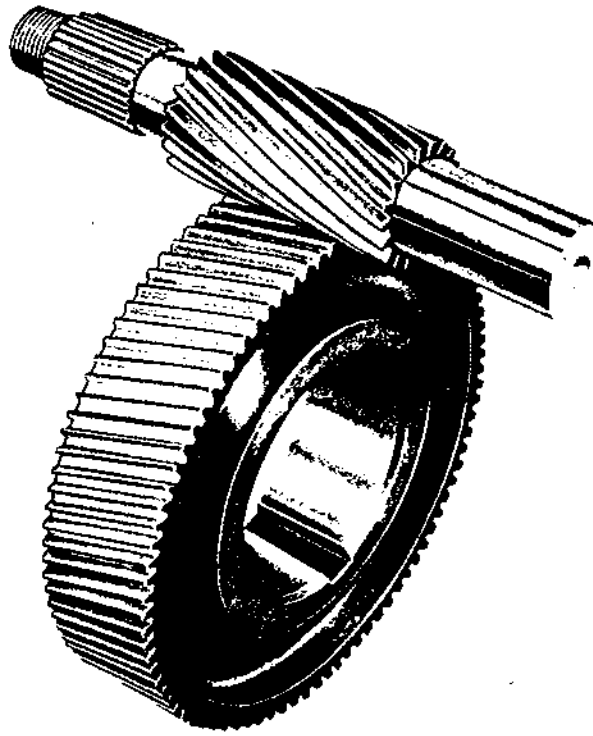


Fig. 9 – Single Helical Gears

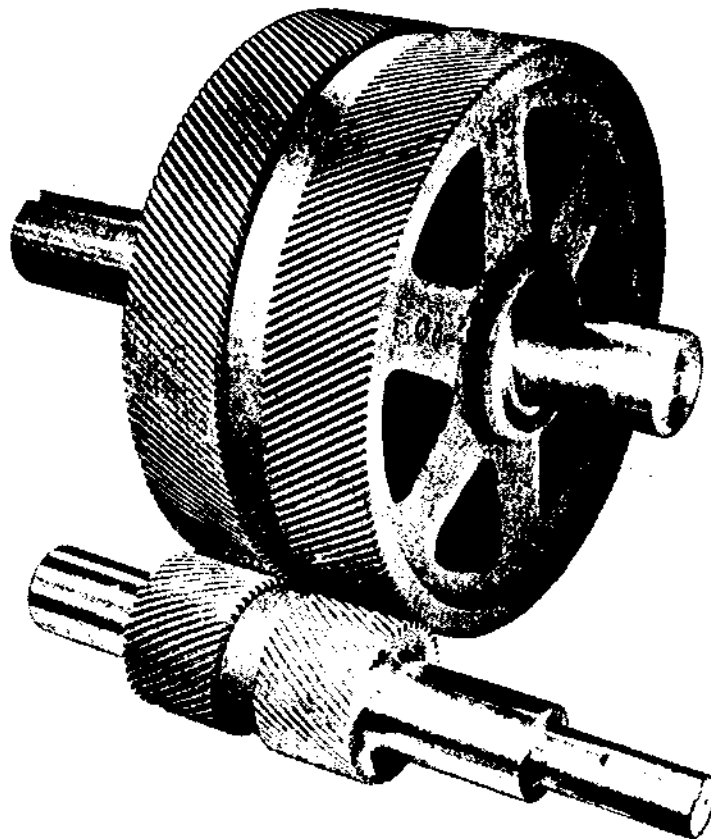


Fig. 10 – Double Helical Gears

Thrust loading from the corkscrew action of helical gearing results in the need for application of bearings which have suitable thrust load capacity. Maximum gear ratios and efficiencies of helical gearing are about the same as for spur gear sets. The overall efficiency of a gear unit depends upon speed range, temperature rise, and lubrication. In helical gear units the range is normally about 98 percent in a single stage gear unit, 96 percent in a double reduction unit and about 95 percent in a triple stage unit. Double helical gears (herringbones) are frequently used in high speed reducers and speed increasers. This type of gear is illustrated in Figure 10. The teeth in this design may be continuous or more commonly, separated by a grooved toothless space. The mating pinion is machined to mesh with the larger diameter gear. One great advantage of the herringbone design is the balancing of thrust by the opposing helices. This characteristic permits use of thrust bearings of reduced size, and the thickness of the thrust resisting housing can also be reduced. These gears are capable of handling large loads at variable input speeds. Because they are more difficult to manufacture, they are more expensive to replace.

Typical applications of double helical gears include ships propulsion using steam turbines, diesel engines, engine generators, or variable speed motor drive systems as prime movers.

16.3 Gear Ratios

Gear ratio is the input speed divided by the output speed. This ratio can also be calculated by dividing the number of teeth on the larger gear by the number of teeth on the smaller (pinion) gear in a simple gear set (two gears). The formula for determining a single gear ratio is;

$$R = \frac{NG}{NP}$$

when; NG = Number of teeth in the output gear
NP = Number of teeth on the input gear

In a succession of gear sets making up a multiple gear train, the final ratio is the product of the individual ratios.

$$\text{Total Ratio} = \frac{NG1}{NP1} \times \frac{NG2}{NP2} \times \frac{NG3}{NP3}$$

On a speed reduction unit, the output speed can be determined as follows:

$$\text{Output rpm} = \frac{\text{Input rpm}}{\text{Ratio}}$$

The AGMA permits ratio errors as high as plus or minus 5 percent depending on the number of reductions on gear trains. Only measured values of revolutions per minute can safely be considered exact. Nameplate values, as a rule, show nominal ratios. This is permitted by AGMA and is standard practice in the industry. Another variable to be considered is the drive motor speed. This speed varies from no-load, nominal, and full load duty cycles. All motors have slight speed variations and a permitted amount of slip under full load conditions. These variations plus the many design variations open to gear manufacturers have lead the AGMA to acceptance of the principle that speed ratios do not have to be stated on nameplates. An error of 3 percent on single reduction, and 4 percent on double and triple reduction gear units is acceptable and can be expected.

16.4 Maintenance

The care of gear units is an important operational function which should be given every reasonable attention to assure long and efficient life. A scheduled inspection and maintenance program is recommended.

Satisfactory operation and length of service of the electric motor used with the gearmotor depends largely on two general rules for inspection and maintenance.

1. When the gearmotor is installed, make certain that the motor rotor turns freely, particularly if the unit is not installed until some months after being received.
2. Never open the bearing housing under conditions which will permit entrance of dirt.

Gear units will show signs of distress when trouble is developing. The following troubleshooting check list should be a help in recognizing symptoms and taking preventive or corrective action:

Gear Unit Troubleshooting

Trouble	Probable Cause	Correction
noisy operation of the unit	1. misalignment	1. Check alignment of unit with driven member. Check condition of couplings, if used.
	2. faulty lubrication	2. Check oil level. Determine if lubricant is of grade recommended.
	3. excessive tension if power take off is by belt or chain drive	3. Check tension and alignment of drive auxiliaries; relieve if necessary. (See that driving pulley or sprocket is mounted as close to the unit as possible).
	4. worn parts caused by normal length of service, or possibly a result of (1), (2), or (3) above	4. Adjust or replace worn parts.
excessive operating temperature	5. overloading	5. Reduce load.
	1. incorrect lubricant	1. Check oil against specification instructions.
	2. incorrect amount of lubricant	2. If check shows low oil level, fill to level indicated by nameplate. Drain a portion if level is too high. See that breather is clean and functioning correctly.
	3. overloading	3. Check air supply for proper fan circulation. Avoid high surrounding ambient temperatures.
oil leakage	4. obstructed air flow	
	1. too much oil in unit	1. Recheck oil level with unit shutdown.
	2. clogged breather	2. Remove and clean breather.
	3. loose bolts or nuts	3. Tighten all joint and end cap bolts.
loosened mounting bolts	4. worn seal(s)	
	1. usually vibration from fluctuating loads or misalignment.	1. Check and re-align system. Tighten all bolts.

16.5 Lubrication

Use only the type of lubricant recommended by the manufacturer. Follow the manufacturer's lubrication instructions carefully. Sometimes there are grease fittings with grease purging outlets that require periodic greasing.

The gear unit is shipped from the factory without oil. The industrial gear oil should be selected depending on the expected temperature range and loadspeed cycles. Guidelines for selection are given in AGMA 250.03 Lubrication of Industrial Enclosed Gear Drives and available from the American Gear Manufacturer's Association, 1330 Massachusetts Ave., N.W., Washington, DC, 20005. The following selection table is extracted from that AGMA publication:

		AGMA Lubricant No.	
		Ambient Temp. F	
Type of Unit	Gear Unit Size	15 to 60	50 to 125
Horizontal			
Parallel Shaft	S7	2 - 3	3 - 4
Single	S9, S11, S12, S15, S18, S20	2 - 3	4 - 5
Reduction	S22, S25	3 - 4	4 - 5
Parallel Shaft	D7	2 - 3	3 - 4
Double	D9, D11, D12, D15, D18, D20	3 - 4	4 - 5
Reduction	D22, D25, D28, D30, D36	3 - 4	4 - 5
Parallel Shaft	T7	2 - 3	3 - 4
Triple	T9, T11, T12, T15, T18, T20	3 - 4	4 - 5
Reduction	T22, T25, T28, T30, T36	4 - 5	5 - 6
Concentric Shaft			
Single	Reducers 10S, 21S, 32S, 43S, 54S, 76S 10D, 21D, 32D, 43D, 54D, 64D, K76D, 88D, 92D, 21T to 92T	2 - 3	4 - 5
Double			
Triple			
Concentric Shaft Gearmotors			
Single, Double and	10, 21, 32, 43, 54, 64, 76, 88, 92		
Triple Reduction	Foot Mounted Motor and Integral Flange Motor	2 - 3	4 - 5
High-Speed Units	All Type SU (>3600 rpm)	1	2
Vertical Gear Units			
Parallel Shaft	V12, V13, V15, V16, V18	3 - 4	4 - 5
Concentric Shaft	V21, V32, V43, V54, V76	2 - 3	3 - 4
	V188, V193	3 - 4	4 - 5

NOTE: A common gearmotor choice is AGMA No. 4 in the 50F to 100F temperature range.

The AGMA lubricant (or viscosity) numbers listed above refer to rust and oxidation inhibited, or R&O gear oils. These meet AGMA performance standards, per ASTM test procedures, and keep gears operating at peak efficiency while inhibiting the formation of corrosive acids. When oil is changed or added the AGMA number which most nearly matches the operating conditions should be used. The proper oil number can be selected from the above chart. The AGMA lubricant number is complete identification and may be used for purchasing. For ready reference, the following table gives the viscosities and also some of the qualified brand names:

**Petroleum-Based R & O Industrial Gear Oils
For Use In Enclosed Gear Reducers**

AGMA Lube. No.	1	2	3	4	5	6
ASTM Visc. Grade	S215	S315	S465	S700	S1000	S1500
Viscosity in SSU @100f (38C)	193 to 235	284 to 347	417 to 510	625 to 765	918 to 1122	1335 to 1632
COMPANY/ Tradename	Oil Number					
CHEVRON/ O.C. Turbine	46	68	100	150	220	
EXXON/ Nuto Teresstic	46	68	100	150	220	320
GULF/ Harmony Houghton/ Hydro-Drive	47 HP 200	53 HP 300	61 HP 500	75 MIH 40	88 MIH 50	121
MOBIL/ DTE Oil	Med.	Med. Hvy.	Hvy.	Ext. Hvy.	BB	AA
SHELL/ Turbo	29	33	41	69	TELLUS 71	TELLUS 75
SUN OIL/ SUNVIS	921	931	951	975	999	9112
TEXACO/ Regal	B	PC	PE	F	G	

EP gear lubricants in the corresponding viscosity grade may be needed where the gear unit is under continuous sustained heavy duty loading. A lubrication specialist should be consulted before using EP lubricants.

Notice: EP lubricants must not be used in a backstop.

Cold Locations

For low ambients, -20 to $+15^{\circ}\text{F}$, the general recommendation is to use multi-viscosity automotive oils, SAE 10W-30 or 10W-40, and for 0 to -40°F degrees, automatic transmission fluid. Good quality low temperature industrial oils should be used when available.

Oil Filling Instructions

Warning: Disconnect all power sources when servicing a gear. Failure to do so can cause severe personal injury or death and damage to property.

Add or replace oil only when unit is at standstill. Remove breather and drain oil from the unit. If unit has a standpipe, add the oil through it until it levels at the top, otherwise add it through the breather opening until it reaches the oil level or dipstick mark. Replace breather and maintain in a clean condition. Check oil level periodically between changes.

Changing Oil

Good practice is to change oil every 6 months or 2500 to 3000 hours. No break-in oil change is required. The original filling should be drained, filtered and replaced in a month. To avoid incompatibilities, it is best to avoid mixing different brands of lubricants.

When draining a unit of oil, remove as much sludge from the bottom of the housing as can be conveniently pulled out of the drain hole.

Flushing oils are good, but they too must be completely removed from the unit so the new lubricating oil will not be adulterated.

When units have force-feed lube systems or recirculating oil systems, refer to the instruction manual for that particular unit. When refilling those systems, special attention should be given to priming the suction line to the pump. If this is not done, some means of determining that the pump is primed is necessary. Oil should be flowing immediately upon start-up.

16.6 Over Temperature

In investigating a gear unit that appears to be running hot, answering the following questions will reveal most problems:

A. Does it reach full operating temperature in a very short time; 15 minutes or less? This would indicate trouble. If possible, try to determine the hot spot. It could be a bearing, internal misalignment of the gears or excessive overload.

Caution: Do not operate the unit any longer than necessary. This could create even greater problems and damage the unit. If you do not locate the trouble in a reasonable period of time, the unit will have to be opened and inspected if alignment is not the problem.

B. Is the unit really hot or being affected by surrounding temperatures? If room temperature is 90F or higher and the air is stagnant, a gear unit might be operating perfectly at 190F.

C. If ambient temperatures can be ruled out, the next step is to systematically review operating conditions that may have changed.

Is there any drastic change in line voltage to the motor? Could it be single phasing, shorted out or misaligned to the gear unit? Is the output coupling under stress, binding, or misaligned?

D. If the unit is equipped with a force feed lube system, is the pump operating? Are all the lines clear and is there sufficient oil in the system? If there is no dip stick, sight gauge or flow indicator on the unit, it may be necessary to disconnect a line or observe oil flow to the gearing by removal of an inspection cover. If there is evidence of oil leakage it should be corrected, the old oil drained out and the unit refilled to recommended capacity with new oil of the proper grade and viscosity. These are routine checks to prevent unnecessary disassembly of a unit which is time consuming and requires relatively high skill.

Once a norm has been established for temperature rise it can be an excellent means of determining if a unit is performing properly recognizing that it will change with higher ambient conditions or added load. Although temperature changes have been known to lead to discovery of problems that are developing in other parts of the gear unit, temperature rise alone is insufficient indication that a gear unit is in trouble.

Procedurally, a newly installed gear unit should be watched to assure that its performance and temperature rise falls within manufacturer's tolerances. Sometimes, normal temperature rise is marked on the name-

plate, if not, consult the instruction book. Manufacturers usually stipulate that operating temperature should not exceed 200°F without consultation with the manufacturer.

Caution: Do not leave a newly installed unit unattended.

Since a sudden change in temperature can be a sign of trouble, leaving a newly installed unit unattended could result in a catastrophic failure.

E. When calculating temperature rise from a cold start, take these factors into consideration:

1. Difference between cold temperature of the unit and that of surrounding ambient air.
2. Motion of surrounding air. It is stagnant, inconsistent, a continuous flow?
3. Is hot air from a nearby source passing over the unit? Is the unit located in direct sunlight?
4. Is unit operating at high enough rpm to assure that oil will be thrown off the gear to the walls of the housing so the bearings will be lubricated? See *Splash System* under 16.7.

F. On older installed units which are showing signs of developing elevated temperatures take these factors under advisement:

1. If a unit has become caked with dirt, the dirt will act as an insulating material preventing convection heat loss.
2. Has it been operating for more than three hours continuously since start-up?
3. Is it under full or partial load and, if fully loaded, is the load within rating of the output horsepower?
4. What is the oil situation? Is it overfilled, operating at low oil level or without oil and, is the oil of the correct type?

G. Most gear units are hot to the touch yet may be only about 130°F under normal ambient conditions. Even this temperature is fairly warm when contacted with the hand but, more realistically, the operating temperatures will range from 160°F to 200°F which is top limit for most units. The allowable temperature rise should not exceed 100°F above

ambient. Above these temperatures, subtle changes take place in gear components, clearances can change in bearings, between mesh of gears and, the lubricating oil is approaching temperatures where breakdown can occur.

16.7 Lubrication Systems

There are four basic lubrication systems generally used in the design of gear units.

A. Splash System

The splash system is one in which oil is dispersed throughout the interior by gear pickup. The oil level, when properly filled, is sufficiently high that the gears transmit oil from one to another by rotation. Excess oil, thrown from the gears drains from the gear case walls into troughs which conduct oil to the bearings. Heat, in this instance, is removed by conduction through the case to outside air.

B. Controlled Splash

A controlled splash system is the same as above except, the lower segment of the gear(s) is shielded in the oil reservoir by a pan. This pan has an oil admission hole which allows only a limited amount of oil to enter and prevents excessive churning of the oil as the gear rotates. Less heat is generated because of reduced agitation of the oil; heat is removed in the same manner as above, by conduction through the case.

C. Circulating Lube System

In a circulating lube system, oil is pumped from the gear unit reservoir to an oil cooler then back into the reservoir. Dispersal of oil to the rotating parts is the same as for a controlled splash system. In this case however, heat is removed by means of an oil to water heat exchanger, similar to a radiator, but water rather than air is passed over the tubes or plates. A splash pan helps keep oil temperature low by minimizing the depth of oil in which the gears rotate.

D. Forced Feed Lubrication

Forced feed lubrication is not uncommon, particularly on heavy duty gearing or high speed units. Oil is pumped from the gear unit reservoir to a cooler then directed via piping to bearings and particularly the mesh areas of gear teeth. In some instances however, gears are allowed to lubricate themselves by dipping in the oil. Heat exchangers are usually provided with a force feed system. When oil is force fed and sprayed on the gears, splash pans are still used to prevent churning and unnecessary heat build up.

E. Care of Cooling Systems

Fans are generally employed to increase the thermal capacity of gear unit to meet requirements of a particular application. Fans are shrouded to protect personnel and guide the cooling air flow across the gear unit housing. Intake air apertures must be kept open, the fan blades cleaned periodically, and the mechanism checked to assure operating efficiency. Oil to water heat exchangers must be maintained in accordance with the manufacturer's instructions; they require periodic inspection and maintenance. Cleaning at regularly scheduled intervals is usually recommended to avoid sludging in the oil tubes and corroding of the water system. These conditions invariably occur if maintenance instructions are not followed. The procedure for cleaning can vary depending on manufacturer's recommendations. Normally, these procedures are recommended.

1. Use extreme care in handling the internal parts of the heat exchanger.
2. Different solvents are required to flush and clean the oil tubing and water heat exchanger sections. Avoid mixing these fluids or contaminating either part of the system while cleaning.
3. Clean the oil side first. This will eliminate sludge and any oil that might mix with the water side cleaning solution. Cleaning should be performed outdoors or in a well-ventilated room since most solvents have some degree of toxicity.
4. If plant safety regulations permit, circulate perchloroethylene or trichlorethylene through the oil passages, using a hand pump or motor driven pump. Pump in the direction opposite normal oil flow. If a circulating pump is not available, seal the water inlet and outlet openings and immerse the cooler in the oil solvent being used. This method is not as fast or efficient but may have to be used.

Notice: Procedures 5 and 6 below should be employed in the absence of specific instructions from the manufacturer of the heat exchanger. In all instances, follow the manufacturer's instructions if they are available.

5. If pumping, or immersion for a reasonable period of time, does not free the oil passages more radical procedures are required. The heat exchanger may have to be taken to someone with radiator cleaning facilities or a more caustic solution such as Oakite or a commercial alkali used instead of the petroleum solvent. The work should be performed by someone with experience in opening clogged radiators.

6. The water side should be cleaned by immersion, for about one minute, in a solution made by mixing one gallon of muriatic acid with two gallons of water and add one half pound of oxalic acid.

Warning: The chemical solution given in 6 below is caustic. Protect eyes and avoid contact with skin or clothing. Remove the core when foaming and bubbling stops. Do not allow the unit to soak in the acid bath. After treatment flush the unit immediately with clean hot water. Failure to heed this warning can cause severe personal injury and damage to property.

7. Check for signs of physical damage, remove all foreign substances between core and fins, clean gasketed surfaces and install new gaskets when reassembling the unit to the oil and water piping. Be sure to use low pressure dry air to remove all traces of solvent and acid from the tubes in the heat exchanger.

F. Oil Immersion Heaters

Warning: Do not energize electric immersion heaters when they are not submerged in oil. The heater will burn and destroy itself if operated in the air. Failure to heed this warning can cause severe personal injury, and damage to property.

Oil immersion heaters are used to prevent high viscosities of gear lubricants at low temperatures.

Immersion heaters are usually thermostatically controlled and will shut off when the gear unit is under load and the oil has reached the desired temperature.

Should a heater continue to draw power after the oil in the gear unit reservoir has reached the desired cut-off temperature, the thermostat should be checked for proper setting. If the thermostat appears to be properly set, then the heater and thermostat should be removed from the gear unit and a calibration test, in oil, made on the thermostat.

G. Oil Wipers

Occasionally oil wipers are used on slow moving gear units. The purpose of the oil wiper is to remove excess oil from gears that are moving too slowly for centrifugal force to perform this function.

H. Ventilating Devices (Breathers)

Breathers allow the gear case to ventilate to the outside air and maintain atmospheric pressure in the unit. Without breathers increased temperature build-up as the gear unit operates would cause seals to leak and in extreme cases break gasketed joints.

Breathers may be as simple as a pipe plug with a small hole drilled in it to vent it, or it may be a complex device with screens and air cleaning cartridges. The primary function is to keep oil mists in the gear case, external contamination out of the gear case, and to prevent pressure build-up.

Caution: A gear unit should never be operated without a breather cap or with the vent stopped. The first instance invites contamination and the second pressure build-up which can blow oil out through the seals.

Breather devices, regardless of type, should be checked and cleaned at not longer than three month intervals, shorter if the environment is dirty. Refer to the breather device manufacturer's instructions for specified directions.

I. Oil Level Indicators

Many gear units have no provisions for visually determining the oil level. Others are equipped with sight gauges and larger units use dip sticks marked for normal and low oil levels. The responsibility for maintaining correct oil level rests with either the oiling crew or maintenance department. A check of oil level while running is not a true reading. The unit should be shut down and a reasonable time allowed for oil trapped in the gear mesh and oil troughs to return to the sump. Keep oil at proper level, do not overfill. Low oil level is equally bad because gears could eventually be starving for oil. If the dip stick has a knurled stem, it is a screw-on type with standard right hand thread. Turn counterclockwise until it can be removed, turn clockwise to tighten. A dip stick with a finger loop is of the automobile type; a straight pull will remove it from its socket.

Units that do not have sight gauges or dip sticks usually have a small pipe plug or screw driver slotted bolt screwed into the case at the "full line". If oil does not flow when the plug is removed, oil should be added as needed.

Notice: Do not check oil level during operation. A true indication cannot be obtained with the gear unit running.

16.8 Backlash and End Float

Backlash is the rotational clearance between two engaging gear teeth. It is that almost undetectable movement which can be felt if the gear is held stationary while the pinion is rocked back and forth. Backlash is necessary for several reasons:

To allow the teeth some room for thermal expansion.

To allow space for lubricant film.

To prevent binding on entering and leaving mesh.

Backlash is measured in thousandths of an inch (mils) and usually requires dismantling of the unit. Should such a measurement ever be necessary, the manufacturer should be contacted for instructions.

There are various procedures for checking backlash; for precise measurements a dial indicator must be used. On a single reduction unit backlash can be measured with the unit completely assembled because there are shaft extensions protruding from both gears. The output gear must be solidly blocked when measurements are made. This procedure can not be used to measure backlash on double, triple, or quadruple gear units.

End float is a measurement of horizontal axial movement of the gear and its supporting shaft. To measure end float, the shaft must be forced into solid contact with one of the bearing thrust shoulders. This is sometimes difficult to do; a pivotal point should be selected and a lever of some sort used on the hub or side of the gear as the shaft is rotated one or two turns with the coupling. Do not apply undue force to the gear face or hub during the procedure. When it has reached its limit of travel, a dial indicator or a depth micrometer can be used to measure the distance traveled from the opposite bearing support in the case.

Some units have lubricating fittings or pipe plugs located off center in the end caps. Removal of a plug or fitting and insertion of a rod to force the shaft to the limit of its travel is often possible under slow roll conditions. Never hammer or drive on a shaft end to move it. Shaft damage or brinelling of bearings can result, cracking of a bearing race is likely because of its extreme hardness.

End float tolerances are usually carefully controlled and may be limited to the clearances built into the anti-friction bearings. On concentric shaft units end float on the low speed shaft is usually held to within tolerances of plus .001 to .004 mils. The intermediate gearing will range from plus .002 to .006 mils.

On parallel shaft units, very little end float is permitted. The low speed shaft, on all sizes, will be held to within plus or minus .001 mil, the intermediate gearing to plus .001 or .002 mils and the high speed gear from .003 to .005 mils. These tolerances must be retained if it is ever necessary to tear down and rebuild a gear unit.

In some instances the manufacturer may call for preload (negative end float) on some bearings. Instructions for reshimming these units should come directly from the manufacturer.

16.9 Oil Leakage

The subject of oil leakage from a gear unit can become a highly controversial one. Being an oil filled unit, relying on seals to contain the oil and restrict losses from gasketed areas of the case and around shafts, a certain amount of oil leakage can be expected to take place.

Even seal manufacturers do not guarantee completely dry performance since a certain amount of lubrication, either grease or oil is necessary to prevent wiping or early wear out of the seal. Pressure build up and vaporizing of the oil makes total retention difficult, if not impossible. After even a short time in service, a gear unit will show evidence of oil seepage. These guide lines are recommended.

A. Contamination requiring a periodic wipe-off of the case is normal; prevent heavy buildup.

B. As the units age, a seal may start to leak a few drops during an eight-hour period and require some clean-up. Any type of drip pan or a layer of oil absorbing material (saw dust or a commercial product) can be used under a leaky shaft to prevent oil from spreading and becoming a personnel hazard.

C. Excessive oil leakage, several ounces a day is cause for concern. Look for the cause.

Overfilling can cause an oil leak and, a sand hole in the casting can allow oil to eventually find its way through the primer and finish coats of paint. Gear units are tested without oil. An occasional porous casting may get by the inspector at the factory.

There is possibility of a hair line crack. If a crack or porosity is suspected, sand or wire brush the suspected area to remove paint and primer then, apply a coating of whiting over the area of seepage. Discoloration of the whiting will confirm whether there is an actual leak. Various commercial preparations for sealing porous metals are available. Avoid welding or brazing if possible because of stresses and heat distortion of the case.

If seals are leaking, replace seals with the correct type as specified by renewal parts data furnished with the unit. Seals degenerate with age and often are damaged from outside contaminants.

Leaks around bolted joints may be due to loose hardware, improperly sealed gaskets or dried out gasket materials; proceed accordingly. It is not uncommon to develop what is called plumbing leaks around oil lines, pipe plugs, breather tubes or accessories; they can usually be stopped with plumbers pipe joint compound.

A change to a heavier grade of oil, if permitted, may stop oil seepage. A routine cleaning of the oil breather may be all that is necessary, since back pressure in a gear case will cause oil to find an outlet if one exists.

A check for under size bolts and washers should be made. Make certain that someone has not installed replacing bolts that are too long or too short if a unit has been down for inspection or cleaning.

If all attempts to stop oil leakage have failed, send the unit to a repair plant for checkout and rebuilding. If the unit is still in warranty, the supplier should be contacted for advice and return shipping instructions.

Some unusual causes of oil leaks have been found. A burr or a score on a shaft can cause a perfectly good seal to start leaking. Not so rare is the seal that starts to leak after a nominal period of time in service. This is often the result of abrasive materials piling up on the outside of the seal on the shaft. Shaft rotation causes seal wear and particles may work their way under the seal, scoring the shaft and wearing out the seal much faster than is normal.

When a shaft seal begins leaking, and seal replacement is necessary, follow the manufacturer's instructions to the letter. For example, prelubricate the seal before attempting to install it. Make certain the shaft is concentric and does not have burrs or nicks on it.

Do not use emery cloth to polish a shaft. Emery dust is persistent and continuously abrasive. Wash the shaft with clean solvent if polishing is necessary.

A special seal mounting tool is usually recommended. It consists of a thin walled cylinder over which the seal is gently pressed after being lubricated according to manufacturer's recommendations. This tube carries the seal up and over any sharp edges such as keyways and to the point of entry in the case. Once in place, a second tool; a ring of soft metal is inserted over the tube and a few light taps with a rawhide mallet will drive it into the machined recess in the case. The pilot cylinder can then be withdrawn and the seal takes a positive position on the shaft.

When handling a seal, do not flex it with the fingers or deform it in any manner. Some seals have springs in them called garter springs; others have finger type compression leaves that exert force against the seal and keep it under tension on the shaft. A blow or indentation in the outer metal guard can deform this spring seating arrangement distorting the rubber, neoprene or leather composition of the sealing ring. This probably won't be noticed and the new seal will begin leaking immediately.

If seal installation tools are not available, cellophane tape can be wound around the shaft with the layers overlapping toward the seal fit. Once the seal has been slid over the cellophane, make certain that all cellophane is recovered when removing it from the shaft. This is important because the cellophane will prevent shaft-to-seal contact.

If the unit has a force fed lubrication system, oil leaks, because of excessive lube pressure, may occur. Hydraulic forces are hard to overcome with common seal methods.

Sometimes it is not the pressure but the volume of oil which results in leakage. A misdirected spray pipe or too much oil being spun off a high speed shaft can provide too much oil to an area not normally deluged with oil.

One of the oldest recognized causes of oil leaks is foaming. Manufacturers are quite specific concerning the type and grade of oil to be used in gear units. An additive to prevent foaming may be called for; be sure to consult instruction books for lubrication requirements before filling with oil. Drain and refill at recommended intervals.

Oil troughs in gear housings lead to the outboard side of the shaft bearings. Lubrication, force feed or gravity, is usually from the large end to the small end of tapered roller bearings. This type of bearing is invariably installed with the small end installed outboard and return oil is fed back to the larger diameter of the tapered bearing. Since there is a natural tendency for old oil to sludge, and any particles in oil will be carried along with the flow, these grooves should be cleaned and flushed with kerosene whenever a gear unit is opened for service or inspection. Keep all sealing compounds out of these oil grooves or drilled oilways designed to return oil to the case reservoir.

A tooth separation or anything that will stop the motion of meshing gear exerts tremendous pressure on all associated components including the case. Cracked cases are often encountered, sometimes caused by a blow from the outside. A small crack can be sealed as mentioned earlier by commercial metal mending compounds. However, large cracks are a real problem. If welding or brazing is necessary, it should be done

under controlled conditions and the alignment and mesh of gears thoroughly checked before putting the unit back in service because of case distortion. Cracks leading into tapped holes are virtually impossible to repair and, if a crack has progressed along or through an extended path which includes reinforcing ribs or embossments, don't waste your time on repairs. If either the top or bottom half is damaged beyond repair the entire case must be replaced because top and bottom halves are machined as a single unit to insure shaft positioning and bearing support alignment.

16.10 General Maintenance Hints

Oil level should always be checked when the unit is shut down; allow sufficient time for all oil to return to the sump and cool off somewhat.

By nature, all gear units produce some kind of noise in operation, either a low pitch rumble or a high whine from the input mesh. Learn to distinguish between normal gear noise and symptomatic noises that could mean lack of oil, bearing trouble or misalignment. Remember that sound is often amplified by the type of mounting or can be induced by coupled apparatus.

A new gear may be initially noisy then quiet down after a reasonable period of service. This decrease in noise level is the result of normal wear, the gear teeth have established a well defined run-in pattern and other more subtle changes will have taken place. Temperatures too, may drop considerably as friction factors become minimal. New units when first put into service are likely to be more noisy and run hotter than older units of the same type.

Solid couplings require no oil but certain flexible and spring loaded couplings do require lubrication. Determine which type you are using then, if oil or grease is used, check, drain and refill at prescribed intervals. A greasable coupling must also be lubricated at specified intervals. Consult the manufacturer's instructions.

Gear rotation can be misunderstood unless a point of relationship is established. A good thing to remember is, that the direction of rotation of a motor is always given as it is seen when viewed from the front end of the motor. Always be sure to specify where you are viewing from when you give the direction of rotation of a gear unit shaft.

Normally, the word rotation, and an arrow, are either cast into the frame of the gear unit or a nameplate or decal is substituted. If there are no markings whatsoever, the direction of motor rotation can be used for reference.

When working on unidirectional gear units, the prime mover must be connected for correct rotation before assembly to the gear unit. If the prime mover is a three phase motor, which can be reversed by interchanging any two of the line leads, be sure rotation is correct before assembly and start-up. Some gear units are equipped with a back stop to prevent reverse rotation for safety reasons. If a motor, improperly connected, is started or jogged under these circumstances, gear unit damage can result.

Frequency of inspection is usually spelled out in the instruction books received with the gearmotor or gear unit. Frequency is based on normal operation under AGMA application standards. Visual inspection of the internal components is necessary at periodic intervals to determine the condition of the gear teeth.

Pitting is the most commonly observed condition. Pitted teeth are not necessarily noisy in operation and should not be construed as signs of early failure. Some gear teeth will pit very early after being placed in operation and, after a period of time, pitting will cease and a well worn working surface will begin to show, indicating there are no interferences in tooth engagement. Cuttings, filings, gritty particles in the oil or even sand from the casting can track a pattern into extremely hard surfaces. If pitting is not a progressive factor allow the gears to continue to operate. One type of pitting is recognized as incipient or corrective pitting. It appears near the pitch line, about halfway up the tooth profile and is not harmful.

When first noticed, a pitting record can be made by sketch, and to record the particular tooth, by using machinists layout dye and painting the top land of a tooth for future reference. Another way to make record of pitting is with a piece of aluminum foil. Put a spot of dye on the tooth to be checked as a permanent marking reference. Then mat the foil over the flank of the tooth. Then use just enough pressure to make indentations in the foil which has been placed over the pitted area of the tooth. Later on, a second impression of the same spot can be taken and compared to the first strip of foil. Progressive pitting will show a different pattern. If pitting has ceased there will be no change in marking.

Daily rounds of inspection should be made. Gearing frequently operates under very adverse conditions, so it requires frequent checking.

Vibration is usually present, frequent starts and stops are common, shock loading and transient overloads are quite common, especially on conveyors, loading machinery and mine-to-mouth belt conveyors. Quarry duty and application to rock crushing machinery is very hard on gear units. Start-up under full or partial load conditions, or trying to break loose a stalled condition, soon creates maintenance problems.

Be on the alert for anything that will contribute to excessive wear and parts breakage or have other determined effects on the unit. Keep guards in place and frequently check hold down bolts, coupling set screws and belt tension. If chain drives are used, idlers should be employed to prevent snap when too much slack is present in the link chain. Belt condition, on belted drives is also important. Too tight a belt or chain puts unnecessary strain on the shaft extension and associated bearing. A stretched belt in a gang belted drive is not pulling its share of the load. Replace all belts when one fails, saving the reusable ones for other single belt applications. In this manner, belts stretch uniformly and tighten uniformly when a belt adjustment is needed. A belt which is frayed or suddenly breaks can become a hazard. They sometimes cause companion drive belts to break if a loose end becomes entangled or goes through the adjacent grooves in the drive pulley. Figures 11 and 12 show belted and chain driven gear units. These are commonly used methods of coupling units to driven loads.

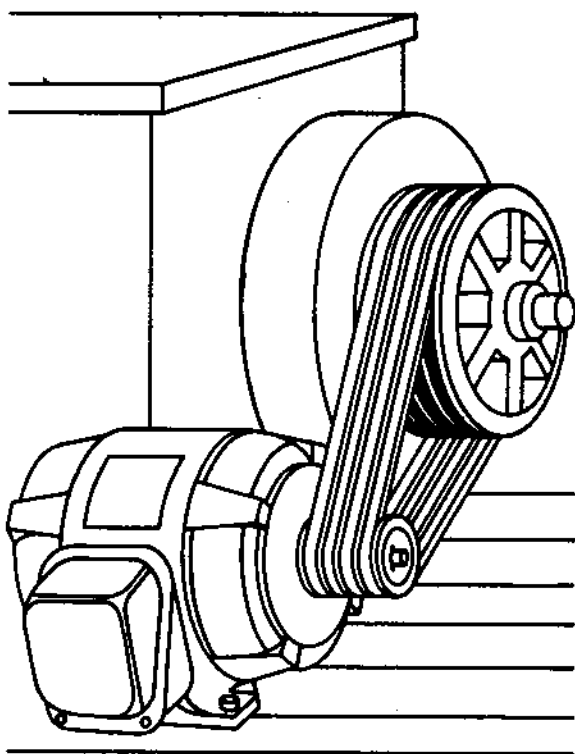


Fig. 11 – Belted Drive Gear Unit

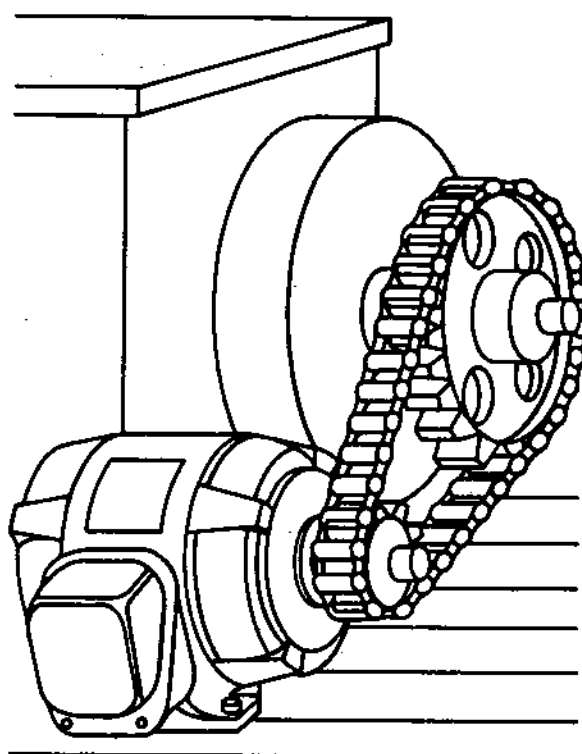


Fig. 12 – Chain Drive Gear Unit

16.11 Record Keeping

To facilitate selection of any gear unit, use forms which contain pertinent application data. The following form, Figure 13, or a variation of this form, could be useful in the maintenance and engineering department files. In the event of a new gear unit or a comparable unit is to be ordered, all significant information is contained on a single card or a sheet of paper. This document, and a history card on maintenance requirements and parts replaced, could help determine if the initial selection was adequate or should be altered to meet changed operating conditions.

1. Application Description of Driven Equipment _____
Type of Load: ☐ Smooth, ☐ Moderate Shock, ☐ Heavy Shock. Duty Cycle _____ Hr/Min Operation Every _____ Day/Hr/Min.
Required Hp and Rpm at Driven Equipment: Peak _____ Hp/ _____ Rpm.
Cycle of Occurrence _____ Normal _____ Hp/ _____ Rpm
Environmental Conditions - Location: ☐ Indoor, ☐ Outdoor. Ambient Temperature _____ °F.
Atmosphere: ☐ Clean, ☐ Dusty, ☐ Abrasive Dust, ☐ Normal Humidity, ☐ High Humidity

2. Prime Mover Driving Equipment: ☐ Motor, ☐ Turbine, ☐ Internal Combustion Engine.
☐ Other Description _____
Hp _____, Rpm _____. If Variable Speed. Base Speed _____ Rpm, _____ Maximum Rpm, _____ Hp/ _____ Minimum Rpm, _____ Hp.

3. Method of Connecting Prime Mover to Reducer ☐ Flexible Coupling. Type and Size _____
☐ V-Belt, ☐ Sprocket P.D. of Driven Sheave or Sprocket _____
Number of Grooves or Strands _____, Belt or Chain Section _____
Rpm of Driven Sheave or Sprocket _____ Rpm. Other Description _____

4. Reducer Type _____, Size _____, Minimum Service Factor Required _____, Assembly Position _____
Input _____ Rpm/Output _____ Rpm (From 1 and 2 or 3 Above). Ratio Req'd _____, Closest Std. Ratio _____
Mechanical Hp Rating _____, Thermal Hp Rating _____, Cooling Required: ☐ Fan, ☐ Heat Exchanger.
If Inclined Mounting Required, Give Angle and Whether Low Speed Shaft Pointing Up or Down _____

5. Method of Connecting Reducer to Driven Equipment ☐ Flexible Coupling. Type and Size _____
☐ Pinion: Pitch Dia _____, Face Width _____, ☐ Sprocket: Type _____
P.D. of Driving Sprocket _____, Number of Strands _____, Type of Sprocket ☐ Type B, ☐ Type C.
☐ Other Description _____

6. Accessories and Modifications

☐ Thermal Assist	☐ Bedplate	☐ Backstop
☐ Moisture Resistant Seals, (Required If Cleaning by Hosing Necessary)	☐ Tachometer Mounting	☐ Special Paint
☐ Abrasive Dust Seals	Make _____, Size _____	Mounting Equipment on
☐ Taconite Seals	☐ Brake Mounting,	☐ L.S. Shaft ☐ H.S. Shaft
Special Shaft Requirement _____	Make _____, Size _____	☐ Mounting Motor on Bedplate
Other Special Feature or Modification _____		

Fig. 13 - Suggested Maintenance Department Record Form for Gear Units

Dry-Type Distribution Transformers

Application 2:17.1

Manufacturing Standards 2:17.1

Sound Levels 2:17.1

Transformer Nomenclature 2:17.4

Receiving, Handling, Installation 2:17.11

Transformer Connections 2:17.14

Standard Single-Phase Connections 2:17.14

Autotransformer Connections 2:17.17

Three-Phase Connections 2:17.23

Testing 2:17.33

Inspection and Maintenance 2:17.34

Drying of Transformer Core and Coil Assemblies 2:17.36

Special Applications 2:17.38

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Dry-Type Distribution Transformers

17.1 Application

Dry-type distribution transformers may be installed in nearly any indoor location where they are not subject to submersion or high concentrations of destructive fumes. Dry-type transformers are available in enclosures and shielding to permit installation in many locations indoors and outdoors, shipboard installations, and locations requiring electrical isolation. Being air insulated and convection cooled, these transformers are less liable to explosion, release of toxic gases, and fire hazards than are other types of transformers. The greatly reduced hazard potential of these transformers makes them particularly suited to indoor installation and especially desirable for use in electrical distribution systems of hospitals, office buildings, and other high occupancy buildings.

A. Manufacturing Standards

Dry-type distribution transformers are manufactured to standards established by ANSI, NEMA, and IEEE. Insulating materials meet ANSI standards. Units rated through 1000 kVA three phase, and 167 kVA single phase, 600 volts and below are Underwriter's Laboratories listed and bear the UL label.

B. Sound Levels

The importance of the level of sound emitted by a dry-type transformer is dependent upon its location. To increase the efficiency of the distribution system transformers are located as near as possible to the load. This results often in bringing the transformers nearer to the building occupants and increases the significance of any noise emitted.

1. Sources of Transformer Noise

The main source of sound in a transformer is magnetostriction. This is a property of electrical sheet steel that causes it to elongate and contract in the presence of a magnetic field. These mechanical movements produce audible vibrations in the transformer core. They have a fundamental frequency equal to twice the flux frequency. Due to the non-linear relationship between magnetostriction and flux density, a number of harmonically related higher frequencies are also produced. The result is a noise spectrum composed of fundamental frequencies of 120 cycles per second and harmonics of 240, 360, 480, 600, etc.

The pulsations of the core travel through other parts of the transformer which have a tendency to vibrate at one of the frequencies set up by the core. These vibrations add to the overall sound level in the form of interlaminar core and coil vibrations, enclosure, and subassembly vibrations. The amount of this additional sound depends on the surface area and resonant frequency of each component.

2. Control of Transformer Noise

There are four primary sources of sound in a transformer:

Core vibration

Interlaminar core and gap vibrations and coil vibrations

Subassembly vibrations

Enclosure vibrations.

a. Core Vibrations

Ventilated transformer designs require air ducts in the coil to assure proper cooling. Higher temperature insulation permits smaller air ducts. The larger the air ducts the larger the coil must be so a longer loop is required to accommodate the winding. The longer the core loop the greater the elongation and contraction and consequent increase in sound producing vibrations. The doubling of the core length results in a sound level increase of approximately 6 decibels.

One way to control sound level is to install transformers with the highest temperature insulation and smallest core possible.

b. Interlaminar core and gap vibrations and core vibrations are contributing sources of sound and are inherent in the structure and construction method of the transformer core and coil assembly. Gap vibrations can be kept to a minimum if the individual laminations are interleaved. Interlaminar and coil vibrations are controlled by varnish dipping of the complete core and coil assembly and curing at high temperature.

Control of these sources of sound is a matter of manufacturing method. The installer should be careful to install transformers with these built-in sound controls.

c. Subassembly vibrations sound producing effect is a function of the surface area and the mode and amplitude of vibration. The most effective method of control is to isolate these components from the inherent core vibrations. This is a matter of design and manufacture of the transformer.

d. Enclosure vibrations are the result of the inherent vibration of the transformer core. The transformer design should have the smallest possible case made of rigid material.

3. Minimizing Sound Amplification

The installer and maintenance operation can exercise some significant reduction in transformer noise level by following some fundamental installation guidelines.

a. Install the transformer in a location where the noise will be the least objectionable.

b. Avoid nearby reflecting objects or enclosures that will resonate. Avoid areas which tend to amplify sound such as stairways and halls.

c. Avoid walls or floors of tile, brick, concrete, or steel. These surfaces are excellent sounding boards. If the transformer must be installed on or near these surfaces, they should be shielded by acoustic tiles or other sound absorbing materials.

d. Do not mount the transformer on walls, partitions, balconies, or floors having a light mass. The weight of the transformer should not exceed the weight of the mounting surface equal to the projected area of the transformer, to avoid the mounting surface from enhancing the sound level.

e. All bolts, fasteners, and other devices, including core and coil mounting bolts should be inspected as possible sound sources.

f. Use flexible connections on all incoming and outgoing lines.

g. Vibration dampers located between the transformer and the surface upon which it is mounted can reduce transmitted vibration and can also be used as levellers.

h. The manufacturer's installation instructions should be followed carefully.

i. NEMA Standards for transformer sound levels

Equivalent Two-winding kVA	Average sound level – decibels self-cooled, ventilated	
	Up to 1.2 kV	Above 1.2 kV
	Line to Line	
0-9	40	45
10-50	45	50
51-150	50	55
151-300	55	58
301-500	60	60

4. Measuring Audible Sound

Sound level tests should be made in a laboratory with anechoic characteristics. The ambient sound level of this room should not exceed 24 decibels.

NEMA standards require that measurements be taken opposite each major sound producing surface at a distance of one foot from the surface. Surface in this instance means the surface of the enclosure of the completed unit.

Figure 1 shows a number of typical overall sound levels to give a comparison reference in judging noise.

The selection of transformers designed, manufactured and tested in accordance with the standards indicated will assure that a quiet transformer is supplied. Such a transformer, installed in compliance with the guidelines given, will assure satisfaction with regard to transformer noise.

C. Transformer Nomenclature^②

It is necessary to have a knowledge of technical terms commonly used in discussing transformers. This knowledge helps in understanding written and verbal instructions on selection, installation, and maintenance.

Ambient Noise Level – The noise level of the area surrounding the transformer, measured in decibels.

Ambient Temperature – The temperature of the atmosphere surrounding the transformer, into which the heat of the transformer is dissipated.

ASA 61 – An ASA designation for color of paint, usually written into specifications as “must be ASA 61 light gray paint”.

Autotransformer – A transformer in which part of the winding is common to both primary and secondary circuits.

BIL – Basic Impulse Level. See Impulse Tests.

Buck-Boost Application – A two-winding, one-phase transformer with low-voltage secondary windings which can be connected as an autotransformer for boosting and bucking single- and three-phase supply voltages in small amounts.

Certified Tests – Actual values taken during production tests and certified as applying to a given unit shipped on a specific order.

^② Based on NEMA ST1.

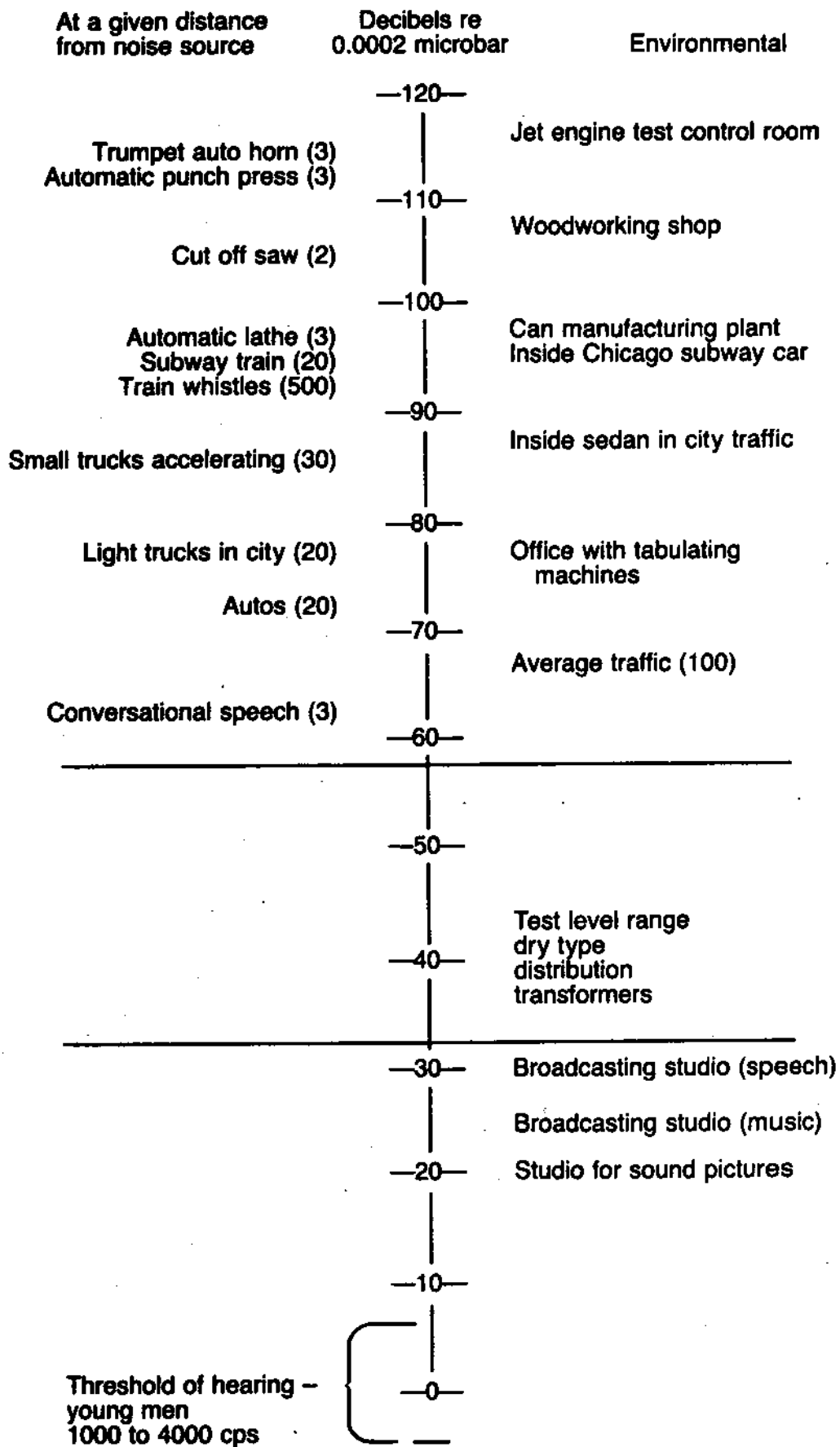


Fig. 1 - Familiar Sound Levels

Class A, B, F, H – The class of insulation system of the transformer.

Continuous Rating – The constant load a transformer can carry at rated primary voltage and frequency without exceeding the specified temperature rise.

Copper Losses – Copper losses are a portion of load losses. See Load Losses below.

Corrosion Resistant (also see Rust Resistant and Rust Inhibiting) – Specifically prepared or treated to resist corroding and rusting.

Current – The flow of electricity in a conductor. Measured in amperes. (See Voltage.)

Current Transformer – A transformer generally used in instrumentation circuits for measuring or controlling current.

Decibel (db) – A unit of measure of sound intensity. A sound intensity change of one db is the smallest change the human ear can detect. See Figure 1 for comparison levels of sound.

Delta (Δ) – A standard three-phase transformer connection with the ends of each phase winding connected in series to form a closed loop with each phase 120 degrees from the others. Sometimes called 3-wire.

Delta-Wye (ΔY) – A transformer connection in which the primary is connected in delta and the secondary is connected in wye (see wye connection below).

Dielectric Tests – Tests of electrical insulating strength of insulating materials and spacings. Tests consist of the application of voltages at higher than rated voltage for a specified time period to determine the adequacy against breakdown under normal conditions.

Dry-Type – A transformer in which core and coils are not immersed in liquid.

Electrostatic Shield – A copper or other conducting sheet placed between primary and secondary circuits of a transformer and grounded to prevent electrical interference and provide additional protection.

Exciting Current (No-Load Current) – The current which flows in any winding used to excite the transformer when all other windings are open-circuited. It is usually expressed in percent of the rated current of the winding in which it is measured.

Extended Winding – A winding made longer than necessary so it can perform duties normally expected of another winding or windings. The best example is an extended primary transformer.

Its primary winding is continued up the core beyond the point where it will do its rated job. In this additional section of the winding taps can be added for regulation of the secondary voltage. See Figure 2.

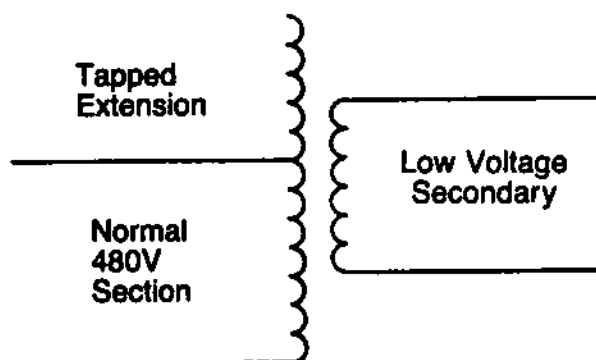


Fig. 2 – Extended Primary Transformer

FCBN – Full Capacity Below Normal Taps—Designates that transformer taps are suitable for full-rated power at voltages below rated level.

FCAN – Full Capacity Above Normal Taps—Designates that transformer taps are suitable for full-rated power at voltages above rated level.

Flexible Connection – A non-rigid connection designed to eliminate transmission of vibration (noise). This is in contrast with rigid conduit, etc.

Flux – The magnetic induction produced in the transformer core by the primary winding which causes the voltage to be produced in the secondary winding.

Fortesque Connection – A connection for polyphase transformers to change from three phase to two phase using three transformers.

Frequency – On alternating-current circuits frequency is the number of times the polarity alternates from positive to negative and back. The number indicates cycles per second and is expressed as hertz (such as 60 Hz).

Full Capacity Tap – A tap through which the transformer can deliver its rated kVA output without exceeding the specified temperature rise.

Grounding Transformer – A special three-phase autotransformer for establishing a neutral on a three-wire delta secondary.

Grounds or Grounding – Connecting one side of a circuit to earth through low-resistance or low-impedance paths. Grounding helps to prevent transmitting electrical shock to personnel.

Group II and Group III Insulation – NEMA designations for insulation systems which are commonly classified as B and H.

High-Voltage and Low-Voltage Windings – Terms used to distinguish the winding having the greater voltage rating from that having the lesser in two-winding transformers. The terminations on the high-voltage windings are identified as H1 and H2, etc., and on the low-voltage windings as X1 and X2, etc.

Impulse Tests – Dielectric tests consisting of the application of high-frequency, steep-wave-front voltage between windings and between windings and ground to test insulation strength.

Impedance – Retarding forces of current flow in alternating-current circuits.

Indoor Transformer – Any transformer not suitable for outdoor service because of its construction.

Induced Test – A standard high-frequency test of transformer insulation.

Insulating Materials – Those materials used to electrically insulate the transformer windings and other components from each other and from ground.

Insulating Transformer – A transformer which insulates the primary from the secondary winding.

Insulation System – Balancing of insulation materials to provide a consistent insulation for an entire equipment.

Isolating Transformer (see Insulating Transformer) – A transformer that isolates the primary circuit from the secondary circuit.

Knockout – Readily removable discs in sheet metal which eliminate the need to drill holes for conduits.

KVA or Volt-Ampere Output Rating – Designates the output a transformer can deliver for a specified time at rated secondary voltage and rated frequency without exceeding the specified temperature rise. (1 kVA = 1000 volt-amperes).

Load – The power supplied by a transformer expressed in kVA or VA.

Load Losses – Losses in a transformer incident to load carrying. They include I^2R loss in the windings due to load current, stray losses due to stray fluxes in the winding, core clamps, etc., and to any circulating currents in parallel windings.

Mid-tap – A reduced-capacity tap midway in a winding, usually the secondary.

Moisture-resistant – Equipment constructed so it is not readily harmed by exposure to a moist atmosphere.

Multiple Winding – See Parallel, and series/multiple.

Natural Draft or Natural Draft Ventilation – An open transformer cooled by the chimney effect in heating the air in the enclosure.

Noise Level – The relative intensity of sound, measured in decibels (db).

No-load Losses (Excitation Losses) – Loss in a transformer which is excited at rated voltage but is not supplying load. They include core loss, dielectric loss, and copper loss in the winding due to the exciting current.

Parallel Operation – Single- and three-phase transformers with appropriate terminals, operated in parallel by connecting similarly-marked terminals, provided the ratios, voltages, resistances, reactances, and ground connections permit parallel operation, and in the case of three-phase transformers the angular displacements are the same.

Percent IR (Percent Resistance) – Voltage drop due to resistance at rated current in percent of rated voltage.

Percent IX (Percent Reactance) – Voltage drop due to reactance at rated current in percent of rated voltage.

Percent IZ (Percent Impedance) – Voltage drop due to impedance at rated current in percent of rated voltage.

Phase – An alternating current producing a cycle pattern. Single phase designates a single pattern, three-phase designates three cycle patterns, none coinciding. Electrical circuits are described as single-phase, 2-wire or 3-wire or three phase, 3- or 4-wire.

Polarity Tests – A standard transformer test to determine instantaneous direction of the voltages in the primary relative to the secondary. (See Transformer Tests.)

Potential (Voltage) Transformer – A transformer used in instrumentation circuits to control or measure voltage.

Power Factor – The relation of watts to volt-amps in a circuit.

Primary Taps – Taps in the primary winding. (See Tap.)

Primary Voltage Rating – The input circuit voltage for which the primary transformer winding is designed.

Primary Winding – The winding of a transformer on the energy input (supply) side.

Ratio Test – A test of a transformer to determine the ratio of the primary to the secondary voltage. (See Transformer Tests.)

Reactance – The effect of inductive and capacitive components of a circuit producing other than unity power factor.

Reactor – A device for introducing inductive reactance into a circuit for motor starting, operating transformers in parallel, and controlling current.

Reduced Capacity Taps – Taps which will carry full-rated power only, thus reducing available power because of lower output voltage.

Regulation – The change in output voltage when the load goes from full load to no load, usually expressed as a percentage change.

Scott Connection – Connection for polyphase transformers. Usually used to change from two-phase to three-phase or three-phase to two-phase.

Secondary Voltage Rating – The load-circuit voltage for which the secondary (output) winding is designed.

T-Connection – Use of a Scott Connection for three-phase operation.

Tap – A connection brought out of a winding at some point between extremities, usually to permit changing voltage or current ratio.

Temperature Rise – The temperature rise above ambient of the winding due to energizing and loading the transformer.

Transformer – An electrical device without continuously moving parts, which by electro-magnetic induction, transforms energy at one voltage or current to another voltage or current at the same frequency.

Voltage – Electrical pressure. A volt is the difference of potential which, when steadily applied to a conductor of one ohm reactance, will produce a current of one ampere. (See Current.)

Wye Connection (Y) – A three-wire transformer connection with similar ends of single-phase coils connected together. This common point forms the electrical neutral point and can be grounded.

Zig-Zag Connection – A special transformer connection commonly used in grounding.

17.2 Receiving, Handling, Installation

A. Receiving

New transformers should be inspected upon receipt for evidence of damage. If damage is suspected it should be reported to the delivering carrier and the manufacturer. Ventilated dry-type transformers showing any external damage should be given an internal inspection. This can be made in any clean dry location by removing the enclosure panels. Sealed dry-types should be inspected in accordance with the manufacturer's instructions. This may require that they be returned to the factory.

Warning: Do not open or remove the cover of a sealed dry-type transformer without first removing the insulating gas in careful adherence with the manufacturer's instructions. Failure to do so can cause severe personal injury or death by asphyxiation.

Insulation and ratio tests should be included as a part of these inspections.

B. Handling

Dry-type transformers should be lifted and moved by crane if possible, by the lifting lugs provided. A spreader should be used to hold the lifting cables apart and avoid damage to the transformer.

If the transformer cannot be moved by crane it can be moved on rollers or skidded, taking care to keep it from overturning or damaging the base. When it is necessary to move the transformer through restricted places where it must be turned or tilted beyond a limited angle, the manufacturer should be consulted for advice and instruction.

If it is necessary to move an indoor transformer outdoors in wet or windy weather it should be protected against rain, snow, or dust.

C. Location

Ventilated dry-type transformers will operate successfully in dry, indoor locations. They can tolerate high humidity when energized but if shut down for an appreciable period provision should be made for keeping them dry. Locations where they may be subjected to dripping or splashing water should be avoided.

Adequate ventilation is essential for proper cooling of the transformer. Clean dry air is preferable when transformers are installed in vaults or other restricted spaces, sufficient ventilation must be provided to maintain the ambient temperature within established limits. This requirement is approximately 100 cubic feet of air per minute per transformer per kilowatt of transformer loss. The area of ventilating openings depends on the height of the vault, the location of the openings, and the maximum loads to be carried by the transformers.

These transformers should be installed in locations free from unusual dust and chemical fumes. They should be located at least 12 inches away from walls or other obstructions that might prevent free circulation of air through and around each unit. The distance between transformers should be at least 12 inches.

If the transformer is to be located in the vicinity of combustible materials, the minimum separation established by the NEC 450-21 (1981) should be maintained.

The transformers should be located to be readily accessible for inspection and maintenance.

D. Mounting

1. *Dry-type distribution transformers can be mounted in many ways:* floor or platform mounting, Figure 3; ceiling or trapeze, Figure 4; and wall mounting when equipped with mounting brackets, Figure 5. Any level, stable surface of adequate strength can be use.

2. *Special enclosures* are available for some dry-type transformers which permit mounting in locations requiring electrical isolation, Figure 6; shipboard deck or bulkhead installation, Figure 7; and with weather-shields for outdoor platform or pad mounting, Figure 8.

3. *Grounding* of the case and the core should be positive, permanent, and adequate.

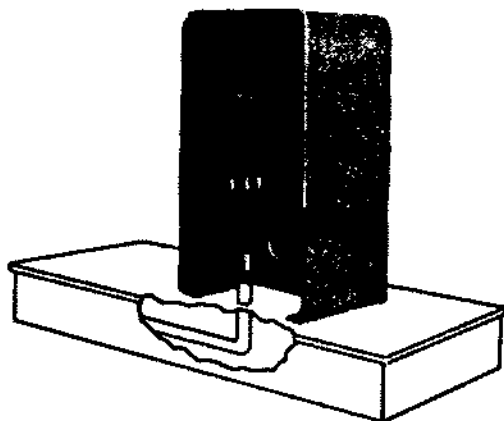


Fig. 3 - Floor or Platform Mounting

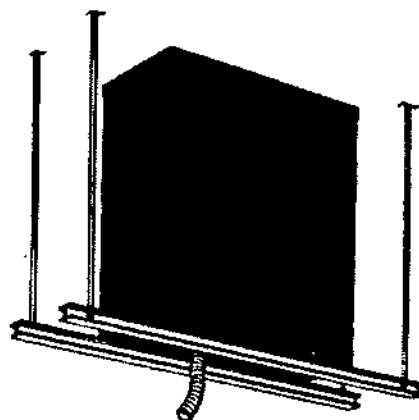


Fig. 4 - Ceiling or Trapeze Mounting

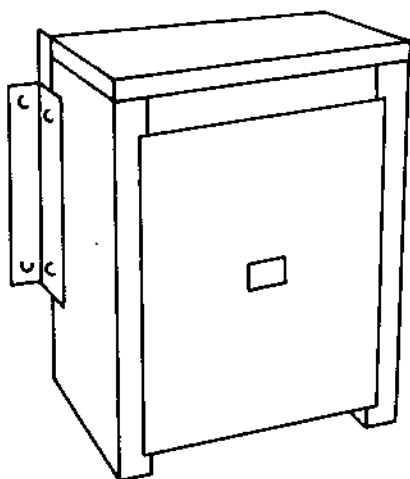


Fig. 5 - Wall Mounting



Fig. 6 - Isolation Transformer for Indoor Mounting in Locations Requiring Complete Electrical Isolation

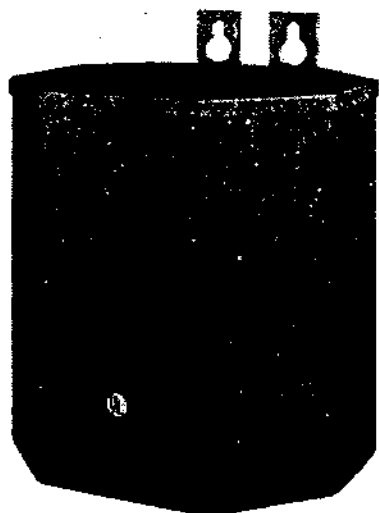


Fig. 7 - Marine Dry-Type Transformer for Shipboard Deck or Bulkhead Mounting

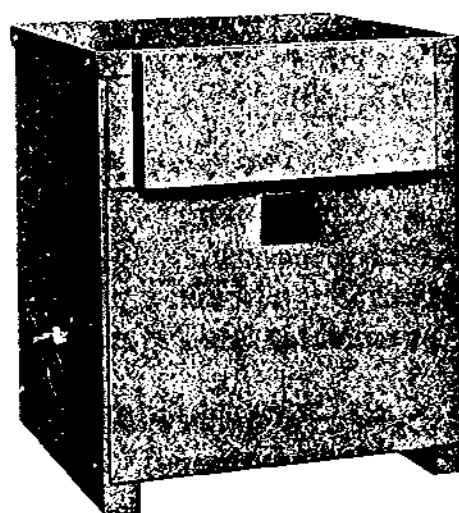


Fig. 8 - Dry-Type Transformer with Weathershields for Outdoor Pad or Platform Mounting in Restricted Access Areas

17.3 Transformer Connections

A. Standard Single-phase Connections

1. Single-phase, Three-wire Secondary (Series Connection)

The most commonly used connection for small distribution transformers is shown in Figure 9, where three-wire secondary is supplied at 120/240 volts. A similar connection may be used for 240/480 volt transformers. The primary may be supplied from a single-phase line, two wires of a three-phase line, or one line wire and one neutral of a three-phase line.

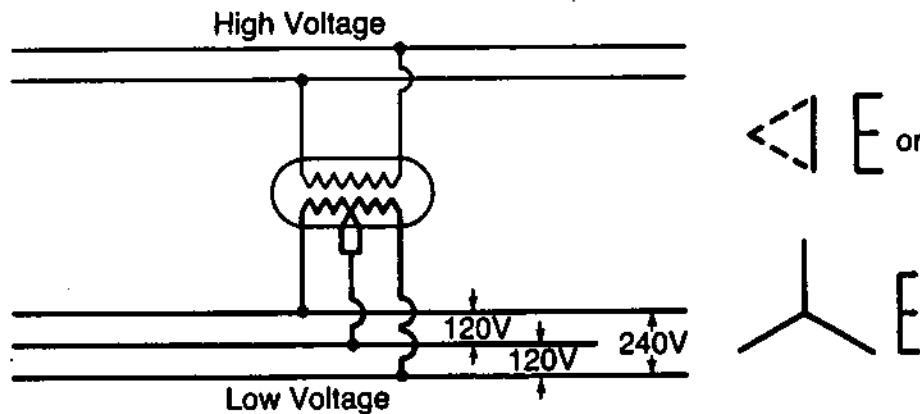


Fig. 9 - Three wire Secondary (Series) Connection

The 120 volt loads should be balanced so the halves of the low-voltage winding will be equally loaded.

Where wiring diagrams show two-wire per phase secondary systems, many of the connections can be used to serve a single phase, three-wire system by using the mid-point of the secondary winding. It is also possible to supply combined two or three phase and single phase (2 or 3 wire) loads. In such cases unequal kVA ratings for the different transformers may be needed so all transformers will carry the same percentage of the rated load.

2. Single Phase Parallel Operation of Two Single Phase Units

The parallel operation of transformers having the same high-voltage and low-voltage ratings is often used in cases where it is necessary to increase the total bank capacity and a single unit of the needed capacity is not available. See Figure 10.

It is not economically efficient to operate two transformers in parallel where a single unit could be applied. The losses of two units in parallel are greater than the losses of a single unit of equal capacity.

When the ratio of reactance to resistance is about the same for both transformers the maximum safe bank capacity may be determined as the lesser of the values produced by the following formulae:

Bank capacity based on not overloading Transformer No. 1

$$= \frac{C_1 Z_2 + C_2 Z_1}{Z_2}$$

Bank capacity based on not overloading Transformer No. 2

$$= \frac{C_1 Z_2 + C_2 Z_1}{Z_1}$$

where C_1 and C_2 are nameplate kVA ratings and Z_1 and Z_2 are nameplate percentage impedances for Transformers No. 1 and No. 2 respectively.

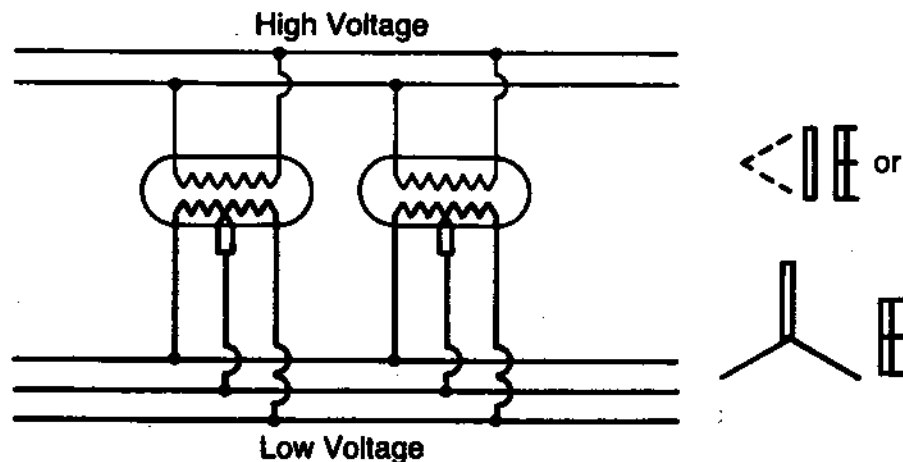


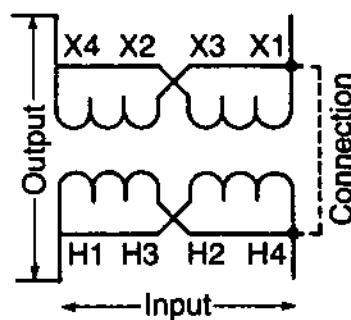
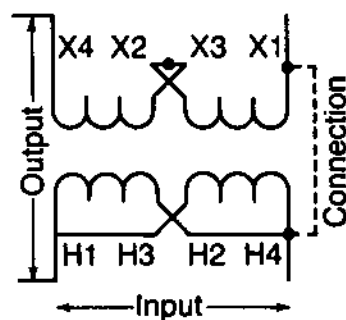
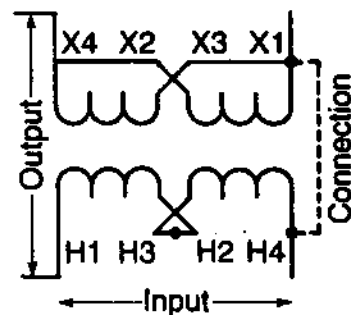
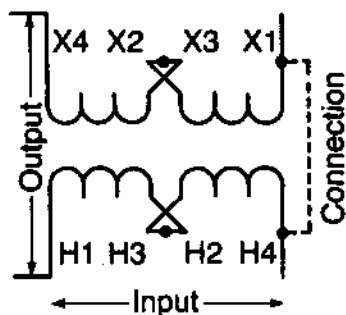
Fig. 10 – Parallel Operation of Two Single-Phase Units

3. The Transformer as a Booster

The purpose of a booster transformer is to raise the voltage of the circuit from which the transformer is excited. The primary winding is connected in multiple and the secondary winding is connected in series with the line. By reversing the secondary winding its action can be changed from boosting to bucking. In this connection the low-voltage winding is subjected to the overvoltages of the high voltage circuit. Transformers specifically designed for booster operation are insulated to withstand these voltages. See connection diagrams Figure 11.

Warning: Make sure the insulation system of the transformer can withstand anticipated high-voltage circuit overvoltage when applying a standard two-winding transformer as a booster, otherwise unit insulation failure may result. Failure to heed this warning can cause severe personal injury or death, and damage to property. With transformers having 1.2 kV class secondaries, ground one end of the secondary winding.

Boost Application
Single Phase



Buck Application
Single Phase

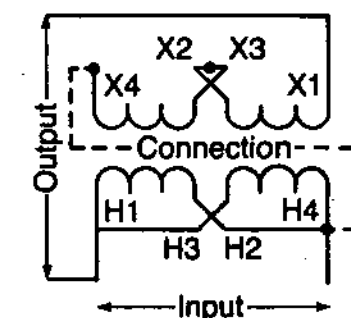
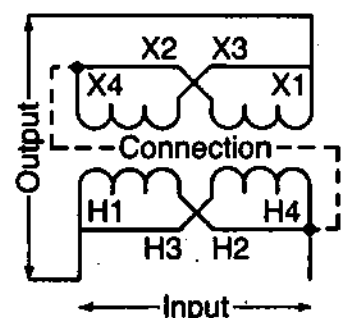
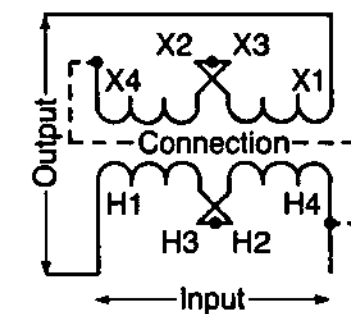
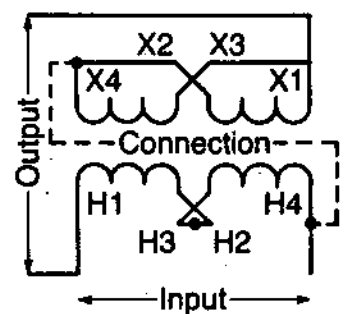


Fig. 11 – Buck and Boost Transformer Connections

Consideration should be given to the reduction in effective transformer impedance when it is connected as a booster. The addition of series impedance may be required to limit short circuit currents to permissible values.

Table 1
Selection of Buck and Boost Connections for Desired Output

Nominal Circuit Voltage	Trans- former Function	Percent Change of Circuit Voltage	Fig. 11 Diagram	kVA Output^③ in Terms of Nameplate Rating- Times
120	boost	10	1	10
	boost	20	2	5
	buck	10	3	10
	buck	20	4	5
240	boost	5	5	20
	boost	10	6	10
	buck	5	7	20
	buck	10	8	10

③ If actual voltage differs from nominal, multiply kVA of output by ratio of actual voltage to nominal.

B. Autotransformer Connections

Single-phase transformers of standard service voltage ratings can be applied as autotransformers to provide step-up or step-down service in general light and power applications.

Application Cautions:

In some places local codes prohibit the use of autotransformers because for some applications the load circuit must be completely isolated from the supply circuit, and supply circuit faults will affect load circuits when autotransformers are used for voltage transformation.

Autotransformers are not usually recommended for step-down service because of the danger of destroying equipment by having a voltage greater than its capacity accidentally impressed upon it.

1. Single-Phase Transformers Applied as Autotransformers

Voltage Trans-formation	Ratio of Low to High Voltage	Fig. No.	Transformer Rating – volts	
			Primary	Secondary
240 to 480	0.5	12	240 × 480	120/240
240 to 480	0.5	13	120 × 240	120/240
120 to 240	0.5	14	120 × 240	120/240
480 to 600	0.8	15	240 × 480	120/240

This table provides data on standard dry-type, low-voltage (600 volt class) single-phase, two-winding transformers used as autotransformers. For step-up service the ratio of low voltage to high voltage in the first three listings is 0.5 and therefore the amount of kVA transformed is 50 percent of the total kVA ($1 - 0.5 = 0.5$). In the last listing the ratio is 0.8 and the kVA transformed is 20 percent ($1 - 0.8 = 0.2$). Output kVA to LOAD is 200 percent of the transformer nameplate rating in the first three listings and output is 500 percent in the last listing.

In Figures 12, 13, 14, 15, lead markings indicate relative directions in windings. If H_1 is the start of one high-voltage winding, H_2 is the end. H_3 and H_4 are the start and finish of the other high-voltage winding. X_4 is the start of the first low-voltage winding and X_3 is the start of the other low-voltage winding.

The two high-voltage windings are connected in multiple by connecting H_1 to H_3 and H_2 to H_4 . The two low voltage windings are connected in series by connecting X_2 to X_3 . The two windings thus formed are connected in series by connecting H_4 to X_1 , completing the autotransformer. The same logic can be applied for dropping voltages by applying the high-voltage connections to the supply and the load to the low-voltage connections.

2. Two-Winding Dry-Type Transformers as Autotransformers to Change Voltages on Three-phase Circuits

Single-phase transformers of standard service voltage ratings can be combined into banks of three-phase autotransformers in several ways.

Recommended connections are the T and the open delta. Not recommended are the wye, the closed delta, and the extended delta. These not-recommended connections require three transformers and realize less economy than the recommended connections which require only two transformers to make a three-phase bank.

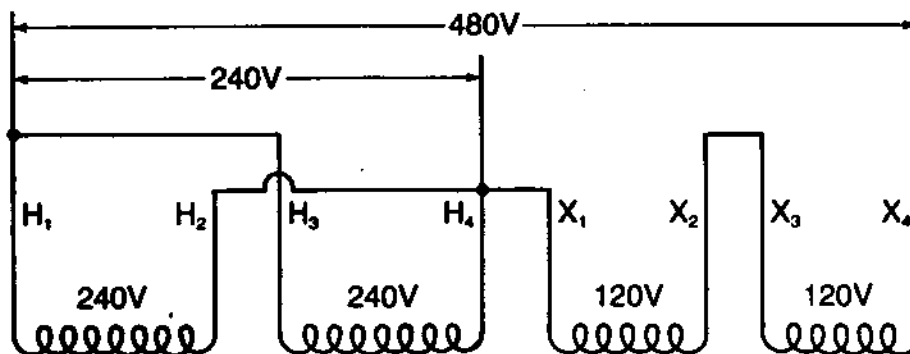


Fig. 12 – Autotransformer Connection of Two-Phase, Two-Winding Transformers to Transform 240 Volts to 480 Volts with 240 × 480 Volt Primary

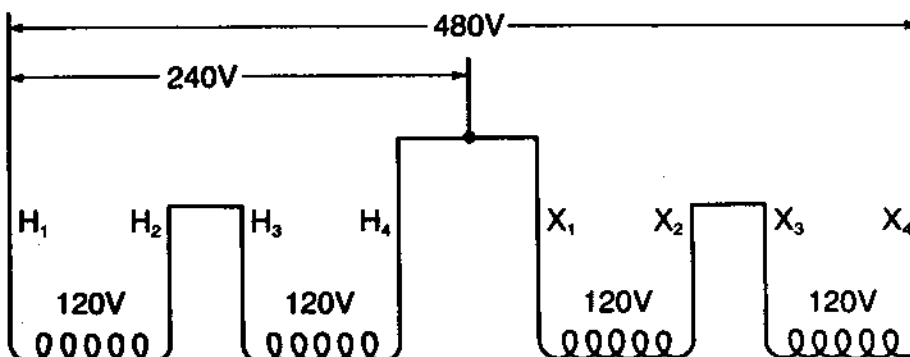


Fig. 13 – Autotransformer Connection of Two-Phase, Two-Winding Transformers to Transform 240 Volts to 480 Volts with 120 × 240 Volt Primary

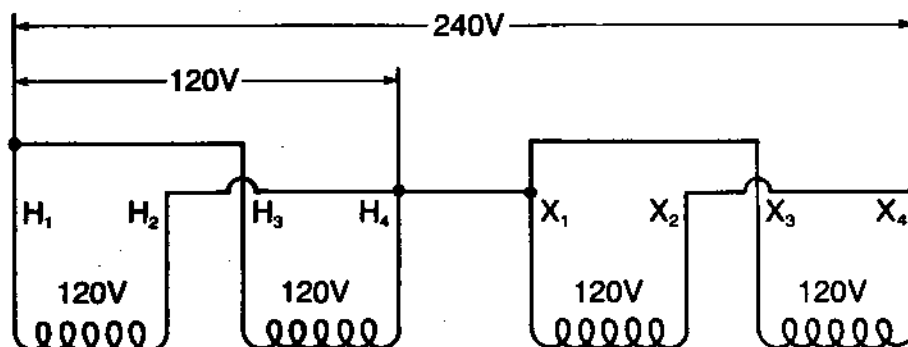


Fig. 14 – Autotransformer Connection of Two-Phase, Two-Winding Transformers to Transform 120 Volts to 240 Volts with 120 × 240 Volt Primary

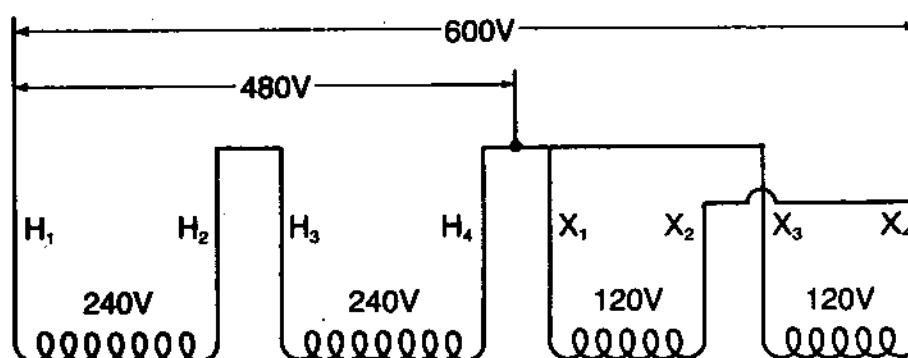


Fig. 15 – Autotransformer Connection of Two-Phase, Two-Winding Transformers to Transform 480 Volts to 600 Volts with 240 × 480 Volt Primary

Figure 16 is a diagram of the connection for two autotransformers in an open-delta bank for three phase conversion from 240 volts to 480 volts, using transformers rated 240 x 480 volts primary, 120/240 volts secondary. Lead markings indicate the relative directions in the windings. The high-voltage windings are connected in multiple, and the low-voltage windings are connected in series. The two groups of windings are connected series aiding (boost) to form the autotransformers. The H₇ points are connected together for the common line to form the three-phase bank. This connection provides a bank output kVA equal to 173 percent of the sum of nameplate ratings of the pair of two-winding transformers.

Figure 17 shows the connections for the same transformers in an open-delta autotransformer bank to provide three-phase conversion from 480 to 600 volts. This connection provides a bank output kVA equal to 433 percent of the sum of the nameplate ratings of the pair of two-winding transformers.

The T-connection for two autotransformers to provide three-phase conversion from 240 to 480 volts, using transformers rated 120 x 240 primary, 120/240 volts secondary, is shown in Figure 18.

All windings of each transformer are connected series aiding (boost) and the teaser unit is connected at midpoint of the main unit. In this connection the nameplate rating of each transformer should represent at least 28.85 percent of the bank output kVA desired, i.e., the bank output kVA is equal to 173 percent of the sum of the nameplate ratings of the two transformers (as in Figure 16).

Three-phase arrangements may be used to drop voltages by placing the load on low-voltage connections and the line on high-voltage connections.

3. 60 Hz Transformers on 25 Hz Circuits

When using a 60 Hz transformer on a 25 Hz circuit, a transformer rated at approximately double the voltage of the circuit would be required to prevent magnetic saturation of the iron core. This can also be accomplished by connecting two transformers of the same voltage in series. Refer to Figure 19.

4. Two-Phase Connections - Two Phase, Four Wire

Two phase, four wire is transformed to two phase, four wire of a different voltage with no connection between the phases in the connection shown in Figure 20.

5. Transforming Two Phase, Four-Wire to Two Phase, Three Wire

Shown in Figure 21, the two phases on the low-voltage side are electri-

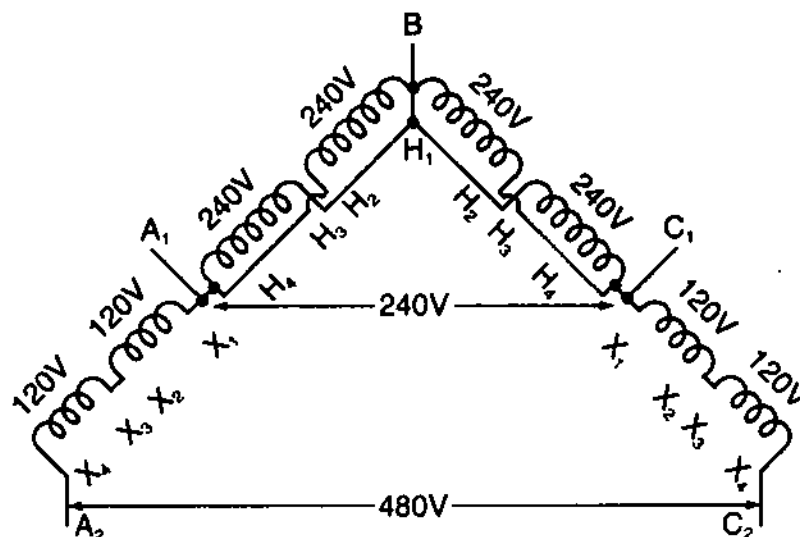


Fig. 16 – Two Autotransformers in an Open Delta Bank for Three-Phase Conversion, 240 to 480 Volts

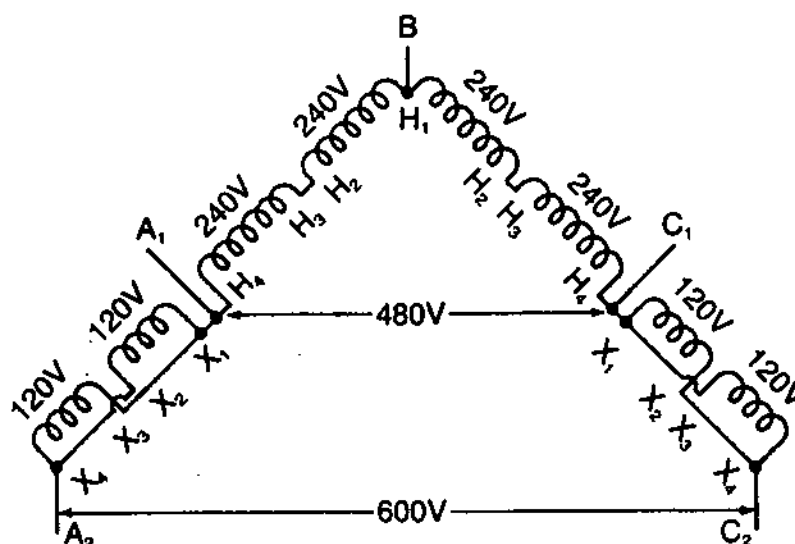


Fig. 17 – Two Autotransformers in an Open Delta Bank for Three-Phase Conversion, 480 to 600 Volts

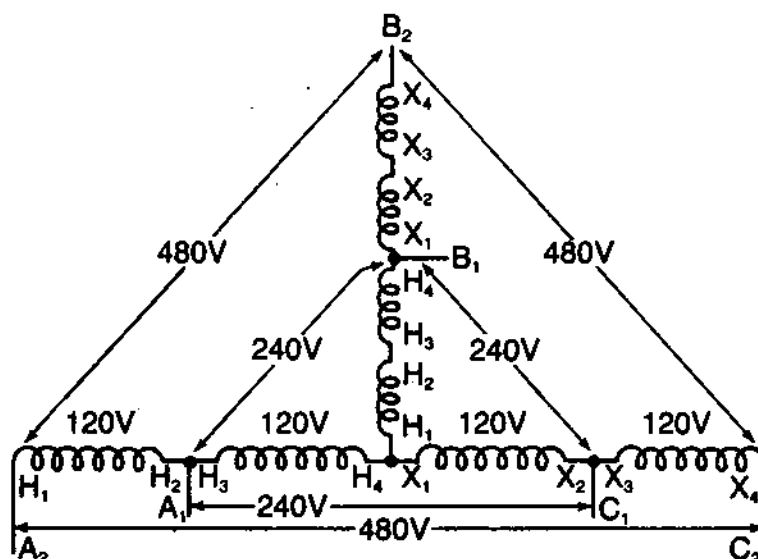


Fig. 18 – T-Connection for Two Autotransformers for Three-Phase Conversion, 240 to 480 Volts

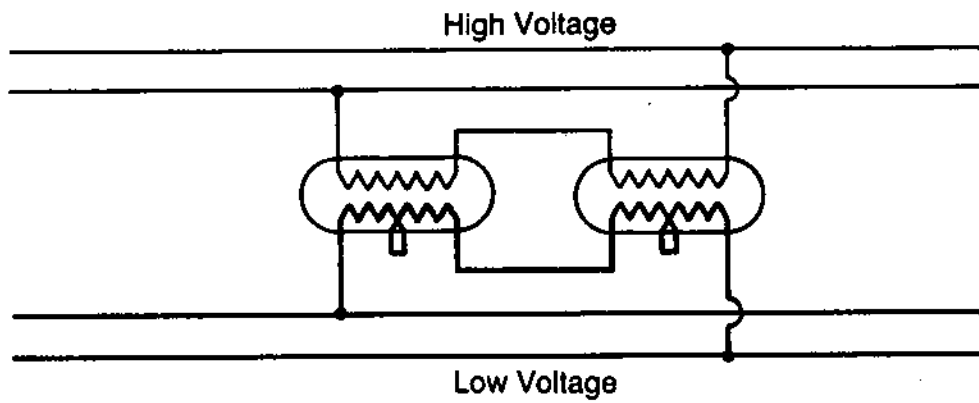


Fig. 19 – 60 Hz Transformers on a 25 Hz Circuit

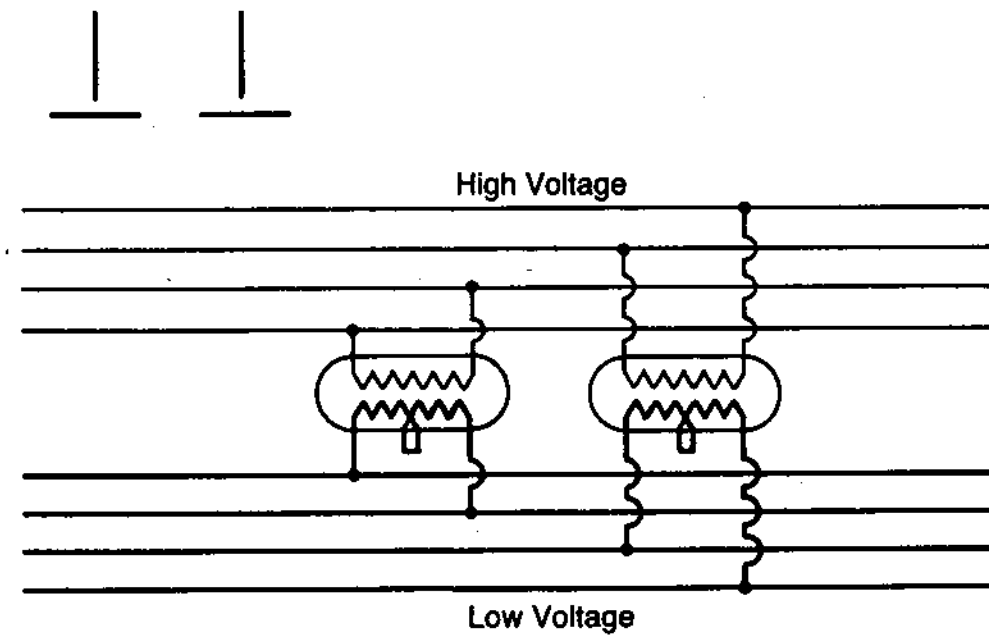


Fig. 20 – Two-Phase, Four-Wire Connection to Two-Phase, Four-Wire

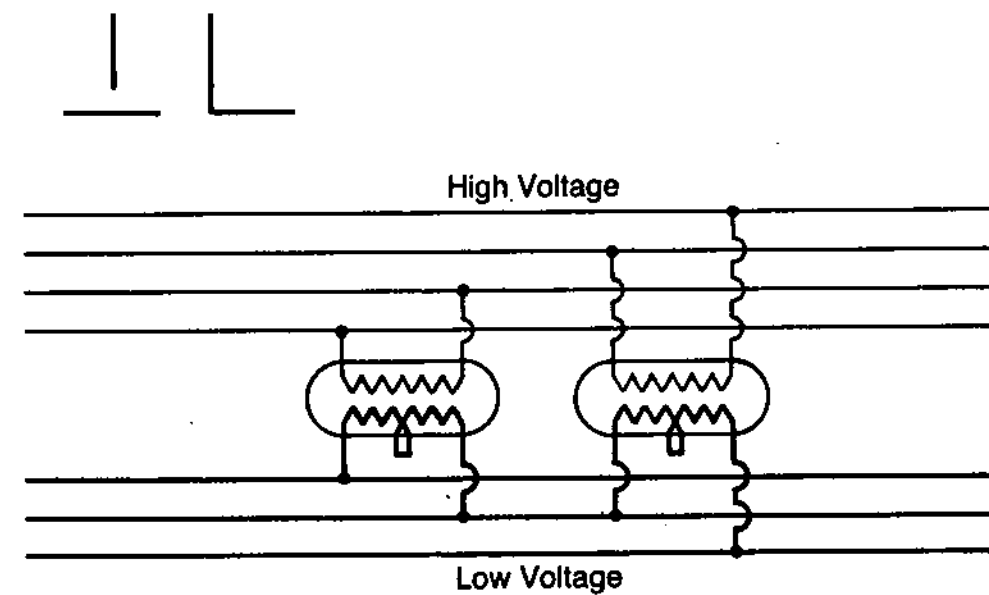


Fig. 21 – Two-Phase, Four-Wire Connection to Two-Phase, Three-Wire

cally tied together. The common third wire is sometimes grounded. With balanced load the current in the common wire is $\sqrt{2}$ times that in the outside.

6. Two Phase, Three Wire Interconnected

In the connection shown in Figure 22, the two phases are electrically tied together by the common third wire. This is permissible only in certain instances. The third, or common, wire is sometimes grounded. With balanced load the current in the common wire is $\sqrt{2}$ times that in the outside wires.

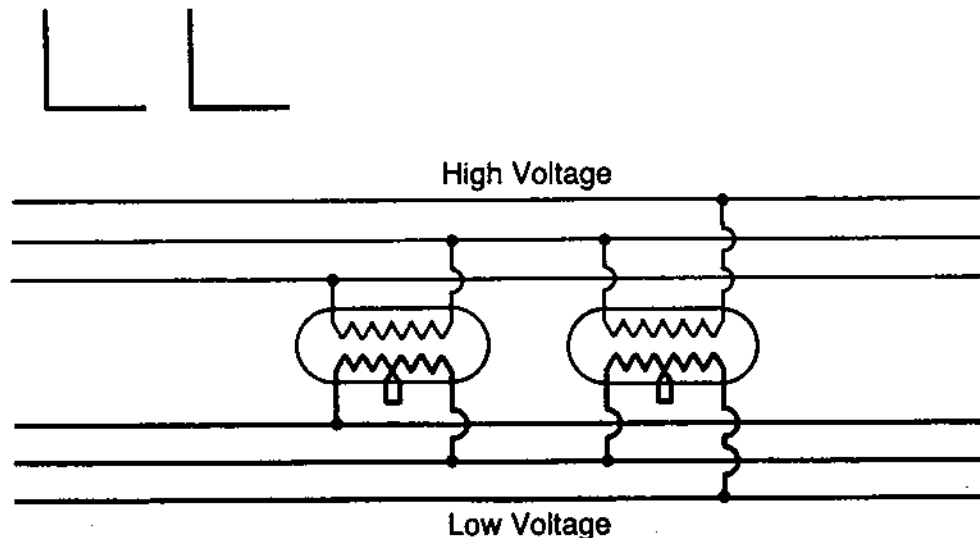


Fig. 22 - Two-Phase, Three-Wire, Interconnected

C. Three-Phase Connections

1. Three-Phase, Closed-Delta

Notice: When three transformers are operated in a closed delta bank, make certain that the impedances of the three units do not vary by more than 10 percent.

Transformers having more than 10 percent difference in impedance rating should not be operated together in a closed-delta bank unless a reactor is used to increase the impedance of the unit having the lower impedance rating to a value equal to the other two units.

If the voltage ratio of all three units is not the same a voltage will tend to circulate a current inside the delta. The current will be limited by the impedance of the three transformers considered as a series circuit.

Before connecting three transformers in a closed delta a fuse wire should be inserted between the ends of the two transformers closing the

delta bank. The fuse wire should be of sufficient size to carry the exciting current of the transformers. The use of this fuse wire is a simple way of making certain the transformers have the proper polarity. Refer to Figure 23 for this connection.

2. *Three Phase Open Delta*

Three phase to three phase may be transformed by use of two similar transformers in open delta connection. See Figure 24.

In this connection the units will transform 86 percent of their rating. Two 100 kVA units in open delta connection transforming three phase, 2300 volts to three phase 230-115 volts will have a bank capacity of 172 kVA.

In the open delta connection it is not necessary that the impedance characteristics be the same, but becomes so when the open delta must be closed with a third unit.

The open delta connection is often used as a temporary expedient pending a contemplated increase of load. By adding a third 100 kVA unit to the example above, the resultant bank capacity will be increased from 172 kVA to 300 kVA.

The regulation of an open delta bank is not as good as a closed delta bank. The drop across the open delta is greater than across each transformer separately.

3. *Three Phase; Star, Three Wire HV; Delta, Three Wire, LV Connection*

This connection is shown in Figure 25. When three transformers are operated with their high-voltage windings in star, the incoming line voltage is $\sqrt{3}$ or 1.732 times the transformer winding voltage. This connection is commonly used as a means of boosting the transmission voltage without purchasing additional transformers.

4. *Three Phase, Star Three Wire HV; Delta Three Wire, LV Connection*

This connection permits three-phase power to be transmitted at the star voltage. At the same time single-phase power can be taken from the mains by connecting the transformer between the neutral and any of the three-phase wires.

In this connection it is not necessary that the impedance of the three transformers be the same. The high-voltage neutral is usually grounded. Refer to Figure 26.

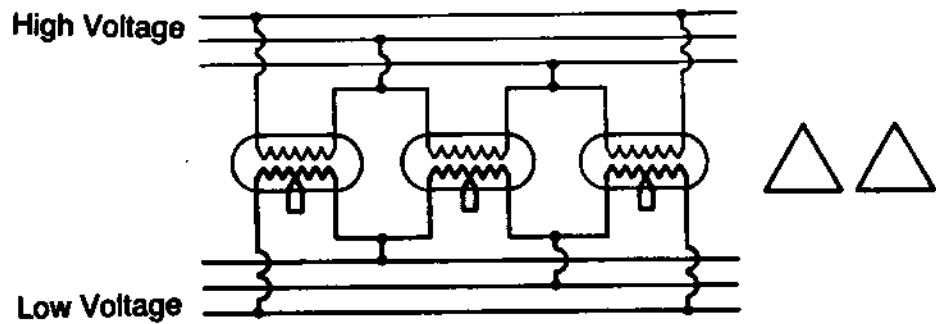


Fig. 23 – Three-Phase, Closed-Delta Connection

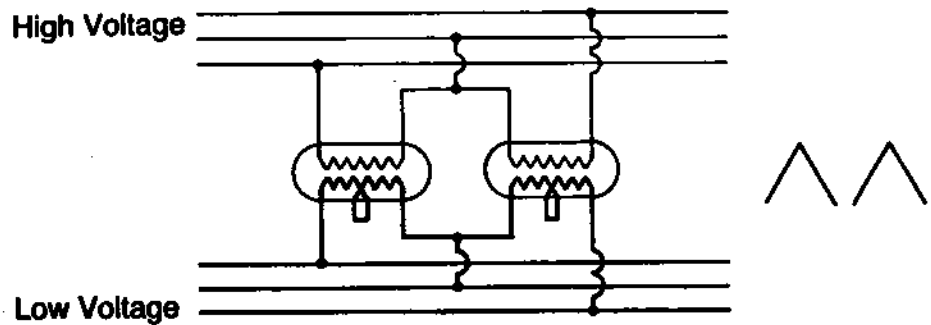


Fig. 24 – Three-Phase, Open-Delta Connection

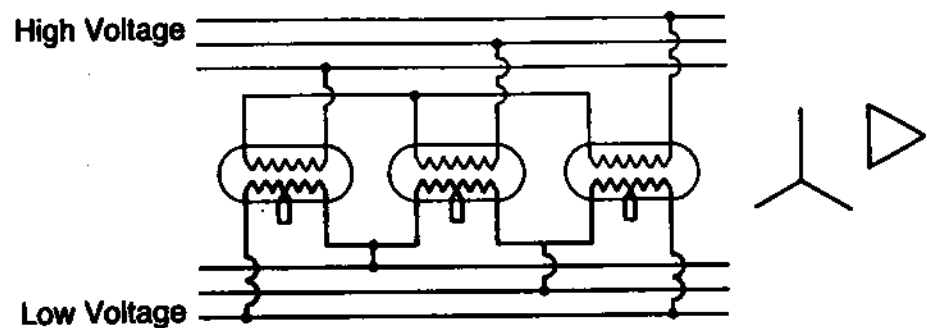


Fig. 25 – Three-Phase; Star Three-Wire High Voltage, Delta Three-Wire Low Voltage Connection

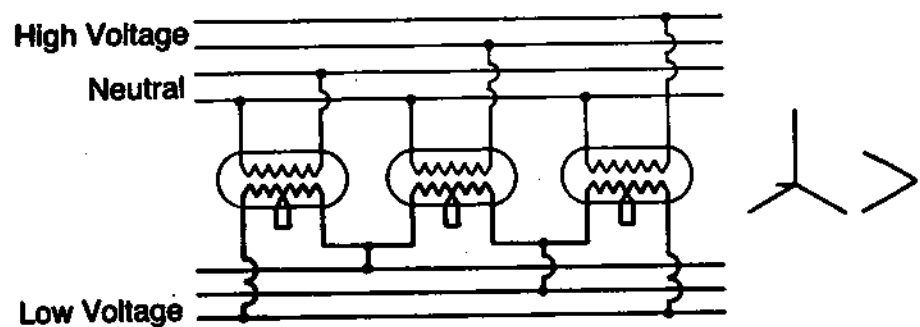


Fig. 26 – Three-Phase; Star Four-Wire High Voltage Connection, Delta Three-Wire Low Voltage Connection

5. Miscellaneous Connections

a. Three Phase; Star, Four Wire, One Leg Out, HV; Open Delta, Three Wire, LV Connection

Figure 27 illustrates this connection which is similar to a V connection. The primary of each transformer is connected between the neutral and one of the three-phase wires. The secondaries are connected to the secondary mains. This is the same as for the delta connection except that the third transformer is not used. The secondaries are in open delta. The two transformers will provide 86.6 percent of their combined rated capacity.

b. Three Phase; Secondary Star, Interconnected

See Figure 28. The primary side of this group may be connected in either star or delta. Each half of the secondary winding of each transformer has a voltage of 57.7 percent of the interconnected star voltage. A bank of transformers designed for connection in this manner must have a capacity of 7.5 percent greater than the kVA to be transformed.

The purpose of the interconnected star winding is to permit the unbalanced direct current from the third wire of the three-wire circuit of a rotary converter to get back into the alternating current system feeding the converter. Since this direct current divides into two equal parts in each transformer and these two parts flow in opposite directions magnetically, the direct current does not magnetize the core. If this current should flow in one direction through the winding, the d-c magnetic flux would add to the a-c flux and perhaps saturate the core.

c. Three Phase; Three or Four Wire Star-Star with Autotransformers

In this connection, Figure 29, the high- and low-voltage windings are electrically connected together, so the low-voltage side and connected apparatus will, under fault conditions, be subjected to the voltage of the high-voltage circuit.

There is less material used in the autotransformer than in a two-winding transformer to transform the same power. The saving in material is significant when the difference in primary and secondary voltages is small but becomes increasingly less as the difference between the primary and secondary voltages increases.

d. Three Phase; Three Wire Open Delta with Autotransformer

The high- and low-voltage windings are electrically connected together in this transformer connection as shown in Figure 30. The low-voltage

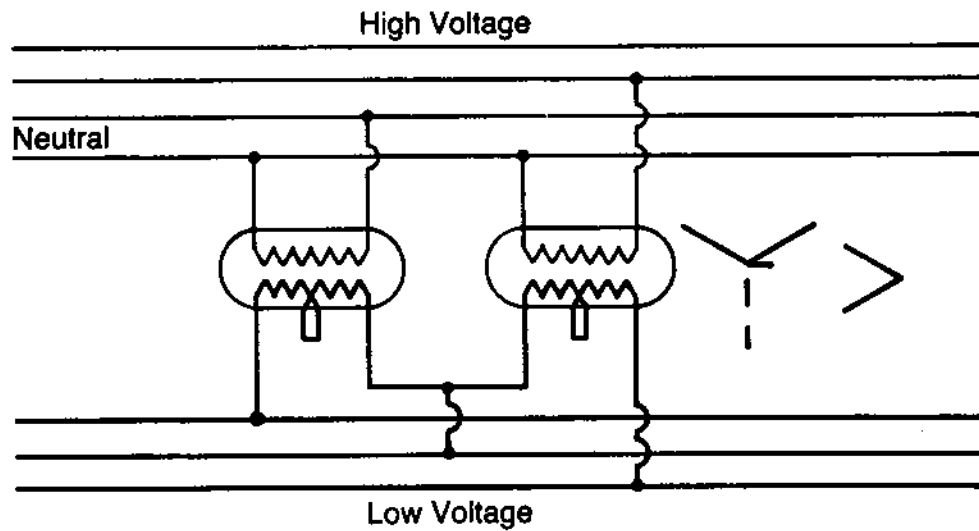


Fig. 27 – Three-Phase; Star Four-Wire, One Leg Out, High Voltage Connection, Open Delta Three-Wire Low Voltage Connection

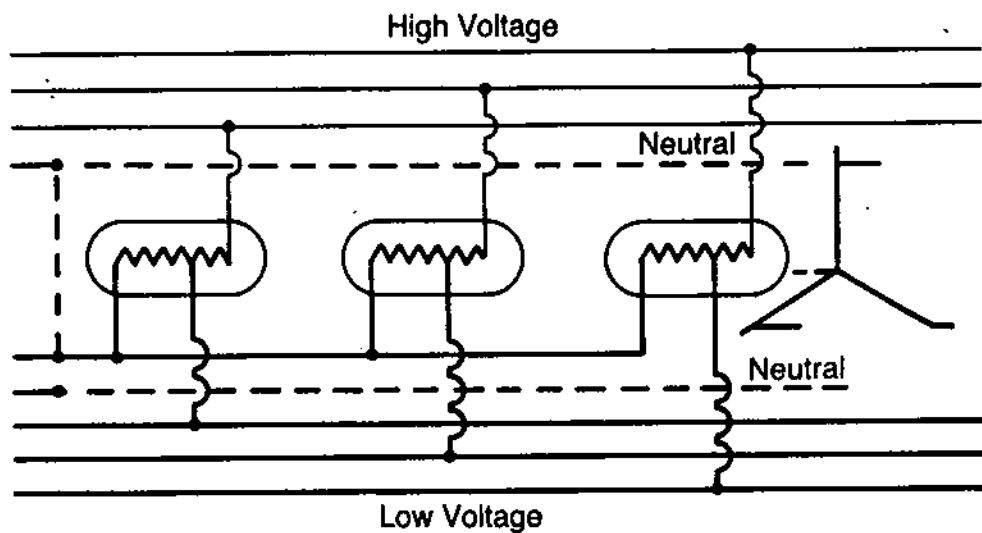


Fig. 28 – Three-Phase; Secondary Star, Interconnected

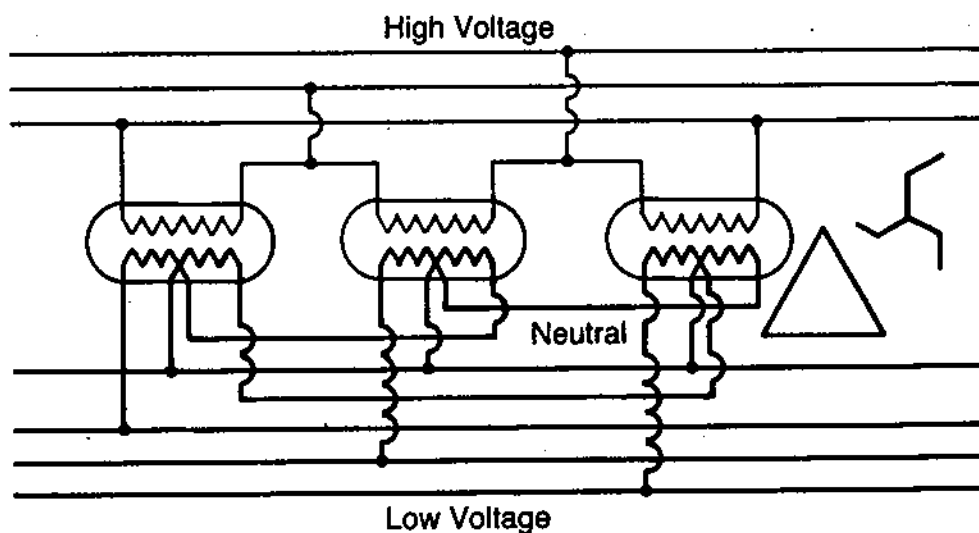


Fig. 29 – Three-Phase; Three- or Four-Wire, Star-Star with Autotransformers

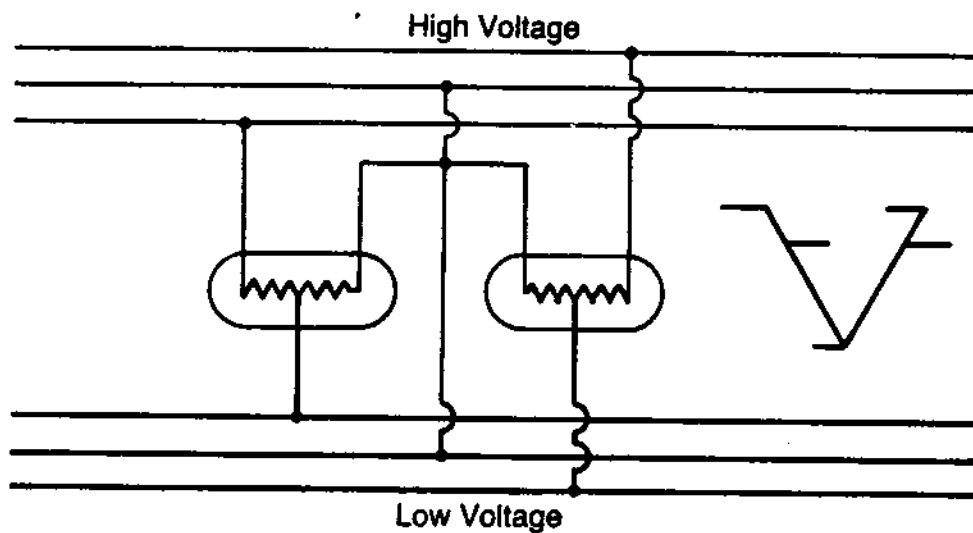


Fig. 30 – Three-Phase; Three-Wire Open Delta with Autotransformers

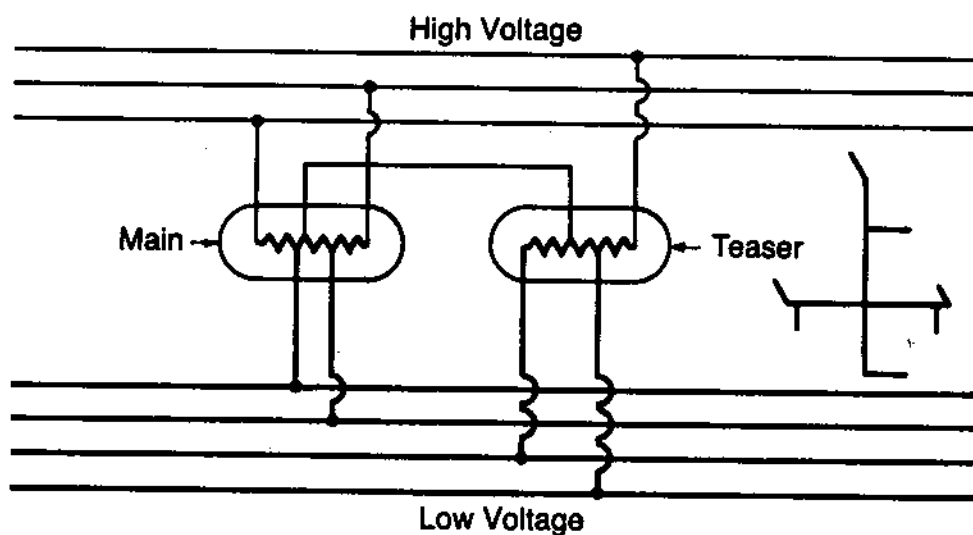


Fig. 31 – Three-Phase to Two-Phase, Four-Wire Interconnected By Autotransformers

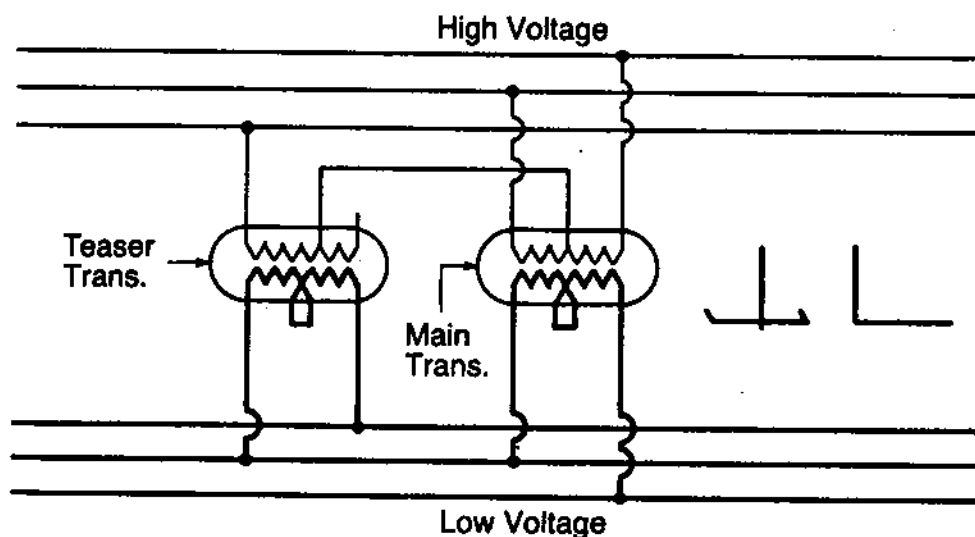


Fig. 32 – Phase Transformation; Two-Phase, Three-Wire to Three-Phase, Three-Wire or Scott, Three-Phase to Two Phase

side and connected apparatus will, under fault conditions, be subjected to the voltage of the high-voltage circuit.

Less material is used in the autotransformer than in a two-winding transformer to transform the same power. The saving in material is significant when the difference in the primary and secondary voltages is small but becomes increasingly less as the difference between the primary and secondary voltages increases. This connection requires 17 percent larger transformer capacity than the star-star autotransformer connection.

6. Autotransformers for Phase Transformation

a. Three Phase to Two Phase Four-Wire Interconnected

When phase transformation is required without any great stepping up or down of voltage, the autotransformer is the most economical and simple arrangement. The connection shown in Figure 31 has the windings on the two-phase side electrically connected together at their middle points.

b. Phase Transformation, Scott

Two phase, three wire to three phase three wire or Scott; Three phase, three wire to two phase, three wire

This is phase transformation from three-phase to two phase or two phase to three phase. Refer to Figure 32.

Either the primary or secondary side may be made three phase. The three-phase side must have special taps to make this transformation. One unit must have an 86.6 percent tap and the other unit must have a 50 percent tap. A three-wire circuit is used on the two-phase side. This circuit is formed by joining two of the wires forming the two phases, so the two phases are electrically connected together.

Dry-type transformers are designed so the full rated capacity of the bank can be utilized without exceeding normal temperature rises.

If the transformers are to be used with motors interconnected at mid-points, the connection shown in Figure 33 is recommended.

c. Phase Transformation, Scott;

Three phase, three wire to two phase four wire or Scott; Two phase four wire to three phase, three wire.

This connection is the same as **b.** above except the two-phase side is made four wire. In this arrangement the two-phase circuits are electrically separated.

d. Scott Transformation; Standard 10 to 1 Ratio

If a Scott transformation is desired, and a transformer and 86.6 percent tap is not available, a unit having a 10 percent tap or two 5 percent taps may be used to give approximate results. Connection illustrated in Figure 34. With this arrangement the two-phase voltages will be unbalanced by about 4 percent.

e. Fortesque Connection

This is a transformation from three phase to two phase using three transformers. See Figure 35. One transformer is standard the other two have special taps on the low-voltage side. One advantage of this connection is that both two- and three-phase current can be delivered at the same time. The total of the power delivered at two phase and three phase must be somewhat less than the normal ratings of the transformers so the transformers will not be overloaded.

f. Autotransformers for Phase Transformation, Three Phase to Two Phase, Four Wire.

This connection is the same as e. above except that the windings on the two-phase side are not connected together at their middle points, but the end of one phase is connected to the middle of the other phase. See Figure 36.

g. Autotransformers for Phase Transformation. Three Phase to Three Phase, Three Wire.

Where voltage change from primary to secondary is small, use of an autotransformer is more economical than two two-winding transformer. The primary and secondary windings are tied together electrically which may be objectionable in some instances. See Figure 37.

h. Phase Transformation using an Autotransformer. Three Phase to Two Phase

Figure 38 shows how two-phase voltages may be taken from a delta bank by the application of an autotransformer. The autotransformer is connected between the apex of the delta and the mid-point of the opposite side. This gives a 1 to 1 ratio which means that the two-phase and three-phase voltages on the low side are equal. The high-delta winding of the bank may be connected either star or delta. The two-phase and three-phase loads may be taken off simultaneously. If no load is drawn off at three phase, approximately 75 percent of the bank rating can be taken off at two phase.

i. Phase Transformation Using Standard Transformers of Different Voltage Ratings.

This is phase transformation from three phase to two phase employing standard transformers. See Figure 39. Transformer 1 is rated 4160 volts at 240/120 volts. Transformer 2 is rated 2400 volts at 240/120 volts. Each transformer will have a rating equal to one-half the two-phase load.

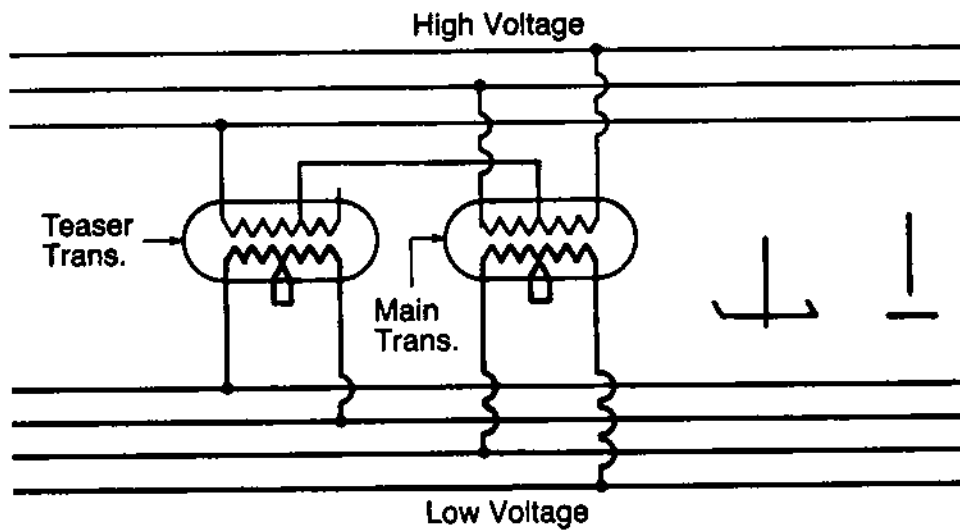


Fig. 33 – Phase Transformation: Scott

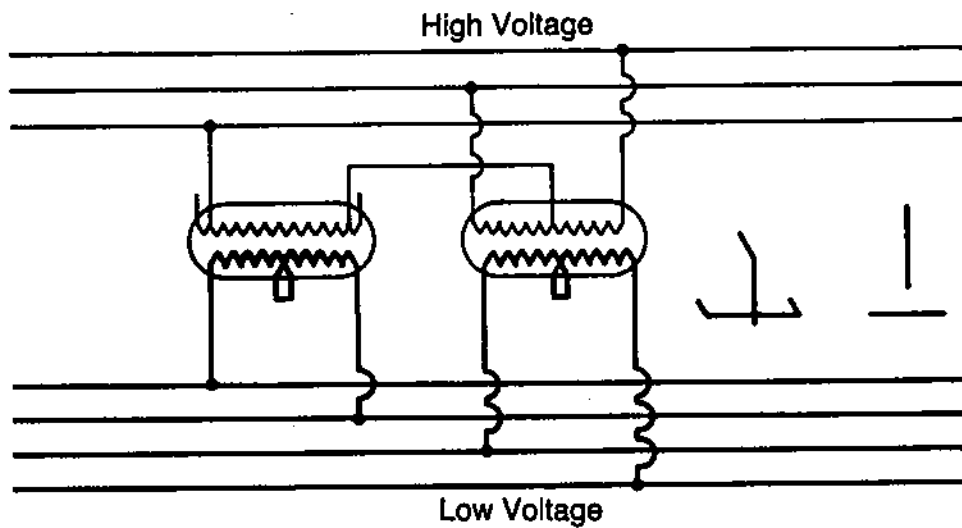


Fig. 34 – Scott Transformation; Standard 10 to 1 Ratio

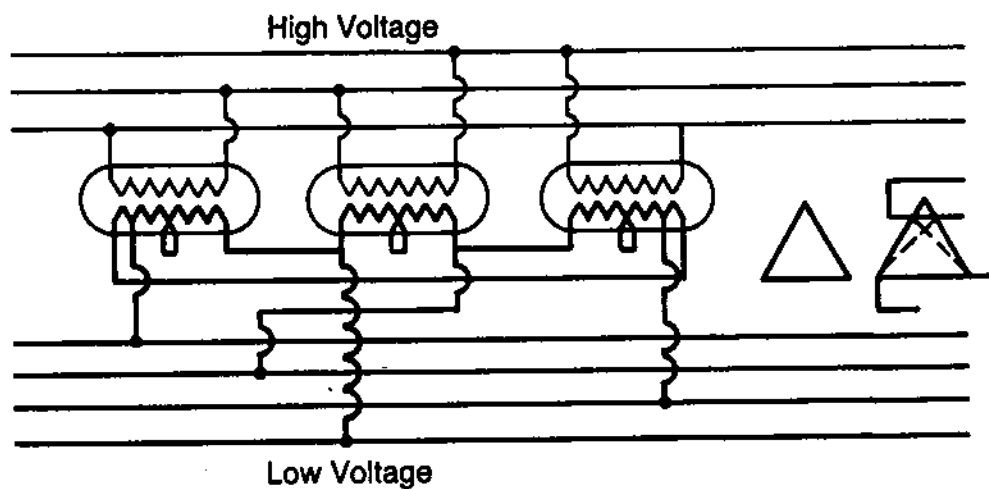


Fig. 35 – Phase Transformation: Fortesque Connection

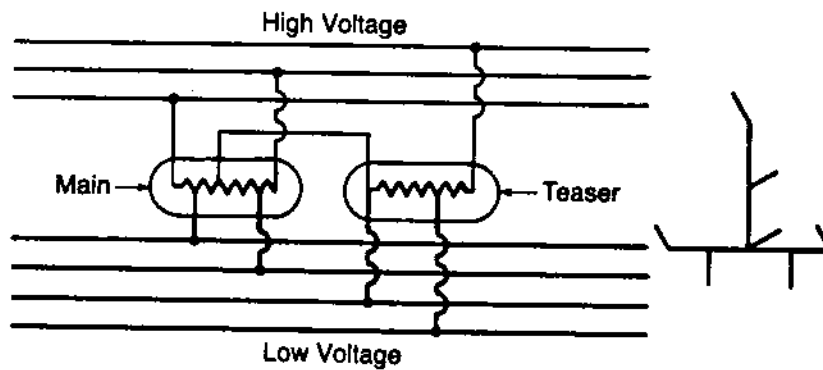


Fig. 36 – Three-Phase to Two-Phase, Four-Wire By Autotransformer

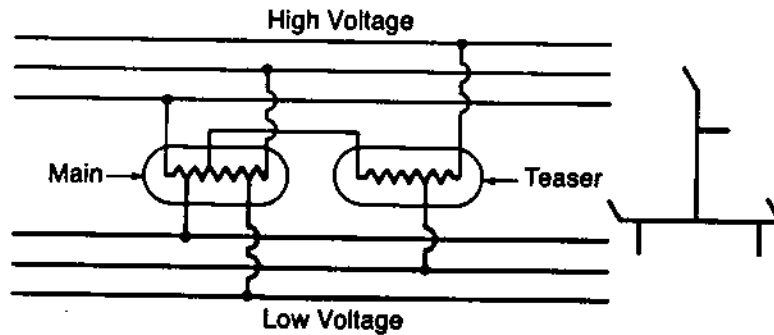


Fig. 37 – Three-Phase to Three-Phase, Three-Wire By Autotransformer

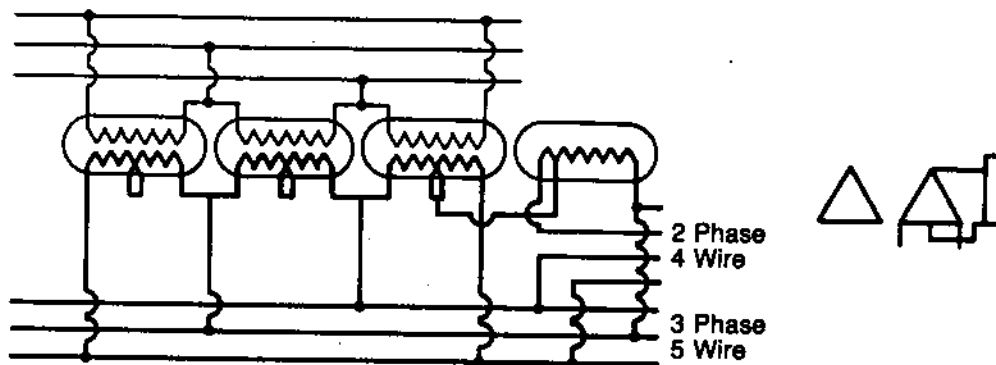


Fig. 38 – Three-Phase to Two-Phase From a Delta Bank By Autotransformer

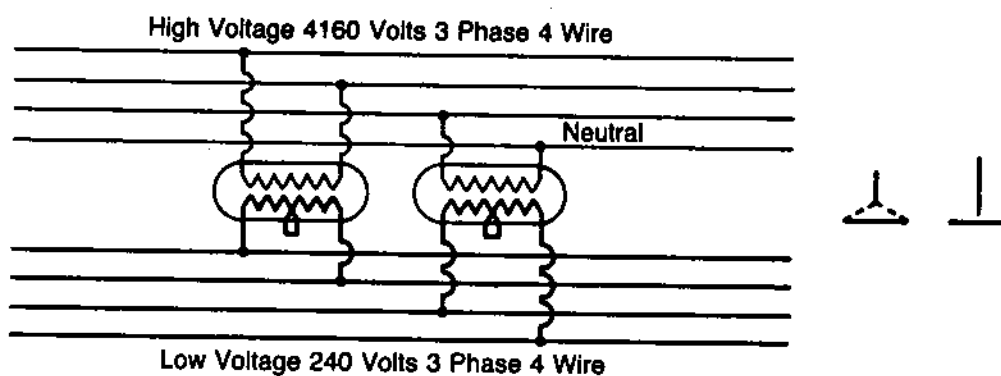


Fig. 39 – Phase Transformation Using Standard Transformers of Different Ratings

17.4 Testing

It is recommended that tests be conducted on a transformer before it is placed in service. This procedure will not only determine that it is in proper operating condition, but will also provide data for future comparison.

A. Minimum Tests

The minimum testing should include:

- Insulation Resistance Test
- Applied-Voltage Test
- Ratio Test

B. Additional Tests

The following tests can also be made if desired, they are recommended:

- Resistance Measurement of Windings
- No-Load Losses and Excitation Current
- Polarity and Phase Regulation
- Power Factor of Insulation

If these optional tests are made they should be made before making the applied voltage test.

Insulation resistance and insulation power factor tests are of value for comparison purposes in checking the condition of the transformer periodically. Since the power factor of the insulation system of a transformer is effected by many factors, such as the design of the winding, the type of insulating material, ambient temperature, humidity, time since being energized, and time of most recent cleaning, complete records of all these factors should be made at each testing.

C. Periodic Testing

As a matter of preventive maintenance, transformers should be tested periodically. Tests should also be made before reactivating a repaired transformer or one that has been out of service for any considerable length of time.

The frequency of inspection and test will be determined by the operating conditions. If the transformer is in a clean, dry location an annual inspection or even longer interval may be adequate. Less favorable operating conditions where the transformer is subjected to air containing dust, chemical fumes, or high moisture, inspection and test may need to be made as frequently as every 3 months.

Warning: Any transformer that has been wet or subject to abnormally high humidity must be dried out before any tests are made. Failure to do so can cause severe personal injury or death, and damage to property.

Minimum resistance values for the transformer should be included in the manufacturer's instructions. In the event they are not available, the following values may be used as a guide. These values are taken from ANSI/IEEE C57.94 and are based on tests made in accordance with C57-12.91.

Winding kV Class	Insulation Resistance-Megohms
1.2	600
2.5	1000
5.0	1500
8.7	2000
15.0	3000

The resistances of a normally dried transformer can be expected to be 5 to 10 times these minimum values.

D. References

For additional information on testing refer to the transformer manufacturer's instructions, *ANSI-IEEE Standards C-57 and C-68*, and *Westinghouse Electrical Maintenance Hints, Vol. 1 Chapter 10. Rehabilitation of Flood Damaged Equipment 10.16 to 10.25*.

17.5 Inspection and Maintenance

Warning: De-energize and ground transformer before attempting to inspect or work on it. The grounding must include the enclosure and all winding terminals. These connections must be removed before returning the transformer to service. Failure to heed this warning can cause severe personal injury or death, and damage to property.

A. Inspection

Like other electrical equipment, dry-type transformers require maintenance to assure successful operation. Inspections should be made at regular intervals and corrective or preventive action taken when necessary to assure continued proper operation. Under favorable conditions, clean, dry locations, annual or even less frequent inspections may be suffi-

cient. Under less favorable conditions more frequent inspections should be made. Experience and good records will indicate the proper schedule.

With the transformer de-energized, covers over openings in the case should be removed. Inspection should be made for dirt, especially accumulations on insulating surfaces and accumulations that may restrict air circulation, for loose connections, condition of terminal boards, and any signs of overheating or voltage creep over insulating surfaces. This is evidenced by tracking or carbonization. Evidence of rust, corrosion, and deterioration of paint should be noted and corrective action taken.

B. Cleaning

If excessive accumulations of dirt are found they should be removed to prevent possible insulation breakdown, and assure free air flow. The windings may be cleaned with a vacuum cleaner, blower, or compressed air. The vacuum cleaner is a preferred first step, followed by compressed air or nitrogen. The compressed air or nitrogen should be clean and dry and at a pressure not greater than 25 p.s.i. Major insulating surfaces should be brushed or wiped with dry, lint-free cloth. Liquid cleaners are not recommended because of their possible solvent or deteriorating effect on insulating materials.

C. Effect of Humidity

As long as the transformer is energized, humidity is not important, but if the transformer is de-energized and allowed to cool to ambient temperature, humidity must be considered.

If a shutdown occurs for more than 24 hours in a condition of high humidity, precautions must be taken to keep the transformer dry. Strip heaters placed in the bottom of the unit immediately after shutdown will maintain temperature a few degrees above ambient and prevent condensation. If precautions are not taken the unit must be inspected for evidence of moisture or low insulation resistance, before re-energizing. If found the transformer must be dried out.

D. Storage

Dry-type distribution transformers should be stored in a dry location with uniform temperature. Ventilating openings should be covered to keep out dust. If stored outdoors the transformer should be thoroughly protected to prevent moisture or foreign matter from entering. Condensation or absorption of moisture can be prevented or greatly reduced by installation of some form of heaters.

17.6 Drying of Transformer Core and Coil Assemblies

There are three methods of drying dry-type transformer:

Internal Heat

External Heat

External and Internal Heat

Before applying any of these methods, free moisture should be wiped or blown off the windings to reduce the drying time.

A. Drying By Internal Heat

Because it is fast and safe, drying by internal heat is the preferred method of drying a dry-type transformer in place. A source of impedance voltage is required and the transformer should be located where there is a free flow of air through the coils from bottom to top.

In this drying process one winding is short-circuited and enough voltage at normal frequency applied to the other winding to circulate 50 to 100 percent of normal current.

Winding temperature should not be allowed to exceed 100C (212F), as measured by resistance or by thermometers placed in the ducts between windings. The thermometers must not be of the mercury type because of the heat generated in mercury by induced eddy currents which would result in false readings. The end terminals of the windings must be used to assure circulation of the current through the entire winding.

B. Drying By External Heat

External heat may be applied to a transformer by one of the following methods:

(1) Directing heat into the bottom air inlets of the transformer case.

(2) Placing the core and coil assembly in a non-flammable box with openings at top and bottom through which heated air can be circulated.

(3) Placing the core and coil assembly in a suitably ventilated oven.

It is important that most of the heated air pass through the winding ducts and not around the sides. Good ventilation is essential to prevent condensation in the transformer or inside the case. A quantity of air should be used to assure approximately equal inlet and outlet temperatures.

When using either (1) or (2) external heating method, heat may be obtained by the use of resistance grids or space heaters. The heaters may be used inside the case or box or they may be located outside and the heated air blown into the bottom of the case or box. The core and

coil and any accessories must be protected from direct radiation from the heaters. Air temperatures should not exceed 110C.

C. Drying By Internal and External Heat

This is a combination method and by far the quickest. The transformer core and coil assembly may be placed in a non-flammable box or left in its case and external heat applied as described above. At the same time current is applied as described in the first method. The current required will be considerably less than when no external heat is applied, but must be sufficient to produce the required temperature of the windings. The temperature limits are those stated in the first two methods.

D. Use of Insulation Resistance to Determine Drying Time

Drying time is determined by the condition of the transformer, size, voltage, amount of moisture absorbed, and the drying method.

Warning: Before taking insulation resistance measurements, interrupt the current and short-circuit the winding for at least one minute to drain off any static charge. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Measurement of insulation resistance is a means of determining the status of drying. Resistance measurements should be taken before the drying process is started and at two-hour intervals during drying. The initial value may be high even though the transformer is not dry. Insulation resistance varies inversely with temperature so resistance is higher when the transformer has not been heated. The temperature should be kept as constant as possible during the drying process, so comparative readings will be meaningful. As the transformer is heated the presence of moisture will be evidenced by the rapid drop in resistance measurement. Following the initial drop in resistance readings the resistance will rise gradually until near the end of the drying process when it will increase more rapidly. Sometimes resistance readings will rise and fall through a short range as moisture in interior insulations works its way through previously dried portions.

A curve with time as the abscissa and resistance as the ordinate should be plotted and the drying process should be continued until the resistance readings level off and remain relatively constant for three to four hours.

Insulation resistance measurements should be taken for each winding to ground with all windings grounded except the one being measured. All readings should be for the same time of application, recommended one minute.

17.7 Special Applications

A. Direct-Current Generator Balance Coils

Three wire d-c circuits pose a problem of unbalance to the d-c generator source. A dry-type transformer can be used to distribute this unbalanced current evenly in the generator. For correct application the following characteristics must be known:

- Generator kW and Voltage Rating
- Generator Speed (rpm)
- Number of Poles
- Unbalance (in percent of generator kW rating)
- Number of Slip Rings

The connection is shown in Figure 40.

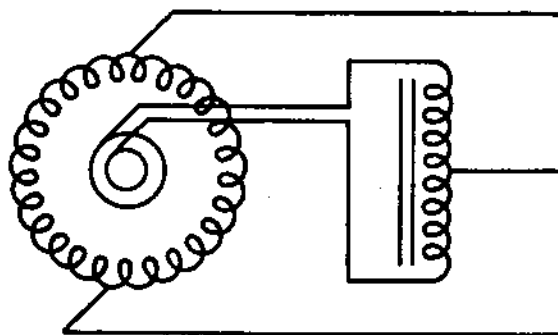


Fig. 40 – D-C Generator Balance Coil

B. Range Application

Electric ranges usually call for 120/240 volt, single phase, grounded neutral supply. Often only 208Y/120 is the source of power. Normally 120 volts can be supplied from line to neutral of the 208Y/120 system. Often a transformer rated 208 to 240 volts, single phase is requested to supply the 240 volt requirement. Since this is a small voltage transformation, an autotransformer is indicated. In this instance an autotransformer cannot be used, so when a range application is specified, a two-winding dry-type transformer rated 208 to 120/240 should be used. The connection is shown in Figure 41.

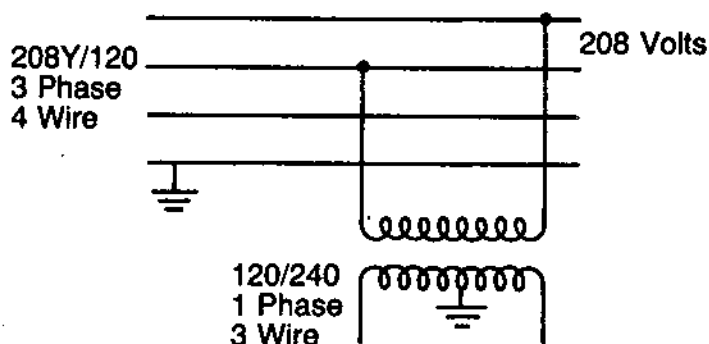


Fig. 41 – Range Application

Instrument Transformers

Insulation Test and Maintenance 2:18.1

Insulation Resistance 2:18.1

Insulation Power Factor 2:18.1

Oil Filled Instrument Transformers 2:18.4

Receiving Liquid Filled Instrument Transformers 2:18.4

Handling Liquid Filled Instrument Transformers 2:18.5

Storage of Liquid Filled Instrument Transformers 2:18.5

Installation, Solid Insulation and Liquid Filled Types 2:18.6

Electrical Tests Before Energizing 2:18.8

Vacuum Filling Liquid Filled Transformers 2:18.9

Maintenance 2:18.10

Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, or property damage.

Instrument Transformers

Electrical measurements of high amperages and voltages are safely and economically made when the measured values are not dangerously high. The most frequently used means of reducing these high voltages and currents is through the use of instrument transformers. Through the use of these transformers proportional samples are made available for instruments to measure. The high line voltages are connected to the primary winding terminals of a voltage transformer and measurements made by instruments connected to the secondary terminals. To measure current, the high line currents are connected to the primary terminals of a current transformer and the measuring instruments are connected to the secondary winding terminals. Figure 1 shows typical tube and bar type current transformers.

18.1 Insulation Test and Maintenance

To provide reassurance of the adequacy of transformer insulation for service, certain field tests can be made:

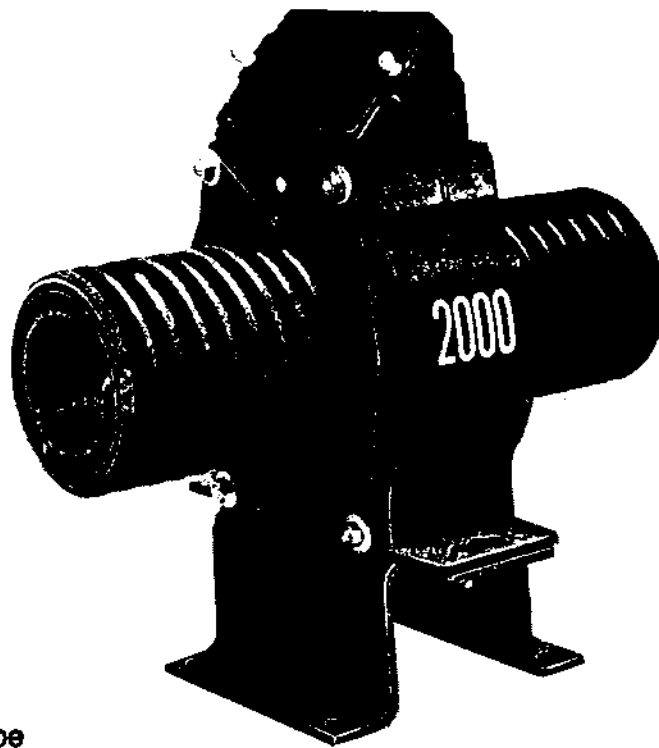
Warning: Do not attempt to make transformer insulation tests while the transformer is energized. Make sure it is de-energized and will remain de-energized until the testing is completed. Failure to heed this warning can cause severe personal injury or death, and damage to property.

A. Insulation Resistance

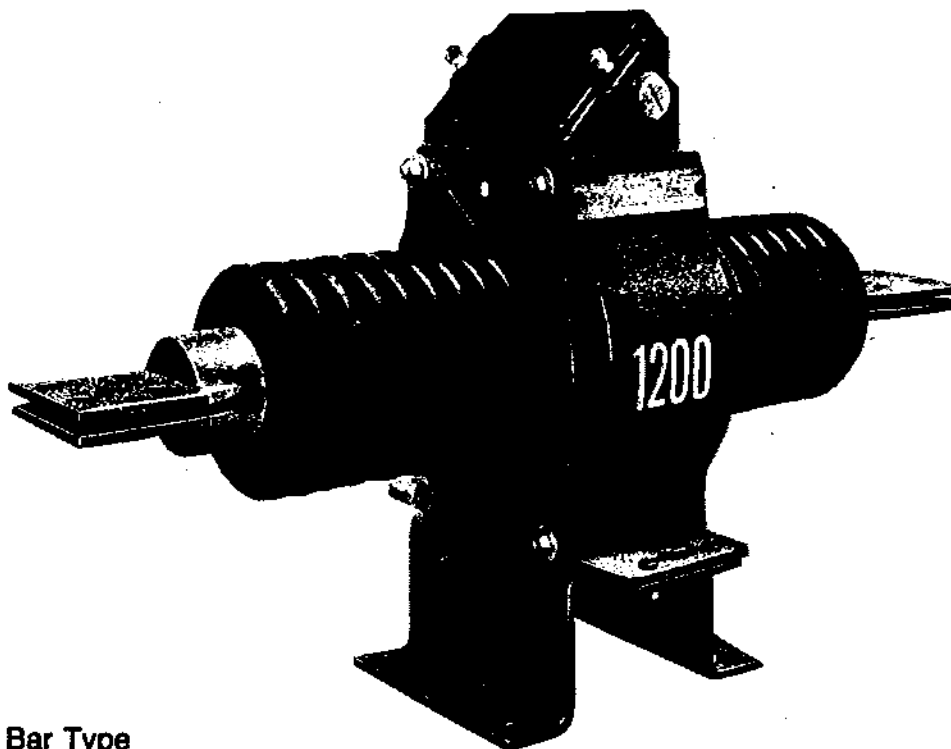
Resistance of the insulation can be measured with a megohmmeter. Measurements should be made of each winding to ground with all other windings grounded. Do not use an instrument whose terminal voltage is in excess of that which it is safe to apply to the equipment to be tested. Typical readings from high voltage winding to low voltage winding and ground, should be above one megohm per volt at 25C. Technical data is usually available from the transformer manufacturer if needed.

B. Insulation Power Factor

Only dielectric loss should be measured in the determination of insulation power factor, but certain spurious losses should be recognized and eliminated.



Tube Type



Bar Type

Fig. 1 - Typical Tube and Bar Types of Current Transformers

1. *Conduction over terminal insulation* due to rust and dirt. If the contamination is on the terminals or on porcelain it can be eliminated by cleaning. If the contaminated surfaces are covered with varnish or plastic, there may be moisture trapped in the protective coating and cleaning will be much more difficult.

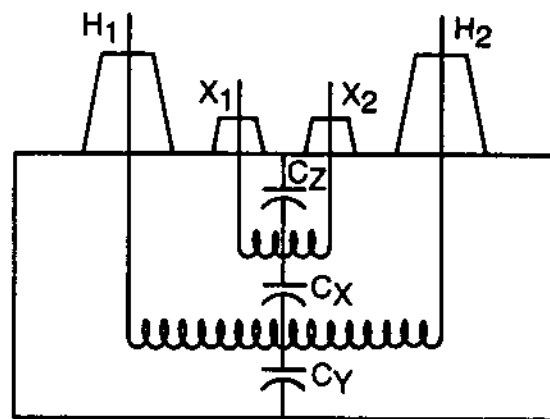
2. *Semiconducting material nearby*, wood or concrete near the transformer, becomes part of the dielectric circuit and can easily double the measurement of dielectric loss. Correct test procedure requires taking the transformer out of shipping crates and mounting it on a grounded plate with no concrete or wood nearby. Even close proximity of test equipment or personnel can affect power factor test results.

3. *The dielectric charging current*, particularly on voltage transformers, can easily magnetize the core and cause iron loss as large as the electric loss. Tests on any winding to ground should be made with all windings short circuited, and all windings, except the one on test, grounded.

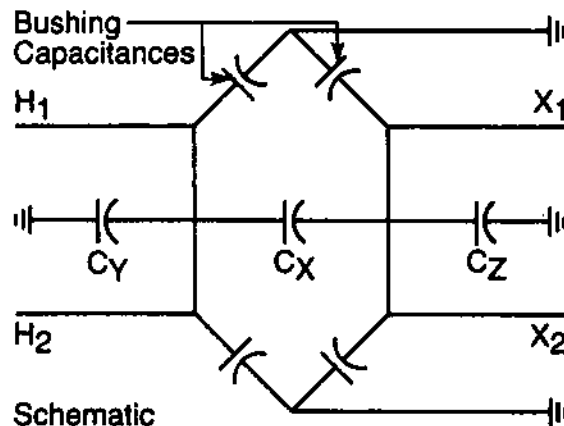
4. *Insulation Power Factor will usually increase with temperature increase*, and the increase depends upon several factors.

Usually if the insulation power factor has increased because of moisture, the readings associated with an increase in temperature will increase even more. If the insulation power factor measurement of equipment in service seems to show a dangerous increase, it is necessary to permit the equipment to cool to 20C or 25C to get a measurement that can be compared.

Depending on the adequacy of the test set, the insulation power factor of various parts of the insulation system may be measured separately. The measurement of most interest is that reflecting the condition of the overall power factor. Figure 2 is a diagram of a typical transformer and an equivalent circuit which includes the capacitances of the principal components of the insulation. Separation of these various capacitances may, in case of a sudden increase in power factor, permit a better estimate of which part of the insulation has deteriorated. This determination is usually of small practical value in instrument transformers outside the manufacturer's laboratory.



Pictorial



Schematic

Fig. 2 – Equivalent Capacitive Circuit of a Transformer

18.2 Oil Filled Instrument Transformers

Oil filled instrument transformers present requirements not found in transformers with dry type insulation, or gas filled transformers.

A. Receiving Oil Filled Transformers

When received, transformers should be thoroughly inspected for evidences of damage in transit. The transformers should be checked for:

Indications of external damage.

Paint finish damage.

Damaged gauges, valves, fittings.

Evidence of liquid leakage.

Porcelains shipped, cracked, otherwise damaged.

All damage or suspected damage should be reported immediately to the delivering carrier and to the manufacturer.

B. Handling Liquid Filled Instrument Transformers

Acute tilting of liquid filled instrument transformers should be avoided. Tilting may result in any air in the gas space being forced into the insulation structure. If excessive tilting is unavoidable, remove the filling plugs at the top of the unit and fill the expansion caps completely full of clean, dry transformer insulating oil. Use the same oil as the transformer was filled with at the factory. After installation, the excess oil added must be drained to restore the proper level to leave room for expansion. Drain out the same amount of oil as was added.

High voltage units may be too high for upright shipment. They will be crated for horizontal shipment and filled with dry nitrogen under slight pressure. When these units have been set upright and uncrated, they must then be handled in the normal upright position.

Lifting hooks or eyes are provided for crane lifting. When the transformer is lifted, all hooks and eyes, and only hooks and eyes should be used. When transformers cannot be moved by crane, they may be skidded or moved on rollers. Great care must be taken not to damage the tank or tilt the transformer. Transformers should not be lifted or moved by jacks and no mechanical force should be applied to the leads or bushings.

If the center of gravity is high, a lifting cable guide should be used to prevent accidental tipping. These transformers should not be moved by skidding or on rollers because of their instability.

C. Storage of Liquid Filled Instrument Transformers

A transformer stored in liquid can be made ready for service at any time by completing the installation steps, provided it has received the same inspection, test, and maintenance as a transformer in service.

1. Storage in Oil

If the transformer is to be stored for more than three months it must be completely filled with oil. Filling procedures are outlined below under *Installation, 18.2, F.*

2. Temporary Storage in Nitrogen

If a transformer cannot be installed immediately upon delivery, and oil filling is impractical, it is permissible to store it in nitrogen for as long as three months.

Storage in nitrogen requires positive assurance that the gas pressure is continuously maintained. The best method of accomplishing this is to

use pressurized gas from a cylinder fed through a valve to the transformer tank. Temporary pipe connections can be made using the vacuum and oil filling connections in the cap at the top of the high voltage bushing.

The transformer must rest on a solid, level foundation during storage. The HV bushing and the transformer tank should be grounded.

The dry nitrogen constant pressure equipment should be installed within a week after delivery of the transformer. Following installation of this equipment the transformer should be pressure tested for four hours at six psig using a full cylinder of dry nitrogen. All leaks in the system should be stopped. Maintained gas pressure, after testing is completed, should be three psig.

Transformer gas pressure and cylinder pressure should be recorded daily for the first two weeks of storage. Readings should be taken at the same time each day and the pressure and the temperature should be logged. After two weeks of daily logging with conditions stable, the frequency of pressure and temperature readings can be reduced to once a week. An accurate log is important as it will reveal any trend in the pressure in the system and it may be the determining factor in any decisions for additional drying of the windings when the transformer is to be energized. The transformer should not be stored for longer than three months without being filled with oil.

To place transformers in service after temporary storage in dry nitrogen, the same procedure should be followed as for transformers that have just been delivered. When vacuum filling (see below, under *Installation 18.2, F*) with oil, the length of the vacuum period prior to oil filling should be increased to six hours and the post filling or tail vacuum period should be extended to two hours.

D. Installation – Solid Insulation and Liquid Filled Types

Before installation is started a careful inspection should be made for breakage or damage during storage. Particular attention should be given to possible oil leaks. If the transformer was stored in oil, a lowered oil level or other evidences of leakage will be apparent. All accessible bolts, nuts, and studs should be checked for tightness.

Transformers should be installed on solid supports and all connections made in such a manner that no mechanical stress is placed on the leads or terminals of the transformer.

1. *Grounding the Secondary Circuit and Tank*

Although the secondary circuit and the transformer tank are insulated from the high voltage, they are coupled to it electrostatically. The windings of the transformer may be seen as plates of a capacitor. The electrostatic voltage from the secondary winding to ground will depend on the relative capacitances and may readily reach dangerous and destructive values unless the secondary winding is connected to ground.

One terminal of each secondary winding should always be grounded. The tank should also be solidly grounded. A ground pad is provided near the base of the transformer for the purpose of grounding the tank.

Warning: Make sure the transformer tank is grounded at all times. Failure to ground the tank can result in generation of currents that can cause severe personal injury or death, and substantial damage to property.

2. *Connection of Current Transformer Secondary*

Warning: Never leave the secondary winding of a current transformer or separate secondary windings of a multiple secondary current transformer open circuited. To do so can allow the development of dangerous and destructive voltages which can cause severe personal injury or death, and substantial damage to property.

The secondary windings of a current transformer (or any secondary winding of a multiple secondary current transformer) should never be left open circuited. If the secondary circuit is opened the impedance of the burden in effect becomes infinite, and if the primary winding is carrying current the current transformer tries to supply infinite voltage. Although practically the voltage is limited, oil immersed transformers generally can develop more than 5000 volts (crest value) which is dangerous.

3. *Connection of Voltage Transformer Primary*

The primary terminals of a fully insulated two-bushing voltage transformer are connected to high voltage lines. In the case of a graded insulation single-bushing voltage transformer the fully insulated terminal is connected to the high voltage line and the reduced insulation terminal is solidly grounded. This ground consists of a copper strap connecting the reduced insulation terminal to the tank. This ground connection and the tank ground must always be in place when the transformer is energized.

Warning: Always solidly ground the reduced insulation terminal of a graded insulation transformer. Failure to ground the neutral bushing will result in dangerous voltages that can cause severe personal injury or death, and substantial property damage.

4. Connection of Voltage Transformer Secondary

Warning: Never short circuit the secondary winding of a voltage transformer. To do so will cause the winding to burn out and the transformer to fail which can cause severe personal injury or death, and substantial property damage.

As in any transformer secondary short circuit, a short circuit of a voltage transformer secondary produces a burn-out in a very short time. Accidental short circuits do occur, and the transformer windings are designed to withstand the large mechanical forces which result, but they cannot be practically designed to carry the short circuit for longer than one second, long enough for protective devices to react and take it off the line, but not long enough if it is deliberately shorted.

E. Electrical Tests Before Energizing

If the transformer has been shipped or stored filled with oil, a sample of the oil should be analyzed not more than thirty days before energizing.

Instrument transformers are sealed pressure tight so the internal pressure and oil level will vary with temperature. In cold weather the units are expected to be under negative pressure.

Warning: Neutralize the internal pressure in a transformer before taking an oil sample. Failure to do so could result in a forceful ejection which can cause severe personal injury or death, and substantial damage to property.

Pressure, either positive or negative, can be neutralized by opening a filling plug located on the top of the bushing cap. This should be done before taking oil samples. The filling plug should be opened only in dry weather. Do not take oil samples on days of high humidity. Once the cap has been opened the sample should be taken promptly and the cap replaced. Teflon® ribbon, or equivalent, should be used on the cap threads to prevent entrance of moisture. Pipe plugs must be fully tightened.

The sampling procedure should begin with draining and discarding approximately one pint of oil from the drain valve to assure that the oil being taken is not that stored in the sampling pipe. The sample then taken must be taken in a dry, contamination-free, approved oil sample bottle.

The oil sample must be tested for dielectric strength per ASTM D877 and it is recommended that moisture be measured per ASTM 1533. Safe limits are 30 kV minimum dielectric strength and 25 parts per million maximum moisture content.

This oil test can be made with a standard oil test cup. ①

Insulation tests on transformer windings should be made with the windings under oil.

F. Vacuum Filling Liquid Filled Instrument Transformers

The procedure described here is general and typical. Specific transformers may have special requirements. The transformer manufacturer's instructions should always be consulted and followed.

This procedure should be undertaken only after the transformer is in an upright position, and preferably permanently installed on a firm foundation. The temperature should be at least 10C above the dew point. ②

Equipment required:

Vacuum pump capable of maintaining a vacuum of not more than two Torr absolute.

A gauge that will read absolute pressure.

Shut-off valve for oil line.

Oil trap for vacuum line.

Piping and fittings, 2-inch diameter.

Drain all residual oil from tank. This will relieve the positive nitrogen pressure.

Remove the pipe plugs in the cap, attaching the oil line to one and the vacuum line to the other. Close the shut-off valve on the oil line and start the vacuum pump.

After a vacuum of 2 Torr has been reached, close the vacuum line and observe the rate of rise of the absolute pressure. If the pressure rises as high as 25 Torr in 30 minutes, leaks are present and they must be located and stopped.

After obtaining an absolute pressure of 2 Torr in the transformer tank the vacuum should be maintained for at least four hours. The filling may then begin.

①For more complete information on testing insulating oil refer to *Westinghouse Maintenance Hints, Vol. 1 Ch. 6, Insulating Materials.*

②For additional information on vacuum filling procedures refer to *Westinghouse Maintenance Hints, Vol. 3, Ch. 4, Power Transformers.*

Open the shut-off valve on the oil line slowly so the vacuum does not fall below three Torr or the rate of filling exceed five gallons per minute. Oil should not spray in front of the vacuum opening and must not be allowed to overflow into the vacuum line. The trap in the vacuum line will protect the pump.

Oil should be admitted into the transformer until it reaches the level established at the factory, adjusted for any variance from the factory temperature when the level was established.

After the oil reaches the proper level and the oil line shut-off valve is closed, vacuum pumping should continue for an hour. Break the vacuum with dry nitrogen.

The transformer should be filled with oil which is at least at the temperature of the transformer, but never below 20C.

If the ambient temperature varies greatly from the temperature at which the oil level was originally established, the oil level should be rechecked when the average ambient temperature is near the factory temperature at the time of original filling. The oil level should be corrected by adding or draining if necessary.

The transformer should be sealed at atmospheric pressure.

G. Maintenance

Warning: Do not attempt to do any maintenance or inspection work on an instrument transformer unless it is de-energized and will remain so during the work or inspection period. Failure to heed this warning may result in severe personal injury or death from electric shock, and damage to property.

Modern transformers are sealed to prevent entrance of moisture and the oxidation of the oil. This eliminates the deterioration of the oil, and oil maintenance is normally unnecessary. A periodic check of the oil level is usually all that is required. In the event of doubt as to whether a leak has occurred and moisture has entered, a measurement of oil dielectric strength and insulation power factor should be made.

1. Insulation power factor should be measured only after the transformer has been disconnected for several hours and has attained a uniform temperature. The power factor (H to L + Grd) corrected to 20C should be approximately 1 percent or lower.

Transformers with a record of increased power factor from one check period to the next may have to be removed from service and dried. If measurements indicate that moisture is entering the transformer, the first action is to find the leak and eliminate it; the second to dry the transformer out. The means to be used depend on the type of transformer and equipment available.

Drying in a vacuum oven after draining the oil is the ideal method, 24 hours at 90-100C in a vacuum (711.2 Torr mercury or better) will usually dry a transformer.

If a vacuum oven is not available, application of vacuum to the tank for 48 hours after draining the oil will dry moisture that has entered recently. Other means can be suggested by the manufacturer depending on circumstances.

Notice: Heating the transformer at a temperature of more than 100C in air can cause sufficient chemical change in oil-impregnated insulation that the power factor will increase instead of decrease.

After the transformer has been dried it should be refilled in accordance with the procedure outlined under *Vacuum Filling*, above.

2. Taking Oil Samples

Warning: Neutralize the internal pressure in a transformer before taking an oil sample. Failure to do so could result in a forceful ejection which can cause personal injury or property damage, or in the event of negative pressure, introduce air or contaminants into the transformer oil.

Oil filled instrument transformers are sealed pressure tight so internal pressures and oil levels will vary with the temperature. In cold weather the units are expected to be under negative pressure. The internal pressure must be neutralized by opening the filling plug located above the oil level.

After taking the oil sample follow the procedure given under *Electrical Tests Before Energizing, 18.2-E* above, before re-energizing.

3. Refinishing Notes

Any portion of the paint film damaged during shipment or installation should be repaired promptly. To repair, clean the damaged area by the best means available, i.e., sandpaper, scraper, blasting, etc. If the paint film is broken to the metal, apply a coat of primer, intermediate, and finish coats with appropriate drying between coats. Surface scratches and mars can usually be repaired by application of the finish coat only.

During the installation procedure, all exposed nuts and bolts should be given a finish coat of paint. Aerosal dispenser cans are ideal for this type of painting.

The life of transformer paint, while long, is limited. The paint should be maintained by periodic inspections, touch-ups, and repainting when needed.

Electrical Instruments

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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Electrical Instruments

19.1 Types of Instruments

There are three basic functional types of electrical instruments:

A. Switchboard Instruments

These are panel mounted instruments of superior quality. They are used where the circuit demand is critical or where performance, readability, or long life warrant an added investment. Where protective relays and instruments share voltage and current circuits, switchboard quality instruments should always be used. Switchboard instruments are built in 90, 180, or 250 degree deflection and are of one-percent accuracy class. Some edgewise instruments are designated switchboard class because they are of comparable quality. They usually are one and one-half percent accuracy class. See Figure 1.

B. Panel Instruments

This classification covers a wide range of panel mounted instruments from miniature one and one-half inch, five percent meters to premium quality one-half percent accuracy custom types. Most commonly encountered are the two and one-half to five and one-half inch sizes in the two percent accuracy class. These instruments are used where accuracy is not a critical factor and where failure would not have catastrophic effect. The cost of these instruments is in the area of one-fourth the cost of comparable switchboard class instruments.

C. Portable Instruments

These instruments are housed in portable cases and are used in field testing. They will be in the 0.25% or 0.50% accuracy class. Digital instruments measuring in direct current are more accurate and more easily used than the 0.25% accuracy instrument measuring in alternating current. The trend is toward the taut-band type of portable instrument for analog measurements of both alternating and direct current. See Figure 2.

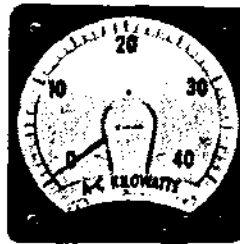
Circular



180° Scale



250° Scale



250° Scale



Navy HI-Shock

100°



Flush Mounting

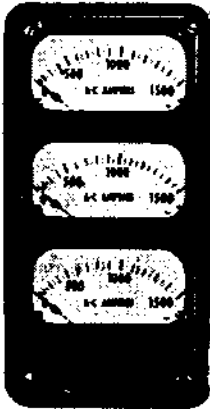


Flush Mounting



Projection Mounting

Triplex



Flush Mounting



Projection Mounting

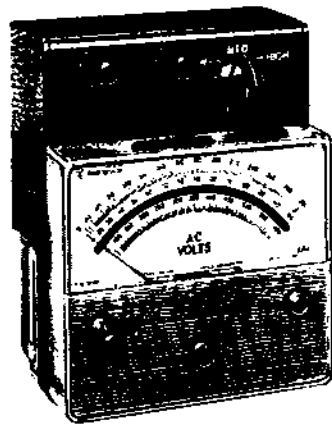
Edgewise



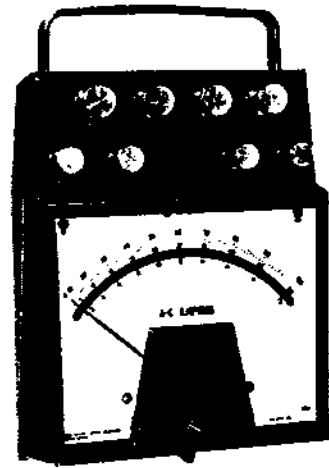
Detachable



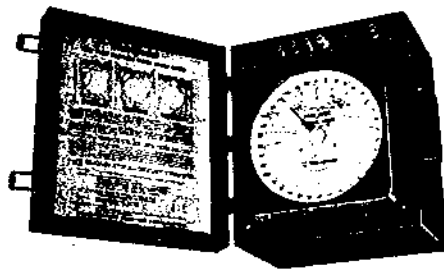
Fig. 1 - Typical Switchboard Instruments



Voltmeter



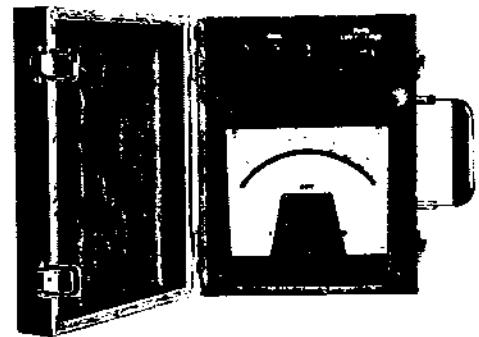
Ammeter



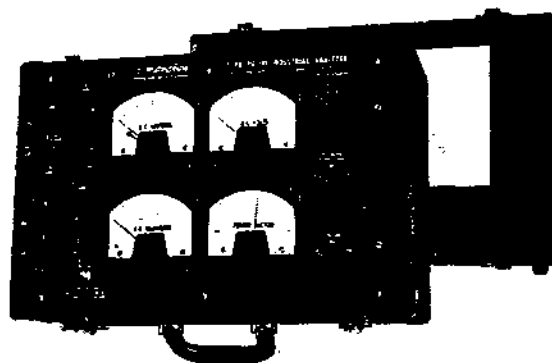
Phase Angle



Wattmeter



Frequency



Multi-Purpose Analyzer

Fig. 2 – Typical Portable Instruments

In circuit testing where readings need not be precise and instrument cost may need to be minimized, any of the multi-meter test sets may be used to advantage. These test sets are not adequate for making absolute measurements, especially on alternating current, because of their low basic accuracy and large waveform errors.

These multi-meters are popularly referred to by initials:

VOM = volt, ohm, milliammeter

TVOM = Transistorized volt, ohm, milliammeter

VTVM = Vacuum tube volt meter

DVOM = Digital volt, ohm, milliammeter

DMM = Digital multi-meter

Digital multi-meters are used in the same way as their analog counterparts. They have capability for greater accuracy on direct current and are available with special circuitry to overcome waveform errors.

19.2 Terms and Definitions

Accuracy – The limit is usually expressed as a percent of full scale that errors will not exceed under reference conditions. Example: Reading 150 volts on a 0-300 volt, 1 percent accuracy instrument, the maximum error is ± 3 volts so the true reading is 150 volts ± 3 volts.

Influence is a temporary error in addition to the basic accuracy. It is caused by such factors as variations from standard conditions of frequency, temperature, waveform etc. These errors are cumulative.

End-Scale Value is the value of the measured quantity which deflects the instrument to the end of its scale. Where the zero is offset, as in 10-0-25 the higher value, 25, is considered the rated end-scale value of the instrument but the lower value may also be referenced.

Full-Scale Value is the arithmetic sum of the measured quantity which deflects the instrument to the right end of its scale and that which deflects it to the left end of its scale. Example: 10-0-25 is a full scale of 35; 0-25 is a full scale of 25. In a suppressed-zero instrument the high end-scale value is considered the full-scale value.

Rated Current/Voltage is that value which the instrument is designed to handle under normal conditions. This term denotes the rating of the instrument.

Range refers to the highest and the lowest end-scale values on the instrument. On multi-range instruments all are given. Example: 0-150/

300/600. A suppressed zero instrument would be described as 90-130 while an expanded-scale type would be 0-90-130.

Reference Conditions – A definition of the conditions under which an instrument will operate at its rated accuracy. For a panel or switchboard instrument the more important are:

Temperature	– 25C
Position	– Vertical
Relative Humidity	– 30-60%
External Field	– Earth field only
Vibration	– Negligible
Frequency (a-c)	– 60Hz
Ripple (d-c)	– Negligible
Waveform	– Sinusoidal (3% max distortion for rms)

Repeatability – The ability of an instrument to repeat its upscale indications when moving down-scale.

Response Time – The time for the pointer to come to rest after an abrupt change in the measured value.

Scale Length – The length of the arc at the tops of the minor divisions between the two ends of a scale.

19.3 Instrument Mechanisms – How They Work

Electrical instruments operate through the action or interaction of magnetic forces generated by the measurand. With a few exceptions they consist of a moving element, with pointer attached, reacting against a stationary element to produce a rotative force opposed by a torque spring and a damping agency.

In permanent-magnet, moving-coil, and dynamometer instruments a proportionate part of the measurand is actually passed through a coil on the moving element. In others, like the moving iron-vane, the iron is magnetized by induction from a stationary coil. In either case the moving element is supported by a taut-band of metallic ribbon, or by pivot and jewel bearings. The moving element is the most vulnerable part of an instrument. If damaged, it can be replaced in a properly equipped shop.

The bearing system has been superseded on the highest-grade instruments by a taut-band system. See Figure 3. With taut-band support there is no friction and no danger of error through flattened or worn pivots. There is greater shock and vibration resistance in the case of

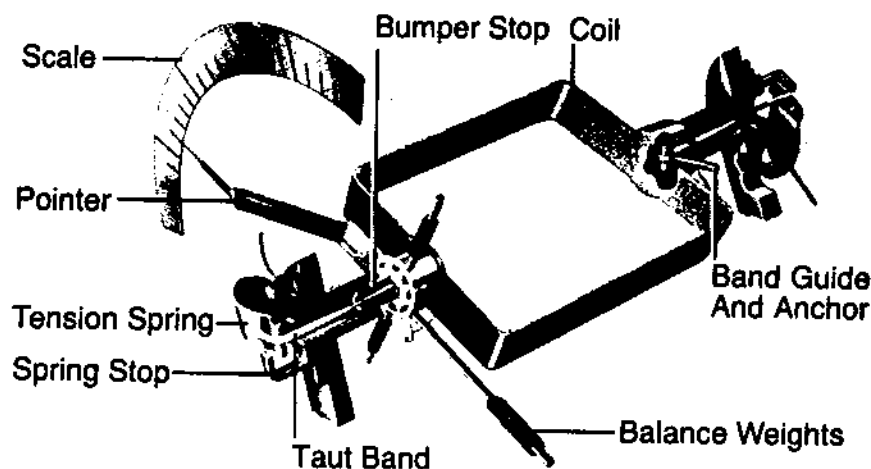


Fig. 3 – Taut-Band Suspension Mechanism

switchboard and portable instruments. However, in low-cost panel meters taut-band suspensions have had to be compromised for price. Generally, panel meters will not tolerate high shock and vibration but will stand lower levels better than pivot and jewel types. The failure of a taut-band is catastrophic; the instrument sticks or floats aimlessly while the failure of a pivot and jewel instrument is gradual. The errors due to friction become greater and greater until readings become obviously wrong. The choice in panel meters is one of function; i.e., which characteristic is preferable at a time of failure? In the more expensive instruments, there is no choice, taut-band suspensions are clearly superior on all counts, regardless of manufacturer, both on switchboard instruments and on precision portable standards.

The torque spring in a pivot and jewel instrument is usually a spiral spring of flat wire similar to the hair-spring of a watch; it is made of phosphor-bronze or silicon-bronze; in moving-coil instruments this spring serves as a conductor. It is vulnerable to burnout on heavy overload or to an annealing action on moderate overload. This can change its torque and render the instrument inaccurate. In the taut-band instrument, the restoring force is a combination of the torsion-bar action of the band and the tendency of a stretched twisted band to flatten out.

The damping device on an instrument resists pointer motion without introducing friction. It brings the pointer to rest quickly without error or excessive overshoot. This prevents damage from suddenly applied loads slamming the moving element against its stops, and minimizes pointer oscillations due to momentary fluctuations in the coil current. Refer to Figure 4.

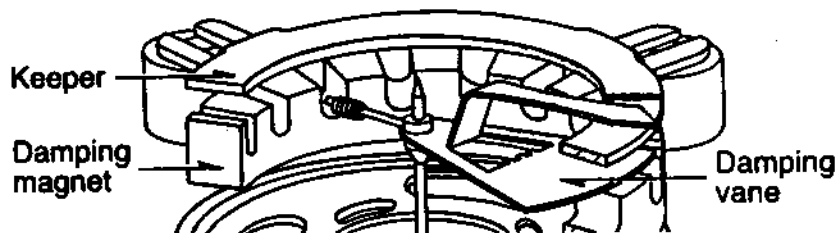


Fig. 4 – Damping Assembly for a Circular Scale Instrument

Some modern instruments use an aluminum vane moving in the field of a small horseshoe or multi-pole segmented magnet to generate eddy currents. The most common damping mechanism in current production consists of a paddle traveling through silicon oil. Illustrated in Figure 46. Instruments of the permanent-magnet, moving-coil type have an inherent damping capability. The motion of the coil through the magnet field generates an opposing force which can be controlled by the external circuit resistance. Generally, the instrument utilizes a short-circuited turn or coil on the moving element for damping. Balancing is done by a set of adjustable weights. These are either threaded screws or helical wire coils mounted at right angles to each other on the cross-piece of the moving element. See Figure 5.

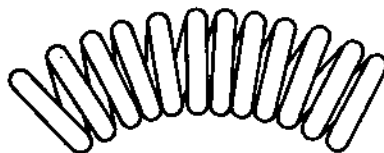


Fig. 5 – Helical Coil Balance Weight

A. Permanent-Magnet, Moving-Coil Mechanism

When there is a measuring coil on the moving element reacting with a stationary permanent-magnet, it constitutes a permanent-magnet, moving-coil instrument (also called d'Arsonval type).

The earliest form of this instrument utilized a horseshoe magnet, now seldom used, but shown here as it is the easiest to visualize, see Figure 6.

The permanent-magnet sets up a uniform field which, in Figure 6, is vertical. The current being measured is passed through the moving coil setting up a flux around each conductor. These fluxes react with the field of the permanent-magnet to generate a force or torque.

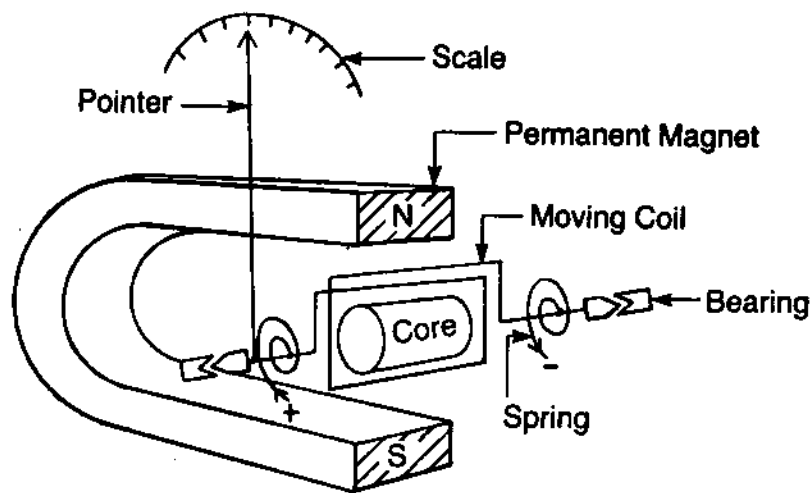


Fig. 6 – Schematic of a Permanent Magnet, Moving Coil Instrument

This may be more readily understood if the resultant fluxes in the coil are considered as setting up a horizontal field which tries to line up with the field of the permanent-magnet. The torque produced is opposed by the springs which are linear. Therefore, the pointer moves upscale to a point which can be calibrated directly in coil current.

Modern permanent-magnet, moving-coil instruments use magnet configurations which are as compact as possible with the absolute minimum air gap. This, together with modern magnet materials, makes it possible to go to extremely high field strengths without loss of field strength with time. Popular configurations in panel instruments are the annular or ring magnet Figure 7-a which uses a soft iron core to complete the magnet's circuit, and the shielded bar magnet design shown in Figure 7-c.

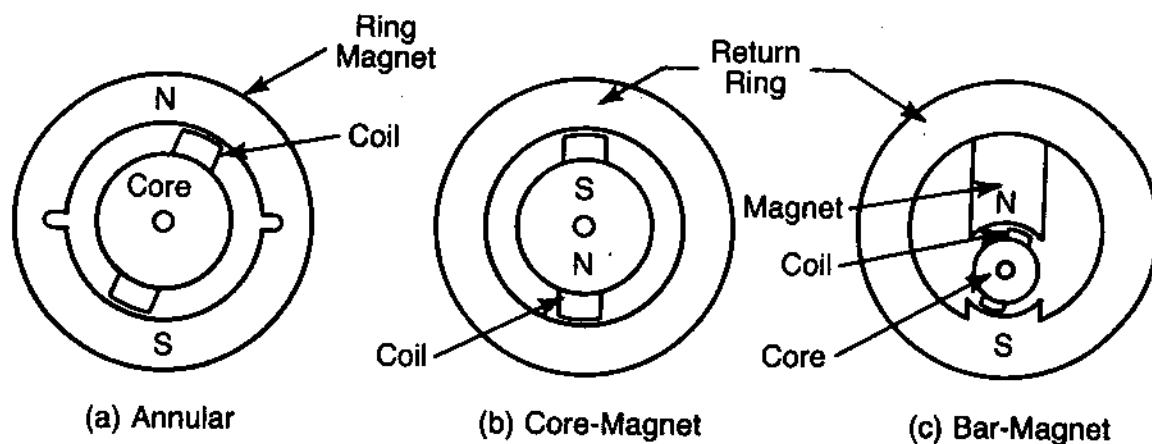


Fig. 7 – Permanent Magnet, Moving-Coil Instrument Configurations

The core magnet mechanism, Figure 7-b, is just the opposite of the ring magnet. It uses a permanent-magnet core and a soft iron return ring.

This design has the capability of holding a very high field strength; it is used in the highest quality panel instruments as well as in 100° switch-board and portable instruments. For 250° rotation on circular scale instruments the mechanisms can be either radial air gap or the newest axial air gap design, see Figure 8. Performance is essentially the same in either case but the axial air gap has some manufacturing advantages.

Permanent-magnet, moving-coil instruments are used for most analog d-c measurements. The basic instrument is a milliammeter; fed through a dropping resistor it becomes a voltmeter. Shunted, so that only a portion of the current goes through the instrument, it becomes an ammeter.

Coupled with an electrical transducer this d-c instrument reads a limitless number of measurands for which transducers exist: watts, vars, temperature, power factor, frequency, speed etc.

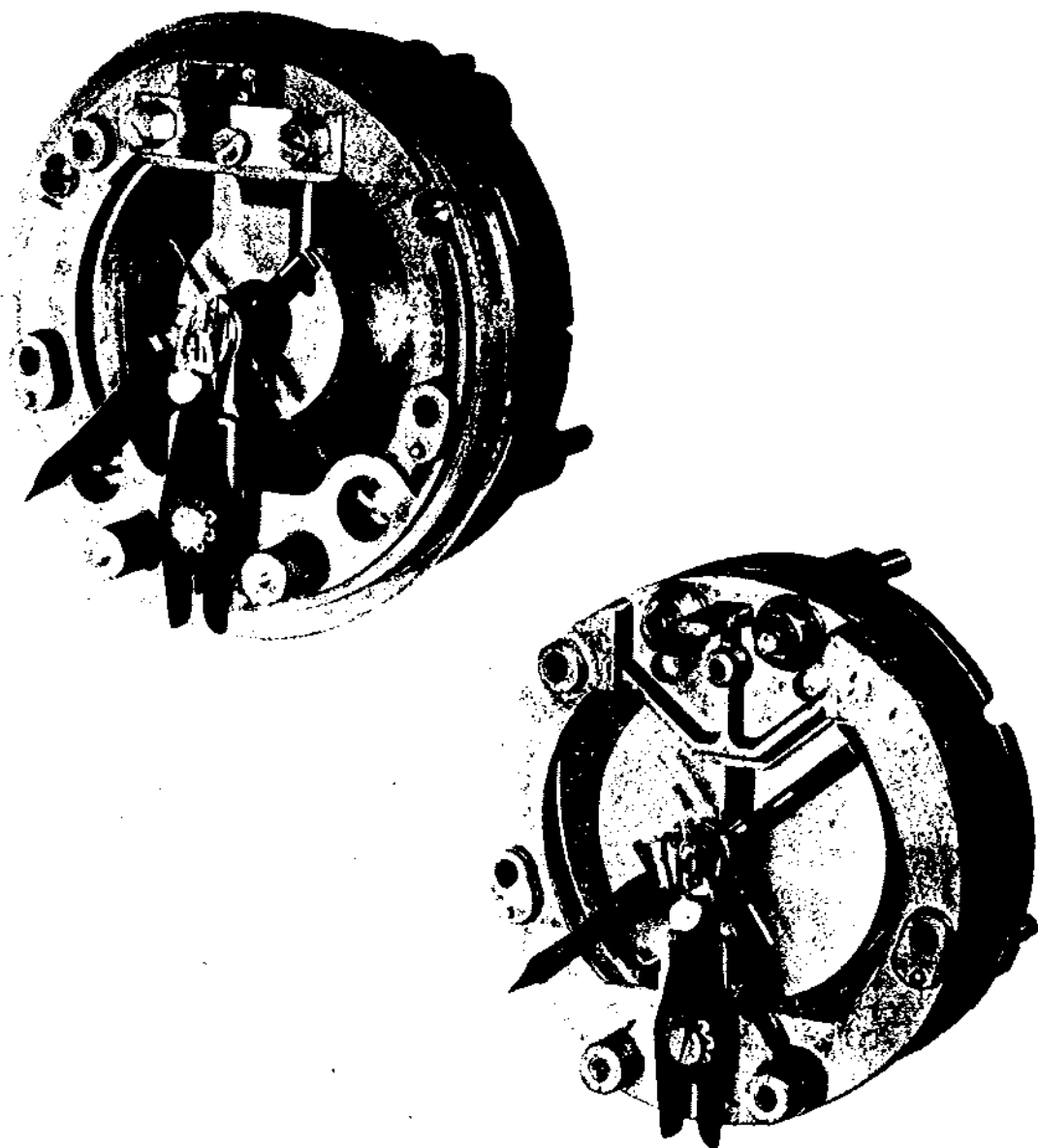


Fig. 8 – Radial and Axial Air-Gap, Circular-Scale Mechanisms

B. Moving-Iron Mechanism

This is a mechanism in which the interaction is between a moving element with a soft iron-vane and a corresponding stationary vane. In order to get unidirectional torque the magnetic field must be unidirectional or, must reverse in both the stationary and the moving vanes simultaneously. Because iron-vanes tend to retain some residual magnetism and permanent-magnet, moving-coil instruments, perform so well on direct currents; the use of the iron-vane mechanism is confined, almost entirely, to alternating-current ammeters and voltmeters. The higher burdens and non-linear scales of iron-vane instruments further influence this preference.

The action of the basic 90 degree deflection iron-vane mechanism is best learned by studying Figure 9.

A coil surrounds a pair of iron-vanes in parallel planes, one vane is fixed in space, the other is free to rotate about a shaft attached to one edge. The shaft is fitted with the usual restoring spring or taut-band, a pointer and a damping device. Any current in the coil induces like magnetic poles at adjacent edges of the iron-vanes causing them to be repelled from each other. The moving iron-vane rotates the shaft against the torque spring causing the pointer to move up to the point of balance. This point is calibrated to correspond to the current in the coil. The deflection of this type of instrument is somewhat compressed at the low end of the scale; this is not really considered a deficiency because critical measurements are usually at the high end of the scale.

In order to get a scale longer than 90 degree, and some measure of control over scale distribution, a variant of the iron-vane mechanism is used. This type is generally called the concentric iron-vane instrument. Motion is produced by either repulsion or attraction of the iron-vane or a combination of both called repulsion-attraction.

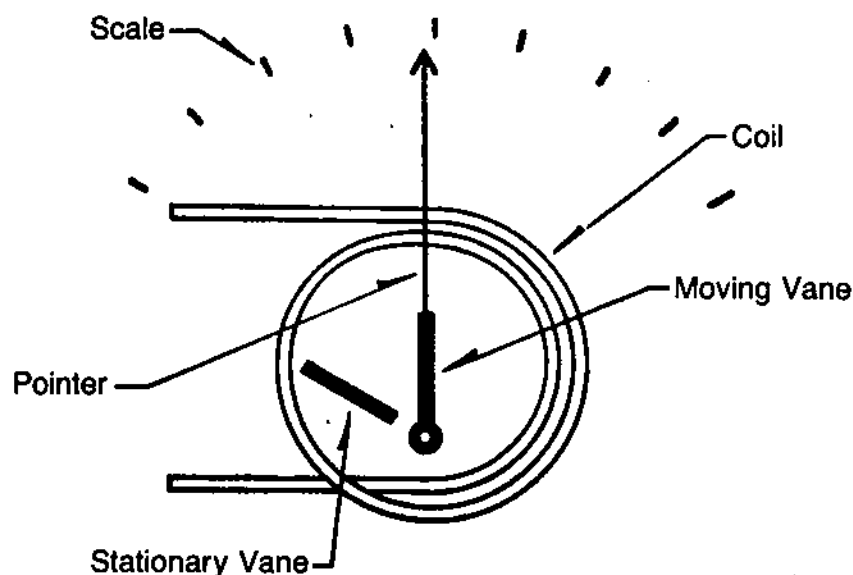


Fig. 9 - Schematic of an Iron-Vane Mechanism

This design can be more readily understood by reference to Figure 10, an end view of a typical mechanism. The stationary vane (a) can be visualized as a short cylinder with a segment removed. The moving vane (b) can be the segment removed from (a), it is attached to a shaft with restoring spring, bearings, and pointer. A large cylindrical coil (c) surrounds the vane assembly. Energizing the coil (c) will induce the like poles of the moving and stationary vanes to repel each other. Because the stationary vane (a) is tapered a rotational force is exerted. Figure 11 illustrates this design concept with the cylinders unrolled and flattened. The unequal repelling forces from the tapered stationary vane will act to move the moving vane (b) horizontally. If the vanes were rolled into cylinders this motion would be rotational.

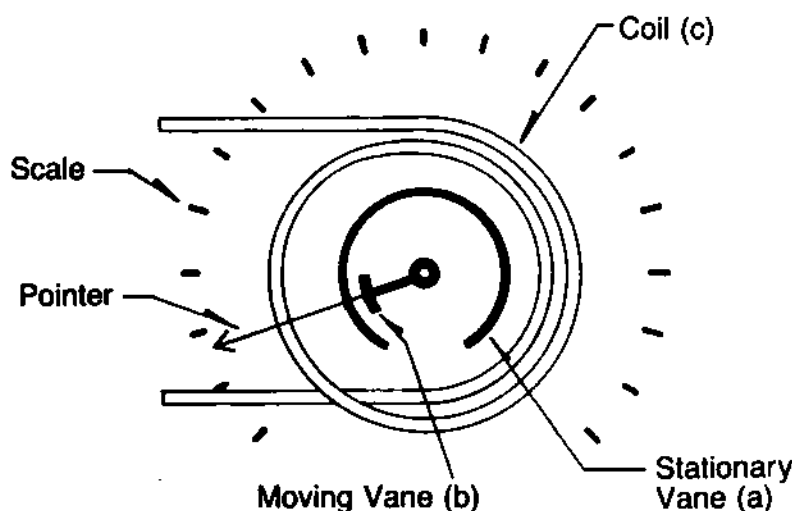


Fig. 10 – Concentric Iron-Vane Mechanism – Schematic End View

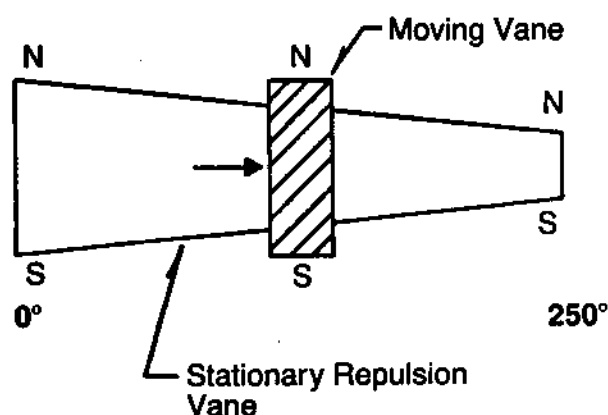


Fig. 11 – Development of a Circular-Scale, Iron-Vane Mechanism

Figure 12 illustrates the same concept reversed with the moving vane surrounded by two stationary vanes. Here the opposite poles exert an attracting force.

In both of these designs the action of the magnetic forces is opposed by a spring so the amount of rotation is proportional to the flux in the coil. This is the repulsion type concentric iron-vane mechanism.

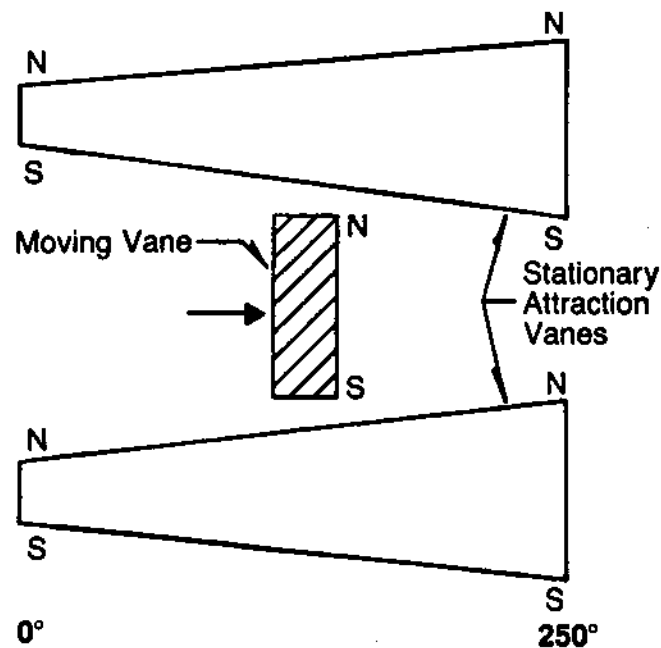


Fig. 12 – Attraction Type Circular-Scale, Moving-Iron Mechanism

Either of the above will work well up to about 140 degrees of rotation. Long air gaps cause an instability at one end or the other. Therefore, for 250 degree instruments, a combination of the two is used. Now we have the repulsion-attraction type concentric iron-vane mechanism.

With this latter instrument it is common to shape the vanes to more nearly linearize the scale distribution or to expand or contract it slightly when needed. The commercial 250 degree vane developments look roughly like Figure 13. Generally the attempt is to approach linearity above 20% of range. In practice, the iron-vane instruments are used for most a-c voltage and current measurements. Current and potential transformers, or resistors, are used as multipliers for measurements beyond the basic instrument capabilities.

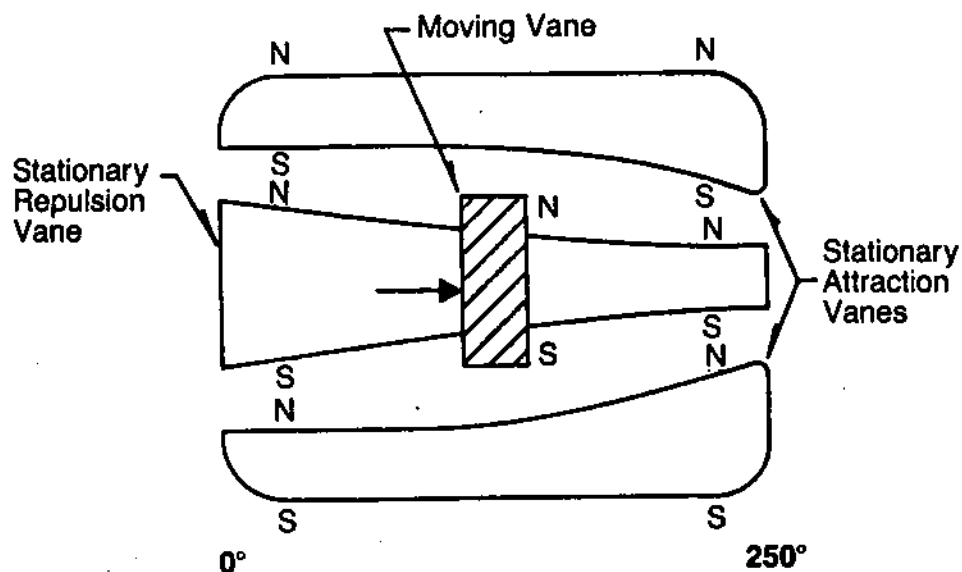


Fig. 13 – Development of Repulsion-Attraction, Moving-Iron, 250 Degree Instrument

C. Electrodynamometer Mechanisms

This mechanism is similar to the permanent-magnet, moving-coil mechanism except that the magnetic field is produced by coils replacing the poles of the permanent-magnet. A current flow through the moving coil produces a rotation. See Figure 14.

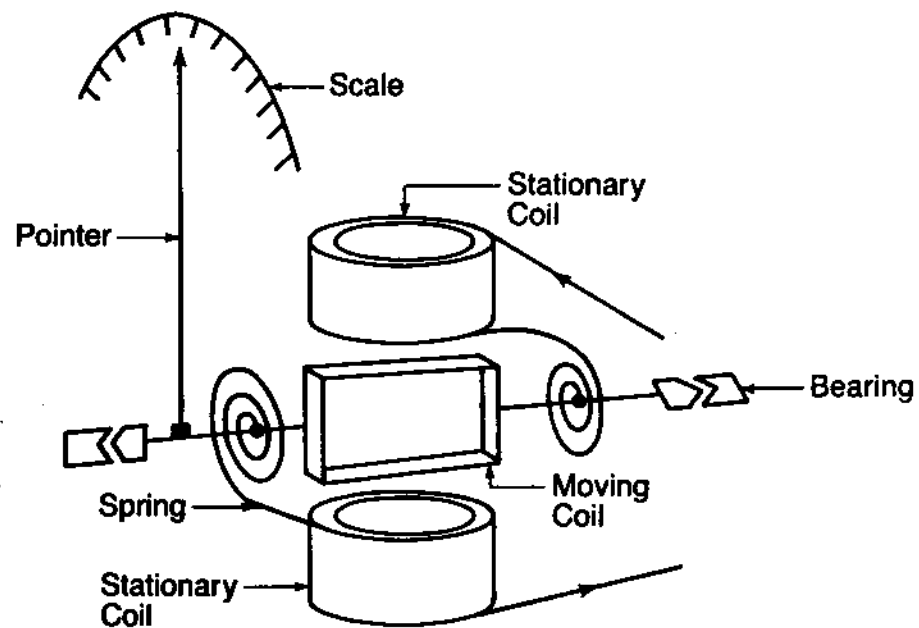


Fig. 14 – Electrodynamometer Mechanism

This instrument operates on direct-current similar to its permanent-magnet counterpart. It operates equally well on alternating-current because both stationary and moving fields, when fed from the same source, will change their instantaneous polarities simultaneously. The schematics shown in Figures 15 and 16 illustrate mechanisms of the electrodynamic type.

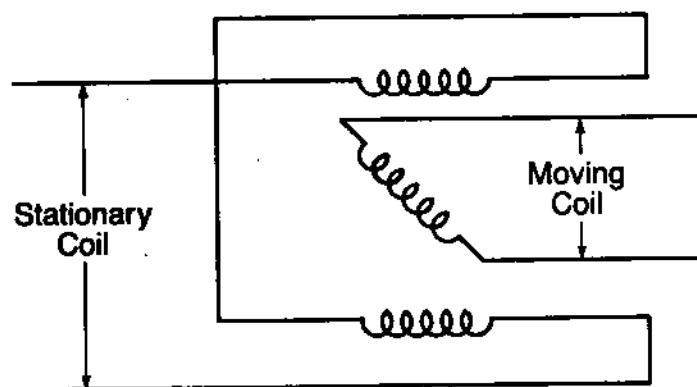


Fig. 15 – Electrodynamometer Mechanism – Schematic

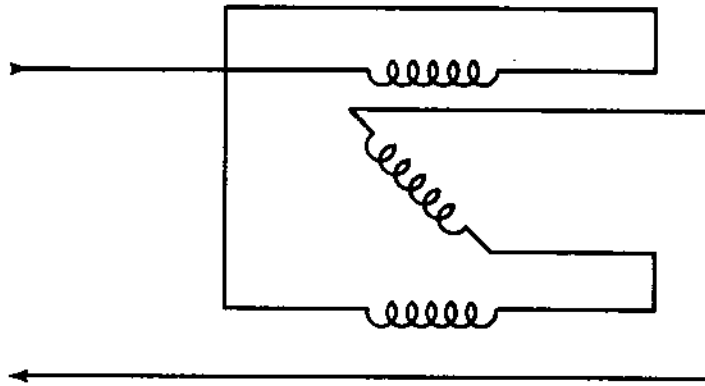


Fig. 16 – Electrodynamicometer Milliammeter – Schematic

The absence of iron and the elimination of the hysteresis problem provides means the ability to apply this design to alternating-current meters. To use the dynamometer mechanism to measure small currents, all elements are connected in series as shown in Figure 16. Deflection is not proportional to current as with the permanent-magnet instrument. As the current in the moving-coil goes up so does the current in the stationary coil, and there is a squaring of torques with current. This is an advantage in developing the meter scale, especially the voltmeter, because the scale opens up on the high end where it is most frequently used. This characteristic is generally less desirable for ammeters.

For heavy currents heavy wire is used in the stationary coils plus a shunt resistor to allow the small wires of the moving coil to carry only a small portion of the load. See Figure 17.

To measure voltage the practice is to use light stationary coils and insert a high series resistance to limit current, see Figure 18.

The capability of multiplying the stationary coil current by the moving-coil current produces a multiplying instrument that can measure watts. If a circuit voltage is put across the moving coil through a resistor, and

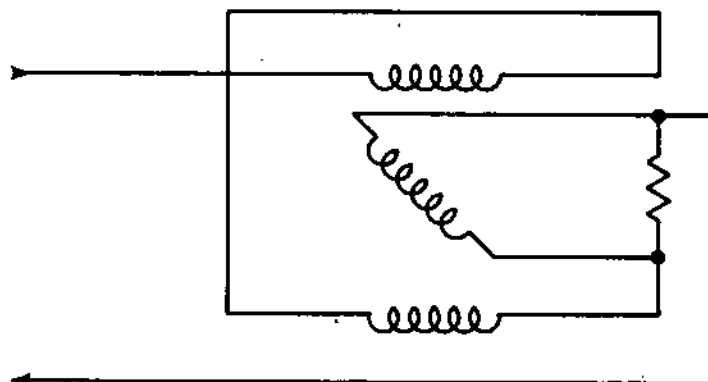


Fig. 17 – Electrodynamicometer Ammeter – Schematic

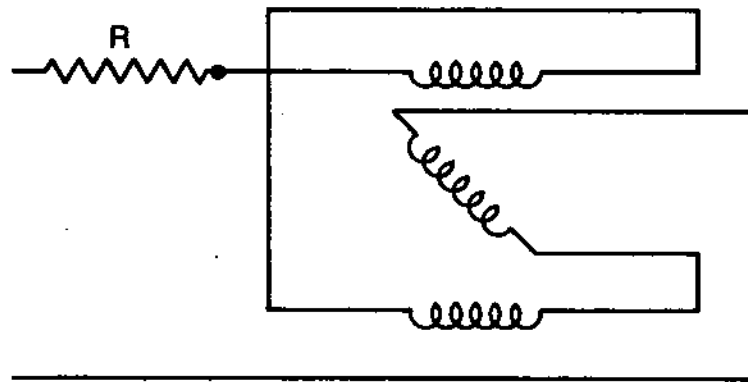


Fig. 18 – Electrodynamicmeter Voltmeter – Schematic

current through the stationary coils, torque is produced which at any instant is proportional to the product of the instantaneous values of current and voltage. The instrument averages these values to measure true watts.

Dynamometers of many variations are used in either alternating-current or direct-current wattmeters, voltmeters, ammeters, ratio meters, power factor, and phase angle meters. A unique characteristic of the dynamometer is its ability to transfer direct-current standard quantities to alternating-current. Figure 19 is a schematic of a typical dynamometer wattmeter. The advent of transducer type self-contained instruments has greatly reduced the use of dynamometer type meters.

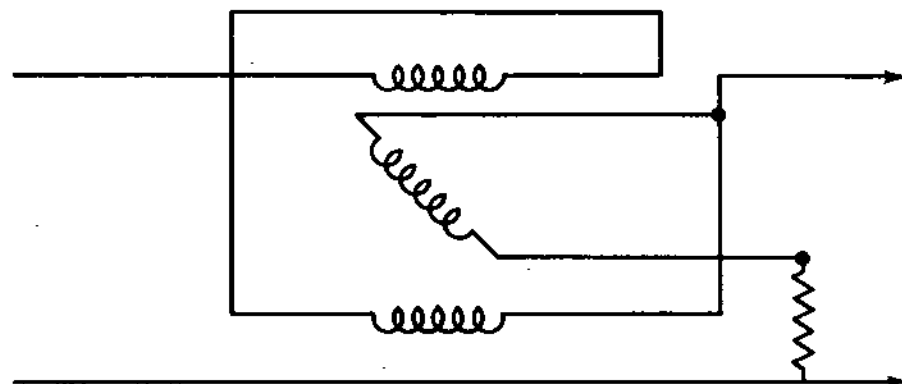


Fig. 19 – Electrodynamicmeter Wattmeter – Schematic

D. Rotating Iron-Vane (Moving Magnet) Mechanisms

This mechanism has an electromagnet for a rotor and a rotating field on the stator, see Figure 20. Stator connections can be polyphase or single-phase with a capacitor and reactor phase-splitting network. The stator is just like that of a motor. In fact, the mechanism is a motor; with d-c on the rotor it would spin at synchronous speed.

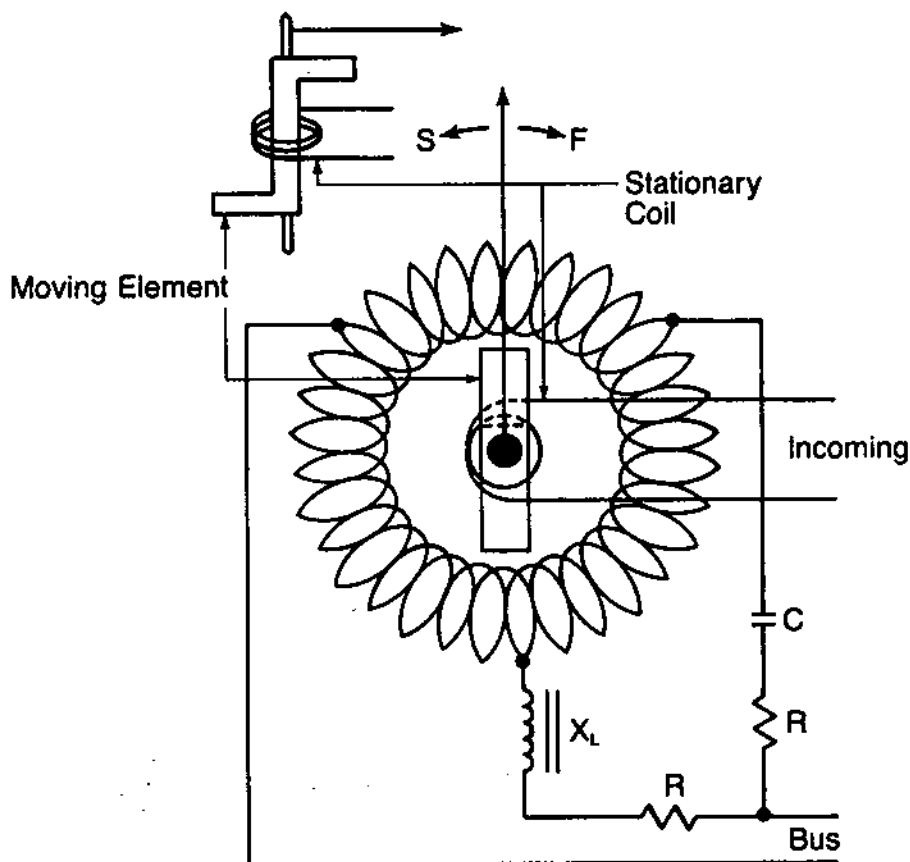


Fig. 20 – Rotating Iron-Vane Mechanism – Schematic

With alternating-current on the rotor, the alternating field will lock in with the rotating field of the stator. If the frequencies are the same, there will be no rotation. If they are not, the rotor will turn at the frequency difference.

If the frequencies are different, but there is a time difference between maximum flux in the rotor and in the stator, the rotor will seek that position in which the flux maximums occur simultaneously. The rotating iron-vane mechanism can therefore be used to indicate power factor or phase angle.

There have been many other mechanisms over the years. Some of these have survived in addition to those described here. There are electrostatic voltmeters, mutual inductance frequency meters, thermal ammeters, and similar devices. The four types covered above, permanent magnet-moving coil, moving iron, electrodynamic, and rotating iron-vane (moving magnet) types are the most frequently encountered.

19.4 Instrument Auxiliaries

In many measurements the current or voltage levels are beyond the capacity of the instrument, or the phase relationships between inputs are incorrect, so an auxiliary device must be used to make the necessary compensations. In some instruments these auxiliary devices are mounted inside the instrument case, in others they are a separate unit.

A. Shunts

These are devices which carry a large current and allow only a small proportionate part to flow through an instrument. In instrumentation, they are designed as low-value resistors having a voltage drop (usually 50mv or 100mv at rating) proportional to the current flow, see Figure 21.

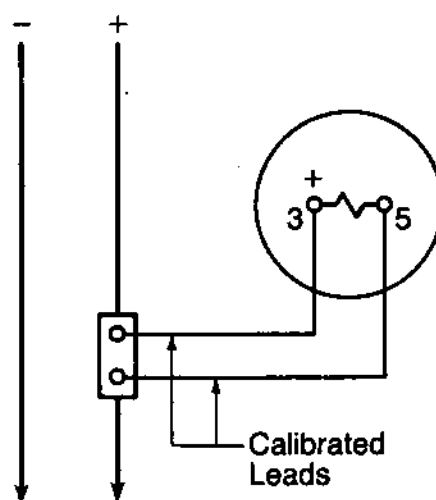


Fig. 21 - Shunt Used with D-C Ammeter - Schematic

Shunts generally use manganin blades because of this material's small change in resistance over a wide temperature range, ($\pm 0.075\%$ from 0-100C). This, when compared to copper ($\pm 40\%$ from 0-100C), illustrates why there are gross errors when a section of bus bar is used as a shunt.

Shunts depend upon conduction into the connected bus bars for cooling, and properly connected meter shunts will carry one hundred percent of their rated load continuously. Deterioration due to high temperatures from overload, causes a gradual increase in resistance of the manganin and in some extreme instances the solder used in the assembly may melt out causing instant resistance increase. In better shunts, especially in ratings above 100 amperes, silver solder or phos-copper is used instead of the softer lead-tin solder, for the manganin-to-copper block connection.

Shunt applications on intermittent repetitive overloads or on pulsed currents must be made on an rms basis. A non-inductive load fed by a full-wave rectifier, for example, would have to have a shunt derated by a factor of 1.57 because of the rms/average relationship (form factor) of the rectifier output.

If the average current output, as read by a permanent-magnet moving-coil instrument, is 50 ampere the rms current in the above example would be 80 ampere continuous. The smallest standard shunt capable of carrying 80 ampere continuous is the 100 ampere rating. For a meter application, a 100 ampere, 100mv shunt would be used with a 50mv instrument having a 50 ampere scale. Batteries, strip heaters, and lamps are examples of non-inductive loads which can cause problems. Solenoids and motors rarely cause problems as they are largely self-filtering.

Shunt leads can be a source of error, either by being situated in an extreme temperature environment or, by being of abnormal length. Millivoltmeters designed for use with shunts are generally calibrated for leads of .065 ohms total resistance per pair. Calibrated leads are available from the manufacturers as standard accessories but with modern instruments, with relatively low current requirement, the lead resistance is not really critical. To calculate the error due to non-standard resistance shunt leads, use this formula:

$$\text{Error (mV)} = I_m^2 R$$

where I_m is current drawn by the millivoltmeter

and R is the deviation from standard shunt lead resistance.

$$\text{Error (\%)} = \frac{\text{Error mV}}{\text{Rated mV}} \times 100$$

In calculating R , figure a resistance change of .004 times the resistance at 25°C for each degree of deviation. The higher the temperature the higher the resistance. To establish the value of (R) due to wire size or length use this table:

Wire Size	10	12	14	16
Resistance, ohms/ft.	.0010	.0016	.0026	.0041
Length for standard .065 ohms				
feet	65	40	25	16

A quick rule of thumb is that for taut-band 100 degree instruments: you can double the normal lead length and introduce an error of only 0.13 percent of reading. For 250 degree circular scale instruments, however,

the error approaches 0.8 percent. When long leads are required with these instruments, they are usually calibrated for special resistance and are furnished with a compensating rheostat.

B. Resistors

In all direct-current and in some alternating-current applications, resistors are used to drop the voltages applied to instrument potential coils. A 150 volt direct-current voltmeter becomes a 600 volt device by adding an external resistor equal to three times the terminal resistance of the 150 volt instrument. Standard voltmeters at 1000 ohms per volt may be used on very high direct-current voltages if the circuit is grounded at the instrument, see Figure 22.

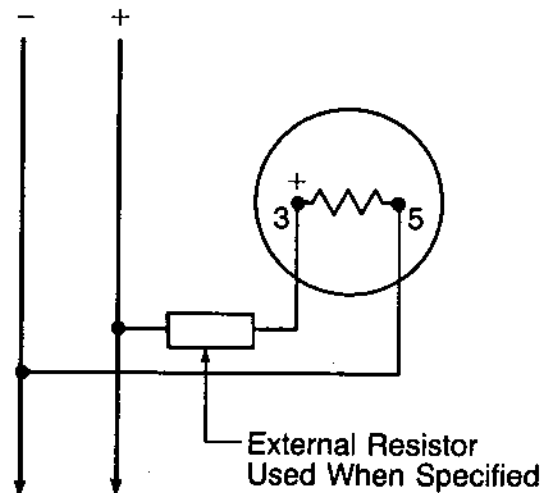


Fig. 22 – D-C Voltmeter with Resistors for High Voltage – Schematic

The instrument connects to ground and the resistor to the hot leg. Resistors are used similarly on alternating-current voltmeters up to 750 volts, above this level transformers must be used. Whenever the instrument contains an internal transformer or other inductive circuitry, a dropping resistor may not be used because a power factor error is introduced. Examples are: transducer type wattmeters, electrically suppressed or expanded voltmeters, instruments with compensators or phase shifters; a dropping resistor should never be used with these. The temperature errors of resistors are insignificant. The usual materials in instrument grade resistors have a coefficient of about 0.0001 per degree centigrade. External resistors should be mounted where they will ventilate freely.

19.5 Instrument Transformers

A. Current Transformers

Current Transformers isolate the instrument from the high-voltage power circuit, and step the current down to a value which can be handled by the instrument, see Figure 23.

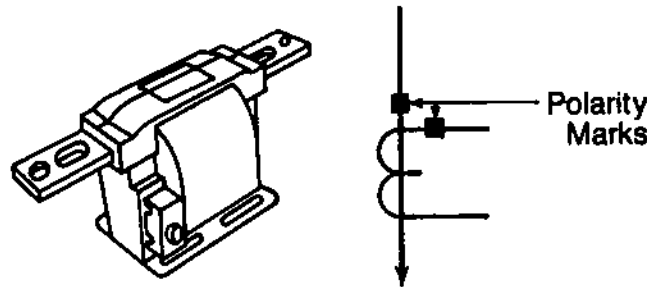


Fig. 23 – Current Transformer and Symbol

A perfect transformer would be a ratio device in which the ampere-turns on the primary equal those on the secondary.

The primary winding carries whatever current is flowing in the line and the secondary winding delivers whatever voltage is necessary to force enough current through the meter circuit to balance out ampere-turns.

The linkage between the primary and the secondary is the flux in the iron core. The perfect transformer would have equal and opposite ampere turns (Lenz' law) so theoretically there would be no flux in the core. But, a flux does have to be present in the core to generate the secondary voltage to cause the secondary current to flow. Obviously, there would have to be a surplus of primary ampere-turns to generate this flux. For metering purposes, some prefer a few less turns on the secondary. This deficit provides the required ampere-turns to magnetize the core. Now, let's see how this affects transformer accuracy vectorially, Figure 24.

Phase angle is of no concern in current measurement but it does influence watts, power factor, or phase angle measurement and introduces an error factor. Referring to the vector, Figure 24, you can see that as the magnetizing current goes up, the angle between the primary and secondary currents increases. The magnetizing current (I) is minimized by transformer design but, is also affected by the nature of the load. If the external secondary circuit has a high ohmic value, the magnetizing current must rise to generate the voltage needed to overcome the secondary impedance. Therefore, the accuracy of a current transformer depends on the secondary burden. Accuracy is denoted by a value such as 0.3

B2.0, which means that the error in a wattmeter reading (due to current transformer ratio error and phase angle error) will not exceed 0.3 percent if the burden on the transformer is less than 2 ohms.

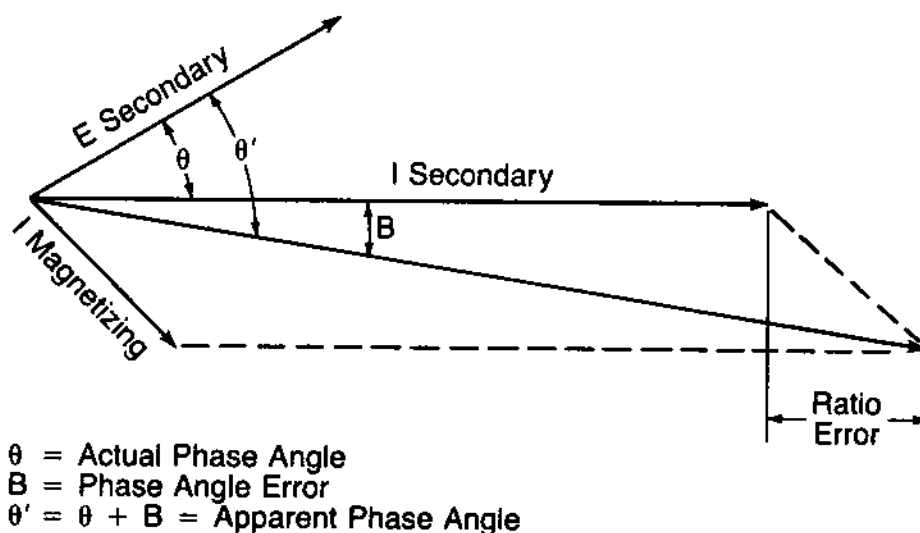


Fig. 24 – Vector Diagram of a Current Transformer

There is also a thermal limit expressed as a rating factor which indicates the maximum current which the transformer can carry at 30 degrees Celsius ambient; these are numbers like 1.00 or 1.33. With a rating factor of 1.33, a 200/5 current transformer can safely carry 266 amperes continuously at 30 degrees Celsius ambient. Most current transformer catalogs provide a derating curve, or table, for higher ambients based on ANSI Standard C57. For example, in a 55 degrees Celsius ambient the above referenced transformer could carry only 180 amperes continuously instead of 266 amperes. In typical enclosed equipment, if you use a transformer, rated 1.33 at 30 degrees Celsius ambient, you should not have to derate it.

It is apparent that in applying current transformers in instrument circuits, it is necessary to determine the total burden on the transformer in terms of the effective impedance, (See formula). The manufacturers of meters, relays, and instruments list the resistance and reactance values of their devices for this purpose; for example:

Devices being fed by Common transformer	Resistance ohms	Reactance ohms
watthour meter	.005	.01
ammeter	.001	.005
relay 1	.004	.02
relay 2	.002	.005
Leads – 200' #10	.208	
total	.220	.04

Formula:

$$\text{Impedance} = \sqrt{(\text{Total Resistance})^2 + (\text{total reactance})^2}$$

$$\text{Therefore: } \sqrt{(.220^2) + (.04^2)} = .224 \text{ ohms impedance}$$

$$\text{Burden Power factor} = \frac{\text{total resistance}}{\text{impedance}} \text{ or } \frac{.220}{.224} = 98.2\%$$

standard transformers are rated for burdens of B 0.1, B 0.2, B 0.5, B 1.0, B 2.0, B 4.0, and B 8.0. In this example B 0.5 is the correct choice owing to some refinements because power factor is so good (90% is used as the standard), and would permit use of B 0.2, but this is beyond the scope of maintenance.

If there is a borderline application it is best to check it out from the transformer data sheets.

B. Potential Transformers

Self-contained voltmeters are available up to about 750 volts where they are limited by thermal and insulation considerations. At 480 volts a-c and above it is common practice to use potential transformers for isolation.

Potential transformers are subject to ratio and phase angle errors as described for current transformers but the causes are different. Refer to Figures 25 and 26.

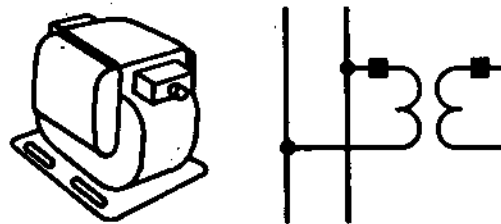
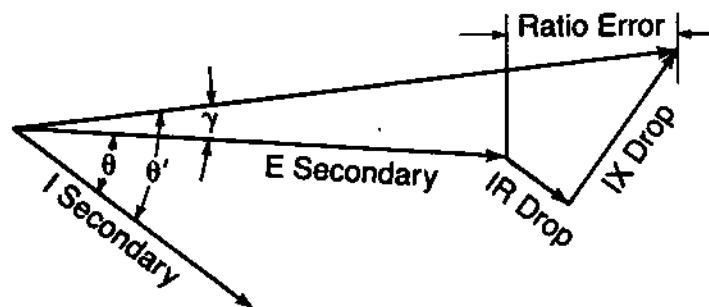


Fig. 25 – Potential Transformer and Symbol



- θ = Phase Angle
- γ = Phase Angle Error
- θ' = θ & γ Apparent Phase Angle

Fig. 26 – Vector Diagram of a Potential Transformer

Accuracies of potential transformers are stated in a coded manner for example accuracy stated at 0.3Z indicates 0.3% accuracy and the Z code means vectorially, 200 VA at .85 power factor. The burden is calculated by adding, but for practical purposes the power factor on potential circuits of instruments is such that the volt-ampere losses of connected instruments need only be added arithmetically.

C. Instrument Transformer Connections

Figure 27 shows three standard transformer configurations for common systems. Many other connection schemes are possible, and are often used.

The polarity markers are shown in the most commonly used position relative to the system. It is possible to reverse any one transformer on both the primary and the secondary sides without affecting the electrical performance in any way. The polarity marks simply mean that at the instant a current is flowing toward a polarity marker on the primary, a relative current will be flowing away from the polarity marker on the secondary. There are exceptions in the case of voltage transformers of the higher ratings used on grounded wye systems. Here, the insulation gradient fixes the primary terminals with respect to ground.

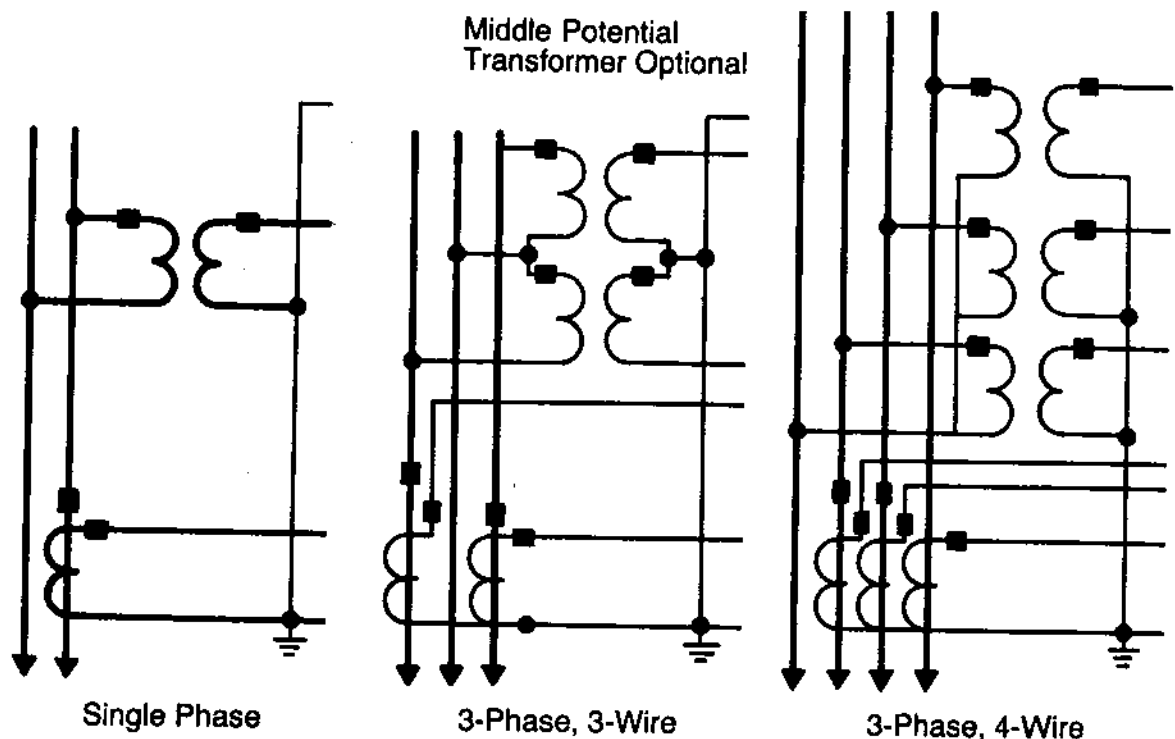


Fig. 27 - Conventional Instrument Transformer Connections

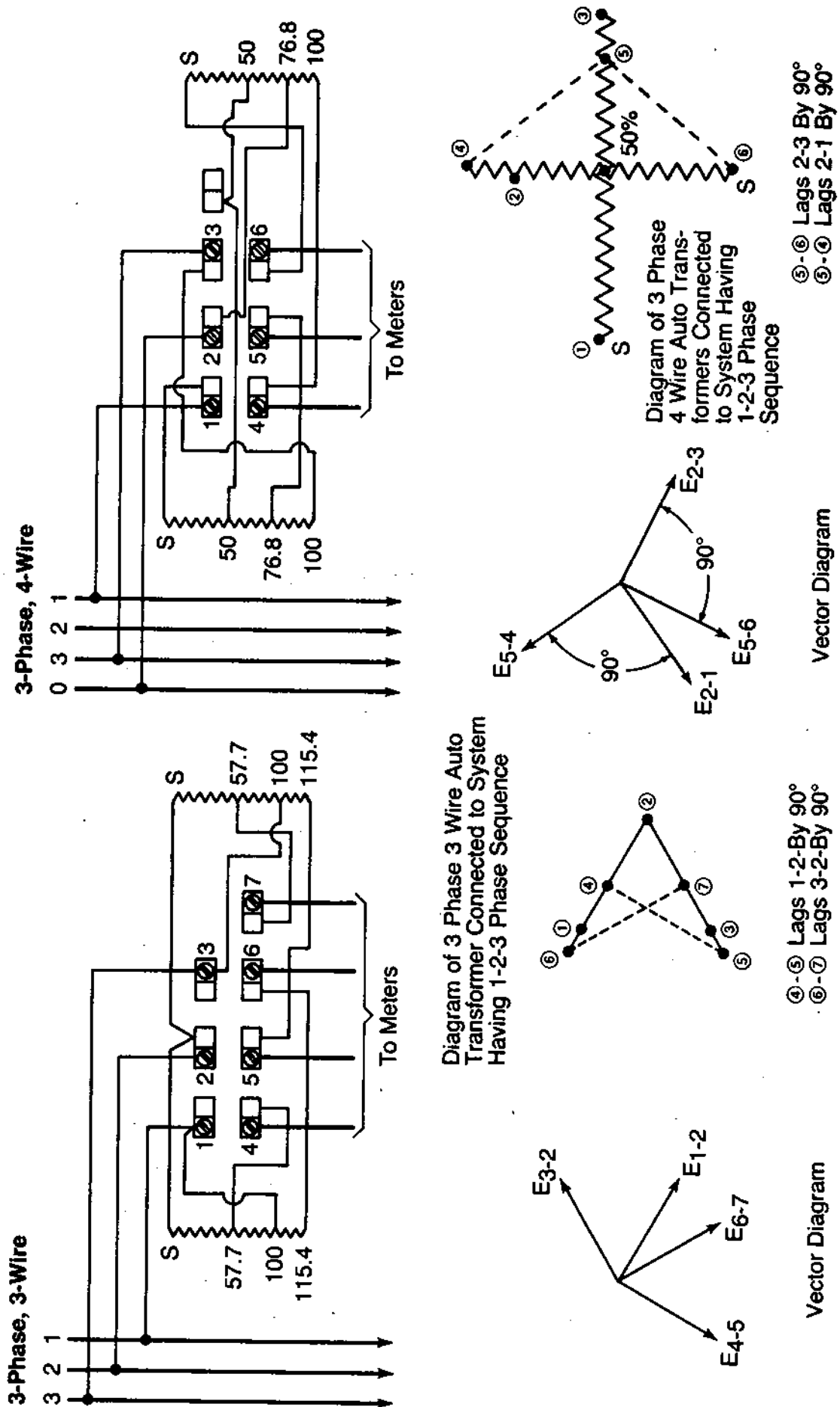


Fig. 28 - Phase-Shifting Transformers - Schematic

D. Phase Shifters

In the measurement of reactive power it is necessary to have voltages 90 degrees out of phase with the currents in a circuit. A specialized form of transformer is used for this purpose as shown in Figure 28.

In some models there is switching of the output from the in-phase to the shifted mode. This permits testing of the varmeter in the watt mode, or the use of a varmeter (optionally) as a wattmeter.

E. Compensators

On single phase, a 90 degree phase shift cannot be accomplished with a phase shifter so a compensator is used. It usually has a capacitor in one leg and an inductance and resistance in the other to shift a specific potential circuit by 90 degrees. These devices are adjusted with, and identified by a serial number to a specific instrument. They are not interchangeable without recalibration of the instrument and compensator as a set.

F. Transducers

Modern practice favors the conversion of complex measured quantities to a proportional direct-current signal. This is done with electrical transducers. There is a transducer for almost every electrical measurand. These will be covered under the paragraphs devoted to specific measurements. Figure 29 illustrates one of these devices.

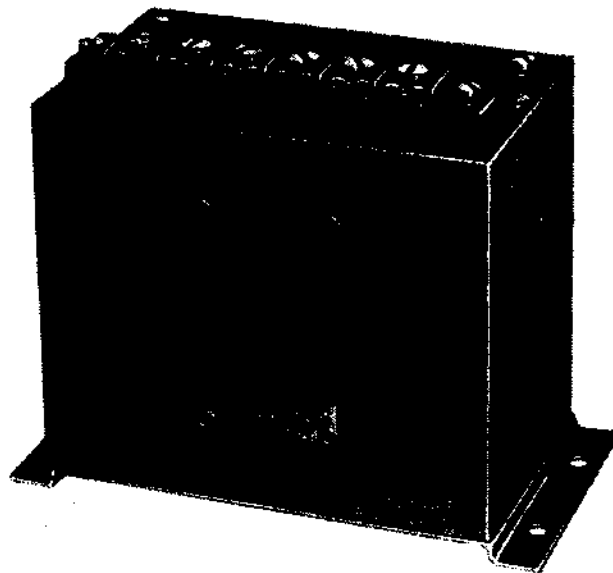


Fig. 29 - Typical Transducer

19.6 Common Factors Relating to Selection and Performance of Electrical Instruments

A. ANSI Standards

An indication of adequacy in electrical measuring instruments is conformance with ANSI C39.1, specification of the American National Standards Institute, Inc. These are minimum standards which are often exceeded by the best manufacturers. Care should be taken if statements in promotional literature claim conformance to these standards in only limited areas as it often means nonconformance in other more important areas. The standards contain tables of permissible influences which may be used to analyze the minimum performance of an instrument. Where maximum performance is needed, it is necessary to consult with the manufacturer. A copy of ANSI C39.1 may be purchased from the American National Standards Institute Inc., 1430 Broadway, New York, NY 10018.

B. Accuracy

The accuracy of an instrument is based on standard conditions at 25 degrees Celsius in a normal mounting position with no stray field other than the earth's and with no direct-current ripple; an alternating-current power source should have a pure sine wave and normal frequency. Accuracy class is now stated as the limit expressed in percent of fiducial value (usually full scale value) at which errors will not be exceeded under standard conditions.

Switchboard instruments are usually 1.0 percent class, panel instruments (2-1/2 to 5-1/2 inch sizes) are usually 2.0 percent class but in special cases may be 1.0 percent. Smaller panel instruments may be as much as 5.0 percent; some of the cheaper, but larger types, also fall into this category. Portable instruments have recognized accuracy classes of 0.25 percent, 0.5 percent, and 1.0 percent. They are the most common and practical class for general maintenance work. The popular multi-meter (VOM, DVOM, DMM etc) testers fall far outside the measurement standards recognized by ANSI C39.1. They may measure one set of parameters very well but not another. For example, a digital multi-meter without compensation will meet direct-current measurement requirements but will not begin to approach the accuracy requirements for measurement of alternating-current with the waveform distortions so common today. Units are available with internal compensating circuits. Manufacturers are beginning to mark instrument dials with a number (0.5 or 1.0 etc) to denote their accuracy class.

C. Dielectric Strength – Insulation Level

In determining the application limits of an instrument the published Working Voltage to Ground must be considered. This is, by ANSI definition "the highest peak voltage which may exist between a terminal and ground on a mounted instrument." Ordinarily it is 1100v. This means that the instrument can be used on ripple-free direct-current at 1100 volts but on alternating-current at only 780 volts because, on a pure sine wave, the ratio of peak to (rms) is 1.41. Variable voltage devices, or regulated devices, which use partial waves can cause some real problems. These devices can have almost any ratio of peak to rms (crest factor). The applied instrument is usually safe enough if it will handle full output of the equipment. In half-wave rectified circuits the crest factor is 3.14. Standard instruments are limited to $\frac{1100}{3.14}$ or 350V for this type of application.

Manufacturers also publish a figure for Dielectric Test. This is the level of 60Hz sine wave, rms voltage which the instrument will withstand from terminals to ground for one minute. This test level relates to the insulation test specification which requires a high potential test at twice the maximum operating voltage plus 1000, for new equipment. An instrument having a test level of 2600V should withstand a high potential test for apparatus rated up to 800 volts alternating-current.

Warning: Do not hold or touch an energized instrument. Exercise care in assuring correct connection of instruments. Failure to heed this warning can cause severe injury or death by electric shock, and damage to property.

Some portable instruments are built with ranges above the 800 volt alternating-current or 1100 volt direct-current limits dictated by the test level. Caution is required when using these instruments to make certain they are properly connected with the $\pm$ alternating-current or the + direct-current terminal connected to the grounded side of the measured circuit. The instrument must not be hand held when energized. Whenever possible, external shunts should be inserted on the grounded side of the circuit. If it is not possible to ground the shunt the instrument must not be hand held at high circuit voltages. The best rule is to avoid holding an energized instrument, especially when measuring above 500 volts.

Some manufacturers show the international symbol of a star with a numeral inside to designate the dielectric acceptance test voltage. See Figure 30.



Fig. 30 – International Symbol Designating Dielectric Acceptance Test Voltage

D. Position Influence

Instruments are position-sensitive to some extent. This means there is some taut-band sag or jewel roll-up which, in even a perfectly balanced instrument, will cause a reading change with a position change. Panel and switchboard instruments are intended for use with the dial in a vertical position, and portables with the dial horizontal. Each may be calibrated (not just a matter of re-balancing) for a dial position other than standard. Instruments are marked with international symbols to indicate mounting position:

vertical dial position

horizontal dial position

inclined dial position (number shows degrees from horizontal).

The permissible change in reading of a panel instrument when moved from vertical to horizontal is not covered by ANSI but will usually not exceed 2 percent. A switchboard instrument to meet ANSI standards should tilt 60 degrees in either direction and not exceed one percent error. Portable instrument standards allow a position influence of .3 percent for six degrees tilt from horizontal. The 0.5 percent portables are capable of considerably better performance than that. The position error for vertical operation will be variable but ordinarily not more than 0.5 percent for a properly balanced instrument. If portable instruments must be used vertically, they should be purchased calibrated for that position. If portable instruments are to be used in both vertical and horizontal positions they should be optimized for dual service by careful balancing, and a compromise on accuracy will have to be accepted.

E. Zero Adjustment

Most instruments have provision for adjustment which permits setting the instrument at zero when de-energized. This is usually a coin slot or recessed set screw near the pivot point of the instrument. To set to zero the instrument should be de-energized, the adjuster turned so the pointer is a bit up-scale, then slowly and continuously turned in the opposite direction until the pointer splits the zero mark on the dial.

On pivot and jewel bearing instruments it is necessary to tap the instrument gently and repeatedly while the adjustment is being made. This is to free the pointer from any error due to bearing friction. When the pointer is on zero the adjuster should be turned slightly to introduce some play into the internal adjusting mechanism. This will prevent pointer movement if there is any slight cover-to-mechanism movement due to thermal, shock, or any other forces. Care should be taken not to turn the adjuster far enough to move the pointer back upscale. A brief experimentation will show how much adjuster rotation represents play.

In making the final adjustment the adjuster should be backed off about half the rotation representing play in the mechanism.

On suppressed-zero instruments the mechanical zero is off the instrument scale. See Figure 31. On these, it is necessary to energize the instrument with a precise source of excitation equal to the low end-scale rating. For direct-current this must be a clean, ripple-free source such as a battery and resistors. For alternating-current, it must be a pure sine-wave from an adjustable auto transformer or a resistor on a pure sine-wave source. Most regulated power supplies or constant-voltage transformers are not satisfactory. To determine their accuracy they should be checked against a calibrated unit.

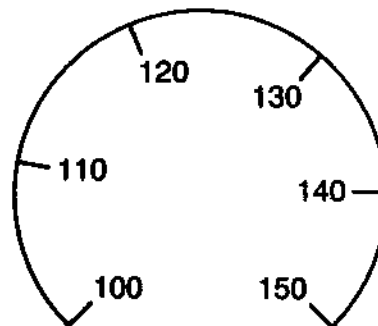


Fig. 31 – Suppressed Zero Scale

F. Balance

It is normal for instruments in service to become slightly off-balance. This can be caused by shock, vibration, or even a slight distortion with age of the moving element. To check an instrument for balance it should be placed in a dial-up horizontal position and set at zero. See Figure 32 (A). The pointer should then be checked with respect to zero with the dial vertical and the pointer horizontal, Figure 32 (B) the 9:00 o'clock position, then check again with the dial vertical and the pointer vertical, Figure 32 (C), the 12:00 o'clock position. The deviation from zero should not exceed the accuracy of the instrument (1 percent of scale length for switchboard and 2 percent of scale length for panel instruments). There is no established standard for balance deviation for portable instruments but many of the 0.5 percent class with 100 degree scale can be checked in this manner and even the 250 degree type portable instrument will usually fall within a one percent deviation. Review the paragraph on Position, above, when considering balancing portable instruments.

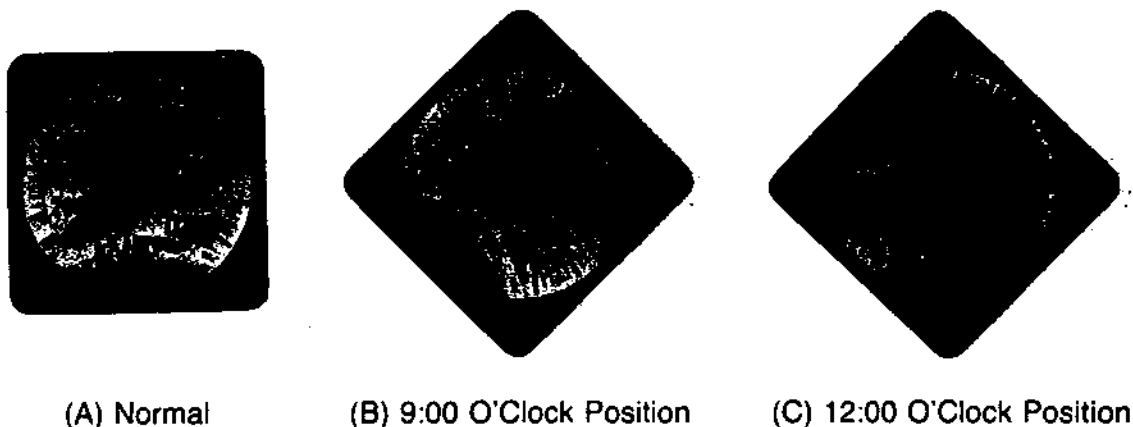


Fig. 32 – Instrument Balancing Positions

Exceptions to the above are frequency meters where the balance requirement is 0.5 percent of scale length, and synchrosopes, where a deliberate unbalance of 45 degrees is introduced to assure that the device never comes to rest at zero when not energized.

Instruments needing re-balancing should be sent to an instrument service shop or returned to the manufacturer where properly trained personnel and appropriate tools and equipment.

If the re-balancing must be done in the field, the following guidelines should be followed. On instruments with pivot and jewel bearings the end play should be adjusted to about 0.004 inches with side play of 0.01 inches, before attempting to balance. Under field conditions these clearances may have to be estimated by moving the instrument element with a tweezer, see Figure 33. The clearance is adjusted by turning the screw cap holding the jewel. Except on spring backed jewels, adjustment should never be to zero clearance, even momentarily. Such setting may destroy either the pivot or the jewel or both.

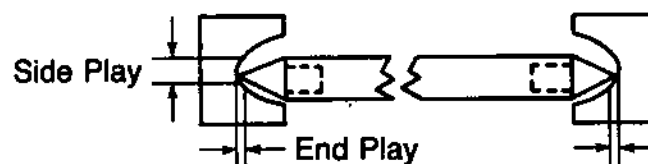


Fig. 33 – Clearances on Pivot and Jewel Bearings

The actual balancing is done by adjusting the balance weights on the pointer. There are two common configurations of balance weights, see Figure 34. The three weight system is used on most instruments and the two weight normally limited to certain panel instruments. The balance weights may be in the form of threaded, elongated nuts (sometimes self-threading) or they may be a helical coil of spring wire, they may also be threaded screws.

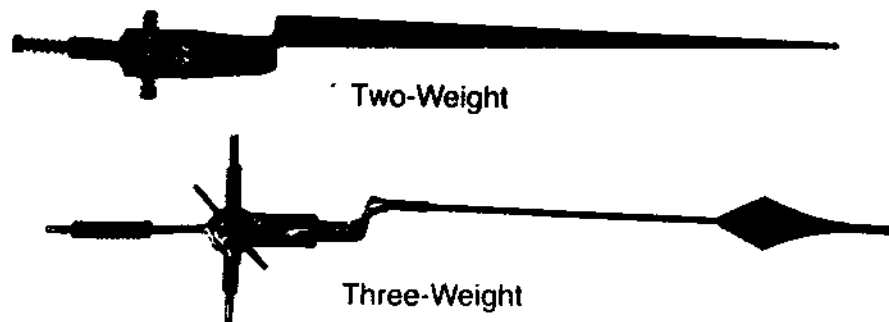


Fig. 34 – Typical Balance Weights

These weights should be inspected and tested to assure they will stay in place when subjected to a light force such as lightly turning with a pair of tweezers. Balance weights are installed in the factory with special tools. In the field, a pair of fine-point tweezers and a pair of broad flat-point tweezers should be used. Tools must be of stainless steel or other non-magnetic material when working on permanent-magnet instruments.

Threaded type weights may be turned using the fine-point tweezers. Helical coil weights are moved by gripping with flat tweezers to remove the curvature and then sliding the spring along the crosspiece, see Figure 35. Do not pull or push helical weights from one end. They will compress or expand and may fail to return to normal. Temperature or vibration relieves the stress.

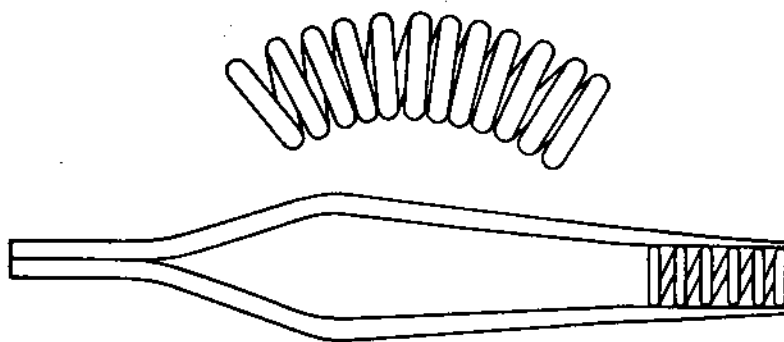


Fig. 35 – Proper Position of Tweezers in Handling Helical Weights

The correct balancing procedure is:

1. Place instrument in the dial-horizontal position and set zero.
2. With the dial vertical and pointer-horizontal (9 o'clock position), adjust the tailweight to cause the pointer to remain on zero.
3. Rotate the instrument to place the pointer in the upright (12 o'clock position) and adjust the side weights to cause the pointer to remain on zero.

4. Check in the normal position. The pointer should still be within the zero mark. If only slightly off zero, the tailweight can be moved a bit; otherwise repeat the balancing process.
5. Where the procedure above states "on zero", closeness is a matter of the degree of balance desired. The overall balance deviations can be the accuracy of the instrument unless there are rigid specifications.

G. Cleaning

A method of cleaning an instrument case is to use a damp chamois, lint free soft cloth, or lint free paper tissue. If necessary a mild dishwashing detergent may be used sparingly. Cleaning solutions containing other solvents should never be used. Except for removing lint with a soft brush or a puff of dry air from a bulb syringe, an instrument dial should be removed if it needs cleaning. Never use compressed air to blow an instrument dial clean. Stubborn dirt may be removed with a mild detergent. An art gum eraser will remove some dirt but the danger of eraser dust falling into the mechanism makes this a risky procedure.

If the mechanism is dirty it should be sent to an instrument repair shop equipped with washing facilities. If only a few stray pieces of foreign material are observed these may sometimes be picked up using a probe of drafting tape rolled back on itself, sticky side out, or if clearances are large enough, drafting tape rolled around a toothpick. This is especially effective in getting stray material out of an air gap. Never use compressed air to clean an instrument mechanism.

H. Shock and Vibration

Sawing, grinding, or filing a hole in a panel for an additional device can cause great damage to instruments already in place in the panel. Mechanical resonances set up during these operations can cause tremendous impact or vibratory forces. Taut-band panel instruments can suffer catastrophic damage (such as a broken band) under these circumstances. Pivot and jewel instruments suffer more subtle damage such as flat spots on pivots and cracked jewels. Taut-band switchboard instruments are especially capable to withstand damage from this kind of treatment.

I. Routine Testing

Instruments require care. It is good practice to set up a routine for checking all mounted instruments about every one or two years with a portable standard of 0.5% accuracy. A-c instruments should not be checked with a digital multi-meter, or rectifier type digital voltmeter,

unless the digital voltmeter, is one of the expensive rms responding types. The typical digital meter is average responding, and so are rectifier instruments. The errors on these, due to the ordinary distortion of commercial waveforms, will usually exceed the errors from all causes in a normal a-c instrument. Dynamometer or moving iron-vane portable standards should be used in a-c calibration testing.

19.7 Influences in Operation

A. Static Effects

All instruments have a tendency toward errors due to static charges on the case, window, and pointer. Glass windows usually do not hold a charge long enough to be troublesome, especially if mounted in a metal case. Plastic cases may be made permanently conducting with a special coating, but it is an opaque material so not suitable for windows or clear cases. There are a variety of anti-static agents, such as Westinghouse style 606B534G01, that can be used to coat plastic cases and covers. They are applied in liquid form by wiping or spraying on both inside and outside surfaces which are then buffed lightly with a dry cloth. This treatment will usually last from one to two years if not washed off. To test an instrument for excessive tendency to hold a charge, wipe the window vigorously with a dry cloth. If the pointer holds up-scale for more than thirty seconds the cover should be treated.

B. Magnetic Field Effects

Inasmuch as electrical instruments develop their torques by means of an internal magnetic field, they are subject to errors due to externally generated fields in the proximity of the instrument. Even field distortion due to the difference between ferrous and non-ferrous mounting panels will affect them. There is no way to predict errors because the effect is a function not only of the strength of the field, but its direction relative to the field within the instrument. It is possible to make some reasonably reliable generalizations:

(a) Permanent-magnet, moving-coil instruments of external or horseshoe-magnet type are susceptible to stray field errors. The stray flux can add or subtract directly from the flux generated by the magnet. This type of instrument will be encountered in some of the sensitive, older design panel meters. It is also used in some portable direct-current instruments. Panel types are usually unshielded so they are affected by the magnetic material adjacent to the instrument and by similar instruments mounted nearby. Portable instruments are shielded by a surrounding metal housing which will diminish the effects of any field or ferrous platform, but will not eliminate it.

(b) The direct-current mechanisms used in most modern instruments are inherently self-shielding. The permanent magnet is inside a structure of soft iron, so constructed that any stray flux is shunted around instead of passing through the air gap. If the stray flux is in a direction parallel to the coil shaft it will pass right through the instrument but its effect will be balanced out to zero as it passes through both coil halves in the same direction. In direct-current switchboard types the axial air gap mechanisms are more susceptible to external field errors than the radial air gap types. Switchboard instruments which use a steel case have enough shielding to bring the axial type well within standards. This difference should be considered when replacing radial air gap direct-current instruments with axial air gap types, especially if problems are encountered in a high flux environment. The effect of a unidirectional field is much greater than that of an alternating field on a permanent-magnet instrument.

(c) The instruments most susceptible to magnetic field influences are the moving iron-vane and dynamometer types. Unidirectional and alternating fields have about the same effect on these instruments. The panel types are usually unshielded and errors in strong fields can be gross.

There is no requirement in ANSI C39.1 specification relative to external magnetic field influences on panel instruments. Some manufacturers will furnish shields in the form of a can to fit over the instrument case. Effectiveness is variable. Switchboard and portable instruments have a requirement that necessitates shielding. It is provided in the form of a steel case or a shield around the mechanism only. See Figure 36.

External shielding may be improvised to improve a poor magnetic environment; this is a cut-and-try process when done in the field. The first consideration is to get buses and cables as far away from the instruments as possible, preferably in separate compartments separated by steel barriers. To further protect an instrument, a barrier of steel can often be constructed around the instrument or between it and the source of the flux. Such barriers may affect the calibration of otherwise unshielded instruments, so the cut-and-try process may result in trading one error for another. Generally, the closer the barrier or shield is to the mechanism there is less effect from external fields but greater errors in basic calibration. In really bad cases, consideration may be given to the use of rectifier type alternating-current instruments, this may, however, be simply trading for waveform error.

The goal is to find a way to get the instrument away from exposure to strong external fields by re-mounting or shielding. Instruments should never be exposed to strong external magnetic fields.

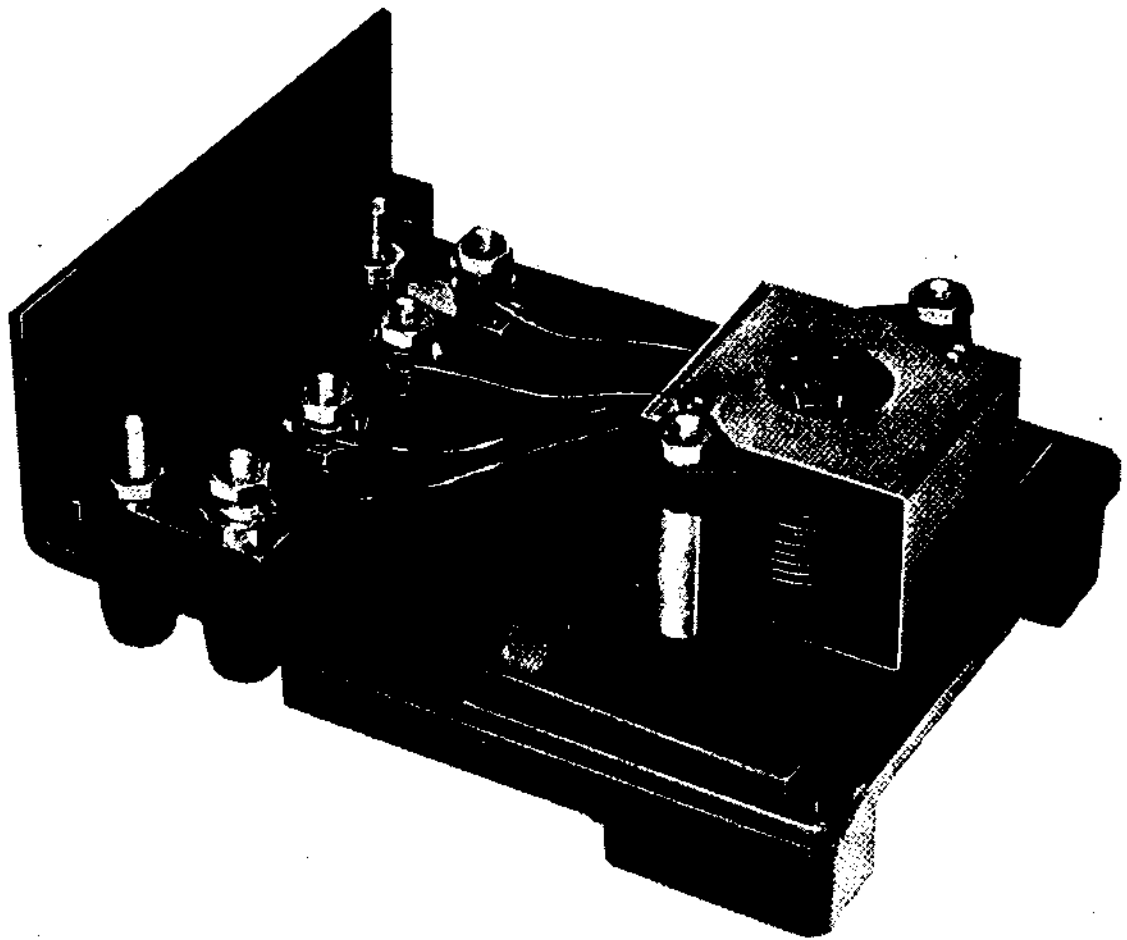


Fig. 36 – Position of Magnetic Shield in an A-C Portable Instrument

19.8 Care of Instruments

A. Replacing Glass Windows

If an instrument window has been broken, it is important to take the instrument out of service immediately, especially a portable instrument. Glass particles can cause serious damage if they work their way into a mechanism. The best procedure is to replace the complete cover and glass assembly after thoroughly inspecting and cleaning the instrument of any glass fragments. If a complete cover assembly is not available, the glass only can be replaced. Break off all fragments of glass and scrape off all cement down to bare metal or plastic. Use a factory-cut replacement glass if available or have one cut locally but, it must be no thicker than the original; a thicker glass can cause re-assembly problems. Most instruments use glass $\frac{1}{16}$ inches thick. The glass is installed using an air-drying neoprene cement or, in an emergency, substitute the cement used to hold rubber parts to metal on an automobile; the cement must remain flexible. Glass windows on portable instruments are made from laminated safety glass. It is seldom available in the proper $\frac{1}{16}$ inch

thickness, except from the factory; temporary use of regular glass is not recommended.

Some instruments use metal retainers as well as cement. These retainers should be reinstalled after the cement has cured; overnight cure is recommended but it can be accelerated with mild heat for an hour or so. Edgewise and some rectangular cases have one-piece plastic covers which must be replaced as an assembly if the window has been damaged.

B. Refinishing

If the surface of an instrument case is in good condition it may be refinished by washing with detergent, rinsing with pure water, drying, and spray painting with acrylic lacquer. Acrylic air drying lacquer is available in spray cans from automobile supply houses. Masking tape should be used to protect windows while painting cases. If a metal case is in bad condition it should be stripped, sanded, and refinished with acrylic primer and lacquer. Plastic cases in bad condition should be scrapped. Paint solvents will damage the plastic if stripping is attempted. Plastic cases in good condition can be repainted.

After a plastic cover has been repainted it should be anti-static treated.

C. Changing and Replacing Dials

It is often necessary to change instrument dials or scales. In most designs this is readily done, some require special tools, on those types it is frequently simpler to replace the instrument.

Some instrument scales are hand-calibrated and some are machine printed, it is difficult to recognize the difference, so when ordering an accurately calibrated replacement scale the replacement order should include a tracing or photocopy of the original. Replacement scales are available from instrument manufacturers and from instrument service centers. Replacement procedure is simple:

- (a) Clean the surrounding panel area thoroughly.
- (b) Remove instrument cover and set aside in inverted position.
- (c) Remove instrument mask and dial noting position of any locators.
- (d) Replace dial and mask after copying.

(e) On some instruments this disturbs the pointer stops. Make sure the stops restrict the pointer to a degree or two above and below the scale end points.

(f) Clean and replace cover.

(g) Set zero.

19.9 Direct-Current Instruments

The permanent-magnet, moving-coil type of instrument is most frequently used for direct-current measurements, some digital meters are also used. Digital instruments, when equipped with the proper internal resistors and shunts, may be used interchangeably with the permanent-magnet, moving-coil types in most applications. Dynamometer or iron-vane instruments can be used where an rms value of pulsed direct-current is to be measured.

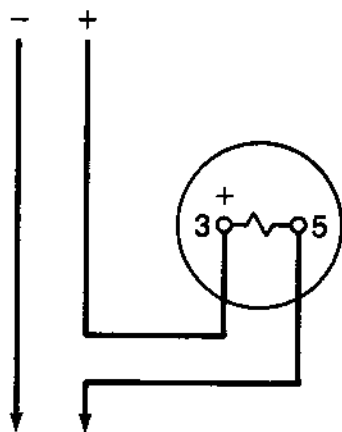
Current measuring instruments, for direct-current, fall into three general classifications depending on the magnitude of current. Microammeters measure from .000,001 to .001 amperes, milliammeters from .001 to 1.0 amperes, and ammeters from 1.0 amperes up. Microammeters and milliammeters, while they may be internally shunted, connect directly in series with the circuit being measured. Ammeters are available (self-contained) for series connection up to about 50 amperes. Above 50 amperes and sometimes down to as low as 0.5 amperes an external shunt is used with a millivoltmeter scaled to read in amperes.

Figure 37 illustrates connections for various switchboard direct current measuring instruments. These are typical, terminal identification will vary with the manufacturer.

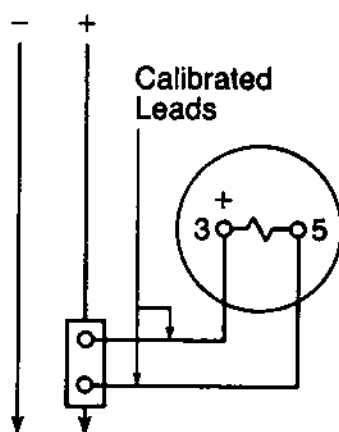
A. Troubleshooting Direct-Current Ammeters

Internally or externally shunted ammeters are subject to very few problems because the shunt helps to protect the instrument coil. Below 10 or 12 milliamperes most instruments will carry the measured current through the moving coil, but sustained overloads or extreme short-time overloads can cause burnout or torque spring damage. ANSI standards call for momentary overload withstand test of 10 times normal current. This is about normal for pivot and jewel instruments. The taut-band type, though variable from rating to rating, will take from 50 to 150 times rated current on the same test without damage. The limiting factor is usually the ability of the shunt to store heat.

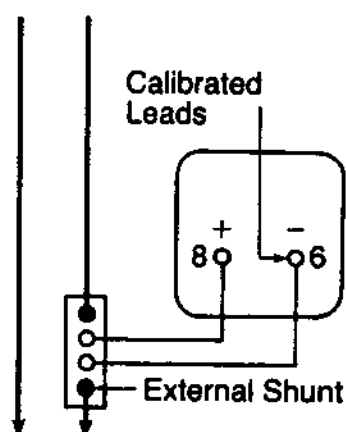
Dc Microammeter, Milliammeter, Ammeter, Self-Contained, KX-221, KX-231, KX-241, KX-261



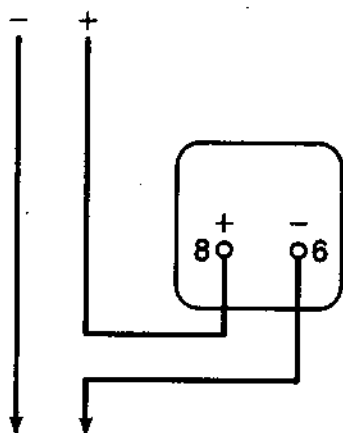
Dc Ammeter With External Shunt, KX-221, KX-231, KX-241, KX-261



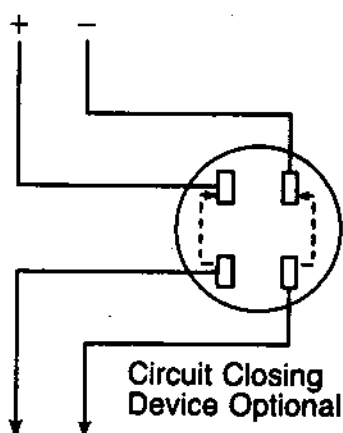
Dc Ammeter With External Shunt, KX-251, UX-251



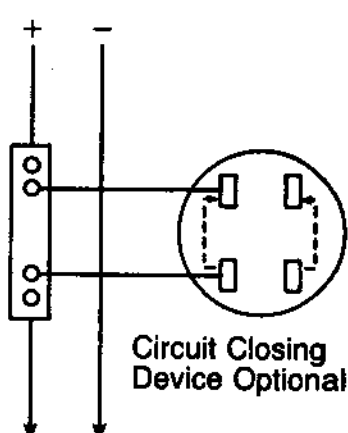
Dc Microammeter, Milliammeter, Ammeter, Self-Contained, KX-251, UX-251



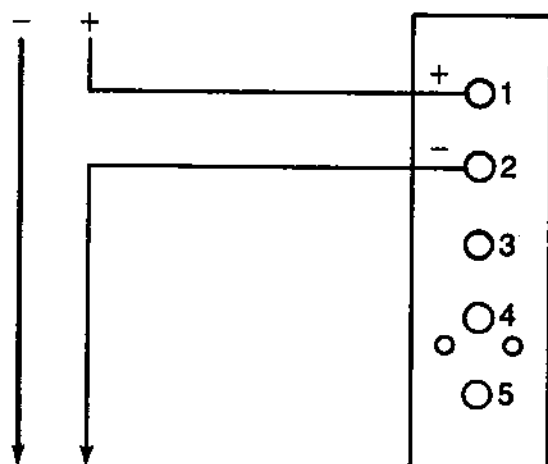
Dc Ammeter, Self-Contained, EX-251



Dc Ammeter For Use With External Shunt, EX-251



Dc Microammeter, Milliammeter, Ammeter V-252, H-252



Dc Ammeter With External Shunt V-252, H-252

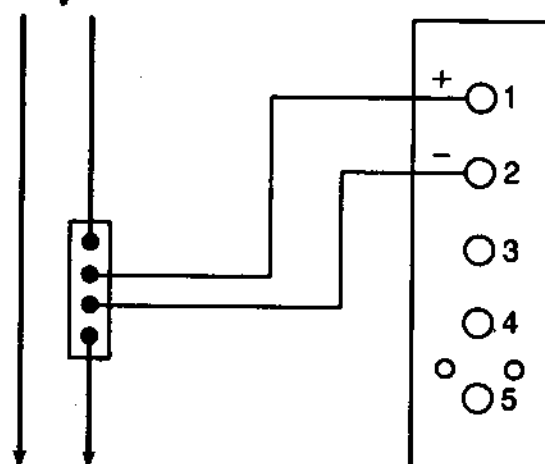


Fig. 37 - Current Measuring Instruments for Direct Current - Schematics

1. Reading Downscale. When a direct-current instrument reads downscale the leads at the instrument should be reversed.

No Indication. If there is no indication by the pointer, but the instrument circuit is live beyond the ammeter, the trouble is in the coil circuit in the instrument. Except for a possible open shunt connection no repair is possible in the field. If the circuit beyond the ammeter is dead, and shorting the terminals makes the circuit live, the ammeter shunt has failed and the instrument must be repaired or replaced. In rare circumstances an ammeter shunt can be open and still pass a test voltage through the instrument coil, but normally if the circuit is energized full voltage will burn out the ammeter coil.

2. Sticking Pointer. If there is some pointer movement but the pointer hangs up at a specific point, investigation should be made for dirt and pivot clearance, there could be coil-to-magnet interference. In a taut-band suspension instrument there is a probability of dirt in the mechanism.

3. Pointer Floating. If the pointer floats aimlessly there is probably a broken or burned out hair spring or taut-band. Taut-band failure will also often cause the element to shift axially and introduce some friction. The instrument will require shop repair or replacement.

4. Overheats. There are conditions under which a direct-current ammeter will indicate normal load yet overheat from overload. The rms current (heating value) may be considerably higher than the average current (as indicated) on intermittent or pulsed currents. A larger shunt and possibly a special rated instrument may be required for the application.

5. Incorrect Readings. If readings are incorrect when checked against a test ammeter known to be correct, zero adjustment and balance should be checked. To make these checks the instrument must be removed from the panel so it can also be checked against a portable standard. If inaccurate when checked against the standard, it should be sent for shop repair or replaced. If it agrees with the reading on the standard, the following checks should be made: position, static effects, magnetic field effect, shunt or shunt lead error. If the instrument has a rheostat for shunt lead compensation it should also be checked. Adjustments should be made using a portable standard millivoltmeter with its calibrated leads connected directly to the shunt in parallel with the questionable instrument and its leads. Necessary adjustments should be made until the readings agree. Spring convolutions on a pivot and jewel instrument may be touching each other or an adjacent part. Check calibration after correcting any defects of this type.

If none of the above checks and tests correct the trouble the instrument and its external shunt should be replaced. If after replacement the trouble persists, tests for magnetic field effect should be made. Persistence in the trial and error method is required when there are no apparent mechanical or electrical causes.

B. Direct-Current Potentials

D-c potentials in electrical power apparatus are measured with millivoltmeters with a range of .001 to 1.0 volts, since accurate analog millivoltmeters are not available below 10 or 50 mv, and with voltmeters from 1 to 1000 volts. Beyond 1000 volts there are no self-contained kilovoltmeters, except for some few portable instruments. Measurements in the higher voltage range are made with a separate high-voltage resistor and a milliammeter calibrated in kilovolts.

Most d-c voltmeters for power measurement consist of a basic movement of approximately 1 ma full scale fed through a resistance element. This limits the current to the movement and, with full scale voltage applied, the current will be 1 ma. This type of instrument is referred to as having a sensitivity of 1000 ohms per volt. Using Ohms

law, sensitivity becomes: $R = \frac{E}{I} = \frac{1}{.001} = 1000 \text{ ohms per volt.}$ On

the other hand, when voltmeters are installed in low energy circuits, they may have a considerably higher sensitivity such as 50,000 ohms per volt (20 microampere).

There are special considerations in a "millivoltmeter" of (50 mv – 50 ohms) drawing 1 ma, that differentiates it from a "milliammeter" drawing 1 ma with a terminal resistance of 50 ohms and a 50 mv drop across its terminals. A milliammeter has an internal circuit consisting principally of copper, while a millivoltmeter has at least 75 percent of its resistance in manganin or other low-temperature coefficient materials. Both instruments actually respond to current but in the case of the millivoltmeter the coil current is determined by the total resistance. With most of the resistance in manganin, there is a minimum accuracy change with temperature. This balancing out of the temperature error of copper or aluminum with higher resistance of manganin is called swamping.

Figure 38 shows typical connections to millivoltmeter instruments.

Dc Voltmeter,
KX-221, KX-231, KX-241,
KX-261

Dc Voltmeter, Self-Con-
tained, KX-251, UX-251

Dc Voltmeter, Self-Con-
tained, V-252, H-252

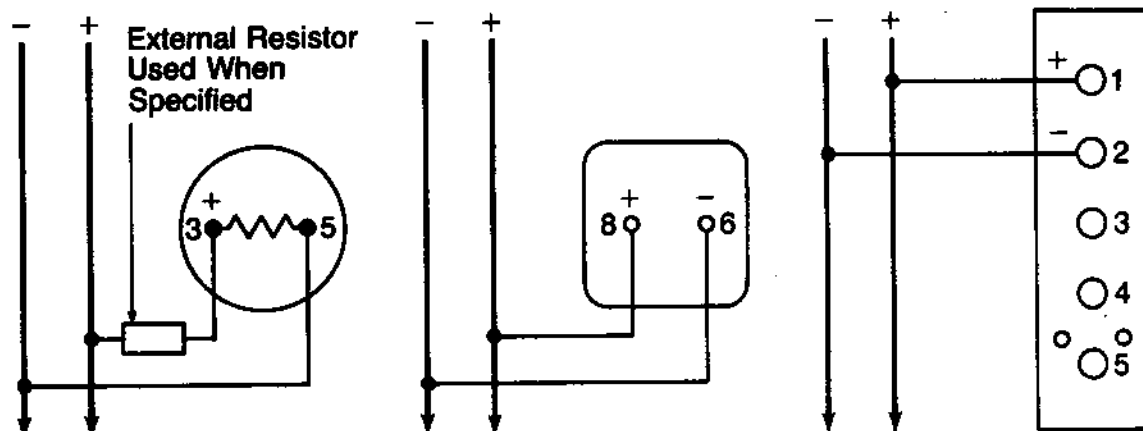


Fig. 38 – D-C Millivoltmeter, Voltmeter – Schematic

C. Troubleshooting Direct-Current Voltmeters

Direct-current voltmeters are somewhat more vulnerable to damage than ammeters because there is no component to protect the coil or suspension springs from accidental overloads. If the instrument is subjected to a short-time overload in excess of its overload capacity as a milliammeter, the coil, hair spring, or suspension band will burn out. If there is a sustained overload within the mechanism's capability as a milliammeter, the resistor will burn up. ANSI standards limit the change (due to 120% sustained overload) to one-half the accuracy rating of the instrument. The actual overload at which resistor burn-out will occur is variable between models and ratings, but 200 percent is an average value.

1. *Reading Downscale.* When a direct-current voltmeter reads downscale the leads at the instrument should be reversed.

2. *No Indication.* The circuit should be traced through with a test voltmeter. If there is voltage across the terminals there is an open resistor, coil, or spring in the instrument and it must be removed for shop repair or replacement.

A temporary replacement resistor may be installed using a combination of wire wound or metal film resistors equal to the voltage rating times ohms per volt sensitivity. This will not be as accurate as the original resistor because the instrument's magnetization was matched to the actual value of the original resistance during manufacture. Resistors should always be large enough; calculate as $\text{watts} = I^2R$.

If there is no voltage across the terminals, there may be a blown fuse in the instrument circuit or a defective separate resistor. Many instruments are fused or protected by an external resistor.

Sticking Pointer – see under 19.9-A *Troubleshooting Direct-Current Ammeters*

Floating Pointer – see under 19.9-A *Troubleshooting Direct-Current Ammeters*

3. Instrument Resistor Overheats. Direct-current voltmeter resistors will sometimes overheat at rated current if subjected to extreme pulsating currents driving the instrument to a normal reading. If this type of problem is discovered, a resistor of higher wattage should be used.

4. Readings Incorrect. If the readings are incorrect, the same calibration checks should be made as for d-c ammeters (see A.5 *D-C Ammeters – Incorrect Readings*, above) except that lead resistance becomes a factor only on millivoltmeters of very low resistance and high sensitivity. A direct-current voltmeter can be adjusted up or down by shunting or adding to the resistance in series with the coils as an emergency field procedure. In the shop it would be done by re-magnetization.

5. Pointer Overshoots. If the pointer overshoots and takes some time to settle down following a load change, incorrect damping is indicated. Damping is inherent in direct-current instruments except for millivoltmeters not used with shunts. The poor damping referred to here indicates incorrect source resistance. This requires that the circuit of the instrument must be changed.

D. Direct-Current Wattmeters

Direct-current power (watts) is the product of current and voltage. It can be measured by simply multiplying the readings of an ammeter and a voltmeter (amperes $\times$ volts = watts). Fortunately, the multiplying can be done with a single instrument (a wattmeter) which reads directly in watts. There are digital wattmeters which multiply electronically but these are laboratory type devices. On electrical apparatus the d-c wattmeter will usually be an iron-core dynamometer. Most self-contained a-c dynamometer wattmeters may be used on d-c. However, it is advisable to run two tests, reversing current and potential leads for the second. If there is a difference in reading, the average will be the correct value. Dynamometer wattmeters will read correctly on pulsed d-c at the pulse rates from power rectifiers but the resistors or shunt may overheat if the instrument is operated full scale with form factors over 1.5 on either current or voltage. Connections for typical instruments are shown in Figure 39.

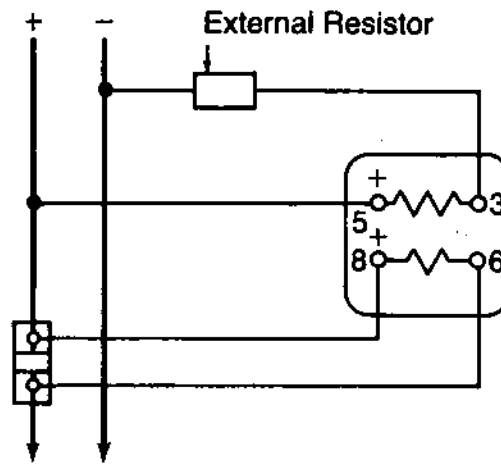


Fig. 39 - D-C Wattmeter with Shunt - Schematic

E. Troubleshooting Direct-Current Wattmeters

The current and voltage circuits should be checked out as recommended for d-c ammeters and voltmeters, with these exceptions: If the instrument reads downscale, reverse either the current or the voltage circuit terminals, not both. If the pointer overshoots, shop repair is indicated as dynamometer instruments are damped with either an air chamber or an aluminum disc moving in a magnetic field.

19.10 Alternating-Current Measurements

For a-c measurements there are a variety of instrument types. Before going into these it will be necessary to understand some of the special considerations in a-c measurement.

Electrical power calculations are made in terms of root mean square (rms) values. These yield true power as defined by the heating effect of a current. Figure 40 shows the relationship between rms and average and peak values for a pure sine wave and for one with 30% third harmonic distortion. Each has the same rms value.

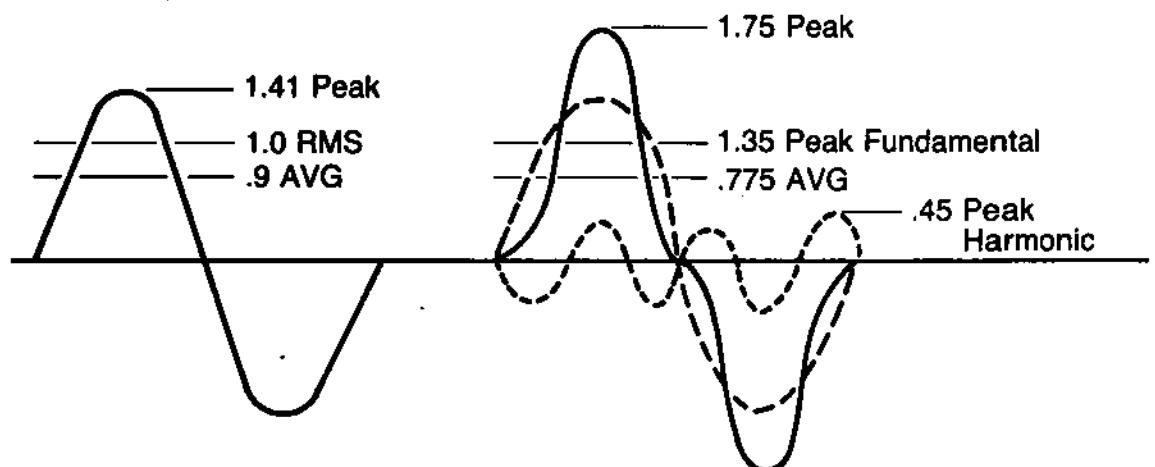


Fig. 40 - Effect of Harmonics on a Sine Wave

If an instrument is defined as rms responding (or sensing), it will read 1.0, or the same in each instance. Moving iron-vane, dynamometer, thermocouple and certain compensated digital instruments and calibration standards are in this category.

If the instrument is average responding, it will read 0.9 in one case and 0.775 in the other. Certain special rectifier instruments are calibrated in this manner for magnetic measurements.

If the instrument is average responding and rms calibrated for sine wave, it will read $.9 \times 1.11$ or 1.0 on the pure sine wave but it will read only $.775 \times 1.11$ or 0.86 on the distorted wave, see Figure 41. Rectifier a-c instruments are of this type, as are all industrial test sets of the VOM, TVOM and less expensive types. Digital DMMs and DVOMs of the portable type are also of this type except for those relatively few expensive models which are certified as being rms responding.

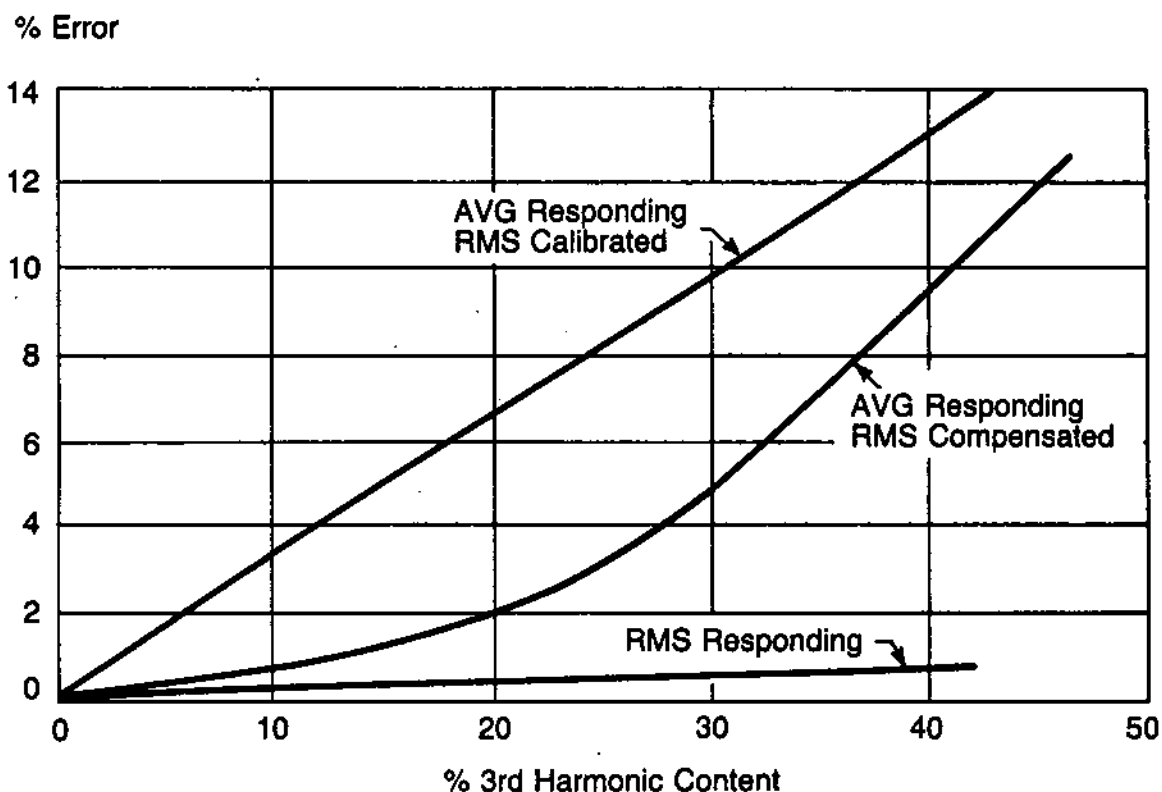


Fig. 41 - Performance of Typical Instruments with Distorted Wave Form Inputs

An approximate rms compensating circuit can be added to a rectifier instrument to partially correct for waveform error within a set range of harmonics.

As generated by a rotating generator, waveform is essentially a pure sine wave, but an alternating current wave depends upon the nature of

the load. An SCR drive uses only pieces of a current wave and so does a welder, or any device using firing-angle control. Gas discharge lamps have a badly distorted current waveform. Half-wave rectifiers use only the positive or the negative sides of the wave and voltage waves generated by static devices are only approximate sine waves.

Although alternating current is defined as a sine wave function it is rarely true in practice. This can be demonstrated by comparing readings of a 0.1% accuracy laboratory type digital voltmeter which is rms responding with a typical DVOM or DMM of 0.5% accuracy, and a portable analog a-c iron-vane or dynamometer instrument of 0.5% accuracy class, all plugged into a number of industrial and commercial circuits. The difference between digital readings will be substantial in most cases, gross in others. The portable analog instrument will track the 0.1% rms laboratory instrument quite closely.

The DVOM or DMM portable instruments are offered as average responding or average sensing, and rms calibrated. This means that the instruments will correctly read rms values corresponding to the average values which they measure but only if the waveform is a perfect sine wave. Deviations which cannot be detected on a five-inch scope will cause significant errors in instrument readings. DVOM and DMM test equipment is excellent for direct-current measurement and good for approximate alternating-current measurement in troubleshooting, for resistance measurement, and continuity checking. They are inadequate for alternating-current power circuit measurement under most conditions.

The same general comments apply to the use of analog type VOM, VTOMs and TVOMs. They, too, are average responding (rectifier type) devices which read within expected accuracy only on a perfect sine wave. This is also true of commercial grade, rectifier type, portable instruments. They are special-purpose instruments which should not be used for general power system measurements.

As a matter of interest, ANSI C39.1 specification for 0.5% class "portable instruments" permits a waveform influence for 30% harmonic content of 1.25%. By a fundamental relationship, this influence will be in excess of 9.0% for the "average responding" digital or analog test set or any "uncompensated" rectifier instrument. One of the real sources of problems in a-c instrument checking is the use of regulated or adjustable voltage sources, using either SCR control or resonance for regulation. Waveform is so bad that reasonable results cannot be obtained.

The moving iron-vane mechanisms are generally used for measuring alternating-current. Instruments can be manufactured with a heavy coil, so self-contained ratings are available up to 20 or 50 amperes, depending on type. At currents of 10 amperes and above, the instruments are usually built with 5 ampere coils for use with current transformers. Rectifier type ammeters are sometimes used where burdens must be small, or where the frequencies are high. Some edgewise a-c ammeters are rectifier type for the reason that the d-c mechanism has better shielding and these instruments can be mounted very close together. These ammeters may or may not be rms compensated, they are all average responding.

A. Alternating-Current Ammeters

In many applications, ammeters are called upon to carry substantial overloads (as in motor starting) for a short period of time. They also are subjected to extreme momentary overloads during fault conditions. The following table shows the time, in seconds, at which a typical 5 ampere ammeter will withstand specific overloads bordering on the threshold of thermal damage but, with cooling to room temperature allowed between tests.

Table 1. Typical Overload Withstand Times, in Seconds

Current Amperes	Edgewise Ammeter	Circular Scale Ammeter	100 Degree Ammeter	Transducer Wattmeter
300	.8	3.1	2.1	1.1
200	1.3	7.5	6.0	2.3
150	2.0	14.3	10.4	3.4
100	4.0	40.0	25.0	8.0
50	25.5	175.0	127	38.0

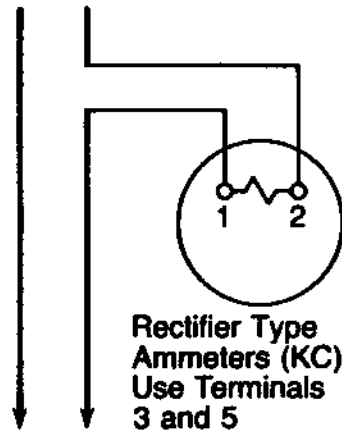
1. Ammeter Connections

Commonly used alternating-current ammeter connection schemes are shown in Figure 42.

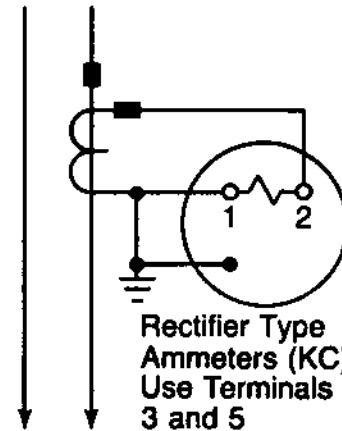
Polyphase Connections

For readings on all phases of polyphase systems suitable switching circuits are used. The 3-phase 3-wire scheme uses only two current transformers because the vectorial sum of the three currents is zero, see Figure 43. The switch used to switch a single ammeter between currents must have a short-circuiting position which shorts out any transformer not in the circuit. A make-before-break switch is used so the current circuits are never opened, even momentarily. See Figure 28 for transformer connections.

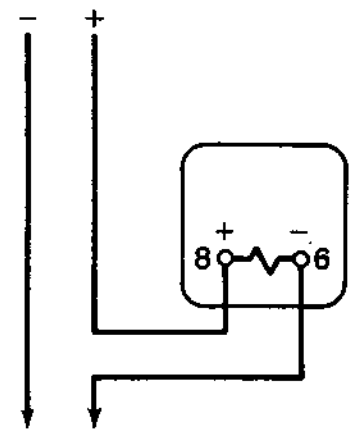
Ac Microammeter,
Milliammeter, Ammeter,
Self-Contained, KA-221,
KC-231, KA-241, KC-
241, KA-261, KC-261



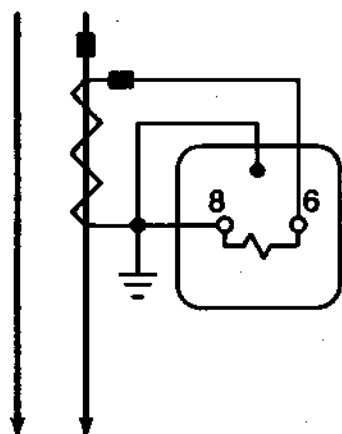
Ac Ammeter, With
Current Transformer,
KA-221, KC-221, KA-231,
KC-231, KA-241, KC-241,
KA-261, KC-261



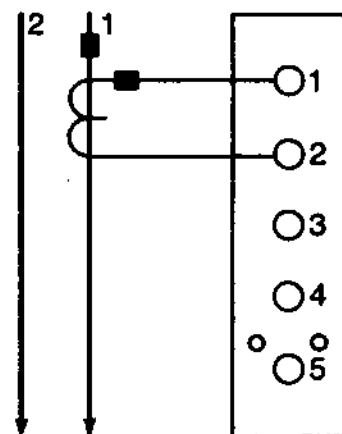
Ac Milliammeter,
Ammeter, Self-Con-
tained, KA-251, UA-251



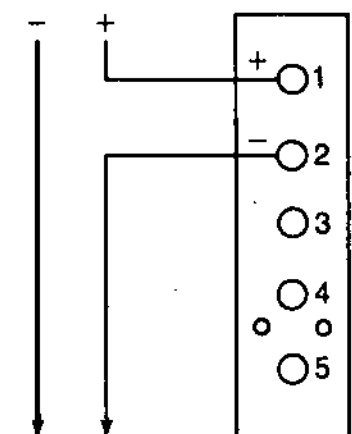
Ac Ammeter With Cur-
rent Transformer, KA-
251, UA-251



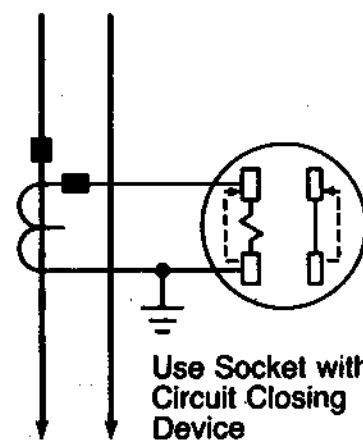
Ac Ammeter With Exter-
nal Current Transformer
V-252, H-252



Ac Milliammeter,
Ammeter V-252, H-252



Ac Ammeter With Cur-
rent Transformer, EA-251



Ac Ammeter, Self-Con-
tained, EA-251

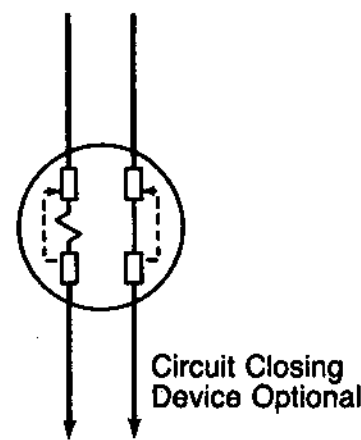


Fig. 42 - Commonly Used Ammeter Connection Schemes

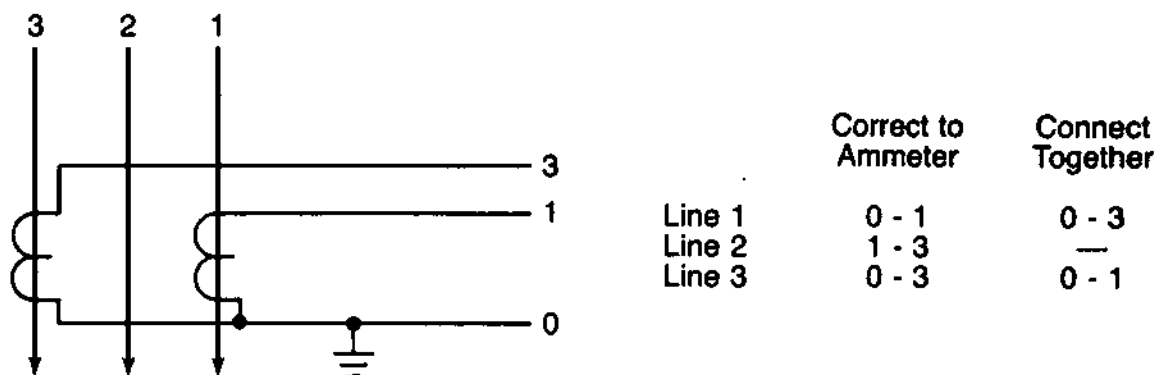


Fig. 43 – Ammeter Connections for a Three-Wire, Three-Phase Circuit

In the 3-phase 4-wire scheme there must be a current transformer on each leg as shown in Figure 44. In this scheme the vectorial addition of currents equals the current in the neutral (zero on a balanced system). An ammeter transfer switch must short out the unused transformers and prevent open circuitry during a position change of the switch.

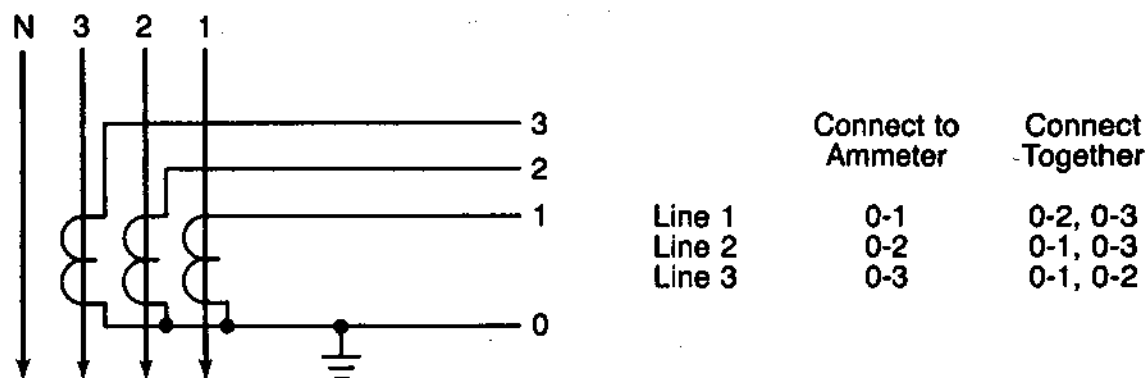


Fig. 44 – Ammeter Connection for a Three-Phase, Four-Wire Circuit

2. Troubleshooting Alternating-Current Ammeters

Operating difficulties with a-c ammeters, moving iron-vane type, are rare. The current flows only through the operating coil. Vane saturation prevents extreme torques and the coil structure is readily insulated. It is generally a sturdy device.

a. No Indication

The failure to show any indication often is caused by a short circuiting jumper left on a current circuit. Occasionally a moving vane comes loose on a shaft or a damping vane or magnet will come loose, but open coil circuits are extremely rare except in low-reading, self-contained instruments. If a coil circuit were to open on an instrument connected to a current transformer (except a doughnut transformer) there would be a powerful high voltage arc which would probably destroy the instrument.

b. Sticking Pointers

If the pointers stick, a check should be made for a broken suspension band or a damaged pivot, jewel, or spring. Interference between damping vane and damping magnet is also a possible cause, as is misalignment of the moving vane. A magnetic particle in the damping magnet air gap is a frequent source of sticking pointer trouble.

If a pointer floats, a broken taut-band or hairspring could be the cause, if so, shop repair or replacement is required.

c. Readings Incorrect

If the instrument readings are incorrect, the zero setting should be confirmed, then a comparison check run against a portable standard, if found to be incorrect, the instrument should be removed from the panel and the balance checked.

If the instrument is checked and proves accurate on the bench it should be reinstalled in the panel. If there is error after reinstallation it is most probably caused by magnetic field effect. The ammeter leads should be positioned as shown in Figure 45 for any unshielded instrument. A check for magnetic influence should be made on any adjacent current carrying buses and cables. If a serious magnetic influence cannot be corrected it may be necessary to change to a rectifier type ammeter, recognizing the potential for wave-form errors.

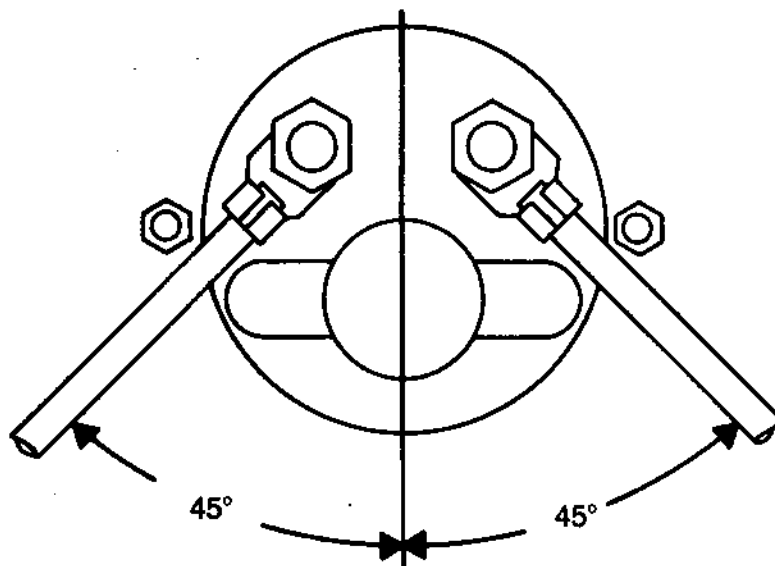


Fig. 45 - Correct Lead Position for Unshielded A-C Ammeters

If the instrument is found to be incorrect on bench test and after adjusting balance, shop repair or replacement is indicated. In the repair shop the instrument can be checked for a loose or displaced stationary vane which is somewhat adjustable on some instruments. In circular-scale instruments one of the stationary vanes can be rotated to change the distribution. See Figure 46.

Vaness must never be bent to adjust an instrument, bending changes the magnetic characteristics of the material so the instrument may never perform correctly.

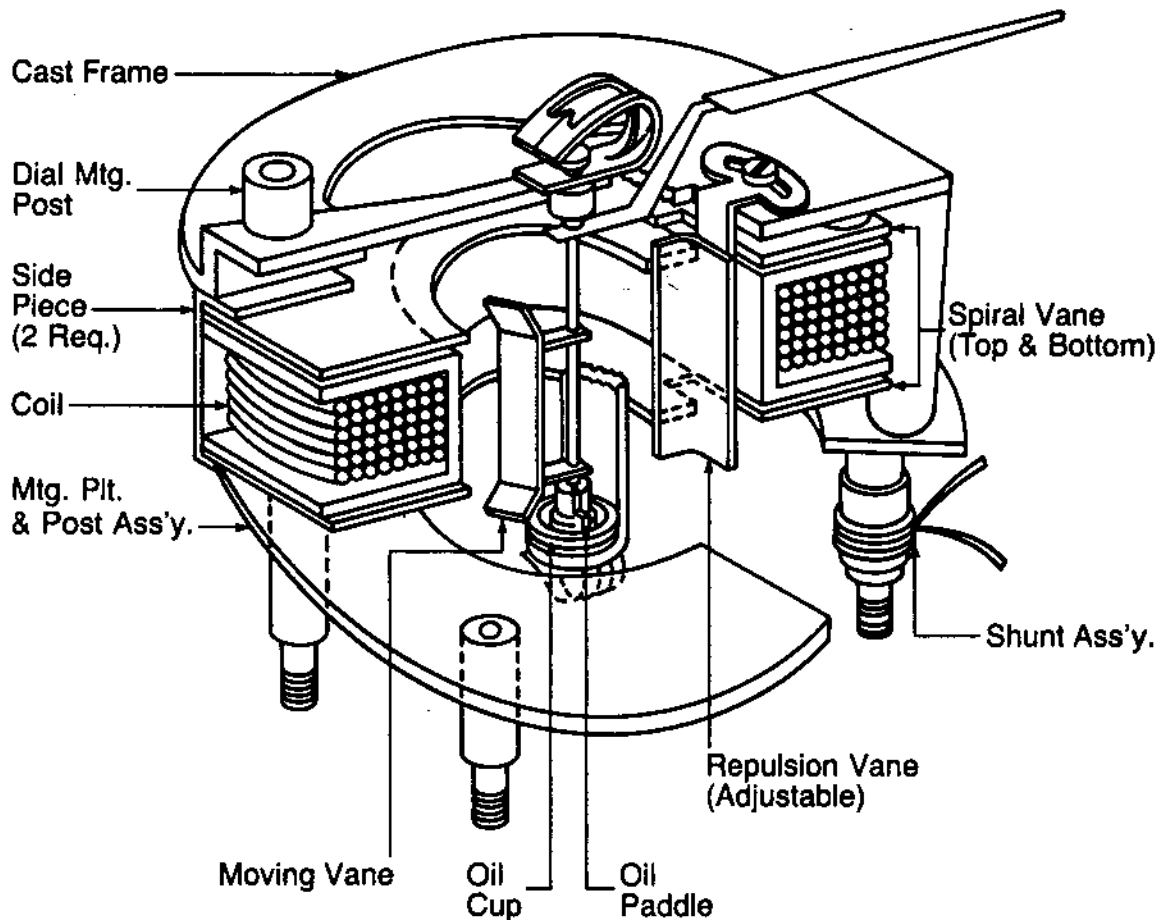


Fig. 46 - Spiral Vane Mechanism

B. Alternating-Current Voltmeters

The mechanisms used in a-c voltmeters are the same as those used in a-c ammeters. Voltmeters are in fact, milliammeters with a series resistance to limit current when voltage is applied to the instrument.

Alternating-current voltmeters are commercially available at 800 volts and below as self-contained devices, but safety and other considerations make the transformer rated instruments more common. This type of

instrument is usually rated at 150 volts full-scale and is used with a voltage transformer of 120 volts nominal. The instrument is scaled to match the transformer.

Voltmeters are rarely expected to carry overloads and are usually designed with 120% of full scale as a continuous maximum. Their momentary capability is about 35 times rating and is limited by the thermal capacity of the series resistor. The saturation of the iron-vane keeps the mechanical forces within reason.

1. Alternating-Current Voltmeter Connections

The standard voltage transformer configurations are shown in Figure 28 for 3-phase 3-wire and 3-phase 4-wire applications. The voltmeter connections shown in Figure 47 are based on the transformer configurations in Figure 28.

Many different hook-ups may be used with voltmeters depending on voltage transformer configurations and the meter reading desired. For example: on a 3-phase 4-wire system, 14.4/25 kV wye, there will be three voltage transformers (120:1 ratio), (14.4 kV to 120 v) connected line to ground as shown in Figure 48. The associated voltmeters will be:

(a) Connected line to ground, full scale 125 volt, calibrated 0-15 kV line to ground voltage.

(b) Connected line to ground, full scale 150 volt, calibrated 0-18 kV line to ground voltage.

(c) Connected line to ground, full scale 144.4 volt, calibrated 0-30 kV line to line voltage.

(d) Connected line to line, full scale 250 volt, calibrated 0-30 kV line to line voltage.

For (a), (b), (c) connect voltmeter N-1, N-2, or N-3. For (d) connect voltmeter 1-2, 2-3, or 3-1.

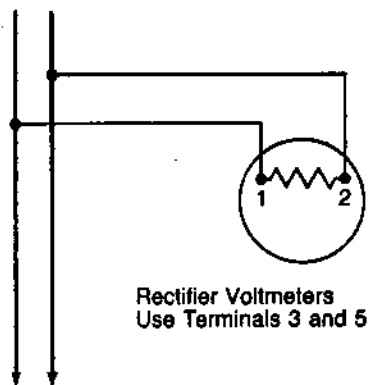
2. Troubleshooting Voltmeters

Basic considerations are the same as those for troubleshooting a-c ammeters.

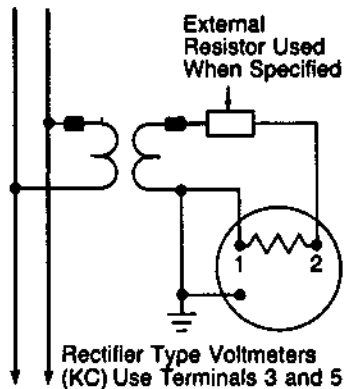
a. No Indication

When there is no indication on the voltmeter the cause is most likely to be a blown voltage transformer fuse, a loose connection, or an open-circuited instrument. The instrument should be checked with a test voltmeter connected across the terminals. An open-circuited resistor can be

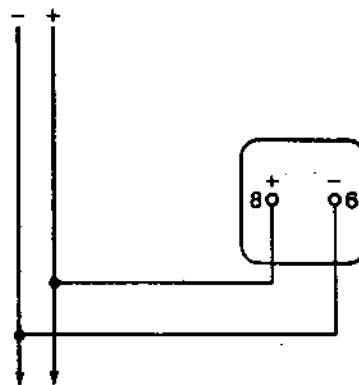
Ac Voltmeter, Self-Contained,
KA-221, KC-221, KA-231, KC-231,
KA-241, KC-241, KA-261, KC-261



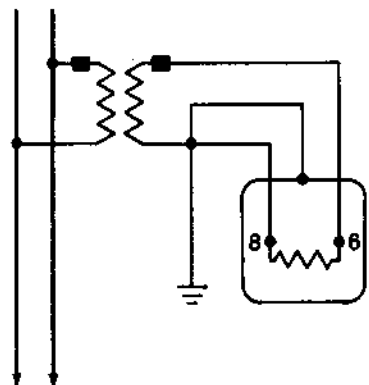
Ac Voltmeter, With Potential
Transformer, KA-221, KC-221,
KA-231, KC-231, KA-241, KA-261



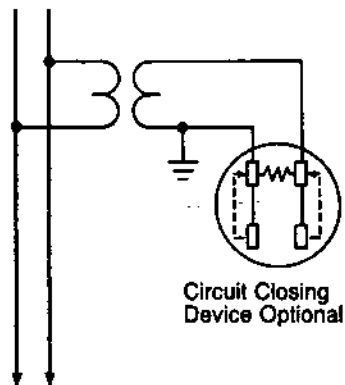
Ac Voltmeter, Self-Contained,
KA-251, UA-251



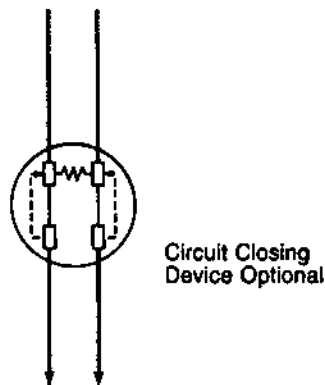
Ac Voltmeter With Potential Trans-
former, KA-251, UA-251



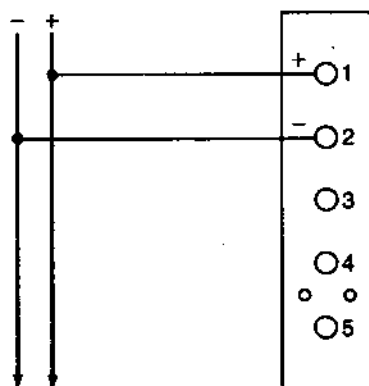
Ac Voltmeter, Self-Contained,
EA-251



Ac Voltmeter With Potential Trans-
former, EA-251



Ac Voltmeter Self-Contained V-252,
H-252



Ac Voltmeter With External Potential
Transformer V-252, H-252

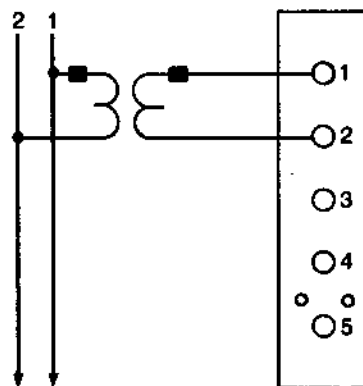
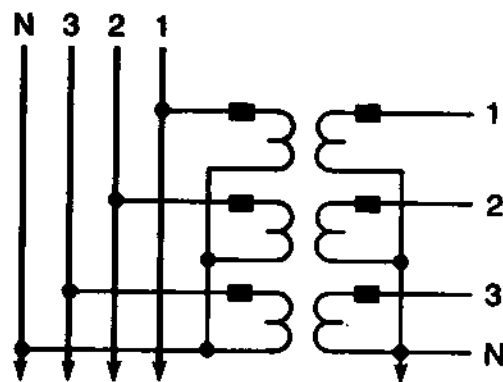


Fig. 47 - Frequently used A-C Voltmeter Connection Schemes



For (a), (b) or (c) connect voltmeter to

N-1, N-2 or N-3

For (d) connect voltmeter to 1-2, 2-3 or 3-1.

Fig. 48 – Voltmeter Switching Connections, Three-Phase, Four-Wire

replaced with an approximate equivalent on a temporary basis but the instrument should go to an instrument repair shop for proper repair.

b. Sticking pointer — see under 19.10-A-2 *Troubleshooting A-c Ammeters*.

c. Floating Pointer — see under 19.10-A-2 *Troubleshooting A-c Ammeters*.

Readings Incorrect. If the readings are incorrect the procedures given under a-c ammeters, page 3, should be followed. In addition, on many a-c voltmeters there is a calibrating rheostat brought out through the rear of the case. It can be used to make adjustments up to 5% in calibration.

If there is no rheostat, a similar or greater change can be made by changing the series resistance value. Any change using this method will be proportionate throughout the range of the instrument. It is imperative that the entire range of calibration be re-checked after making a resistor adjustment.

19.11 Special Purpose Alternating-Current Voltmeters

A. Rectifier Type

The permanent magnet, moving coil mechanism is used frequently for measuring alternating current by inserting a rectifier ahead of the instrument coil, see Figure 49. Rectifier mechanisms are used in all analog type VOM's, in most edgewise, panel, and switchboard instruments, and in a-c and d-c portable instruments, and in any a-c instrument where the burden must be kept low. The rectifier type is also used

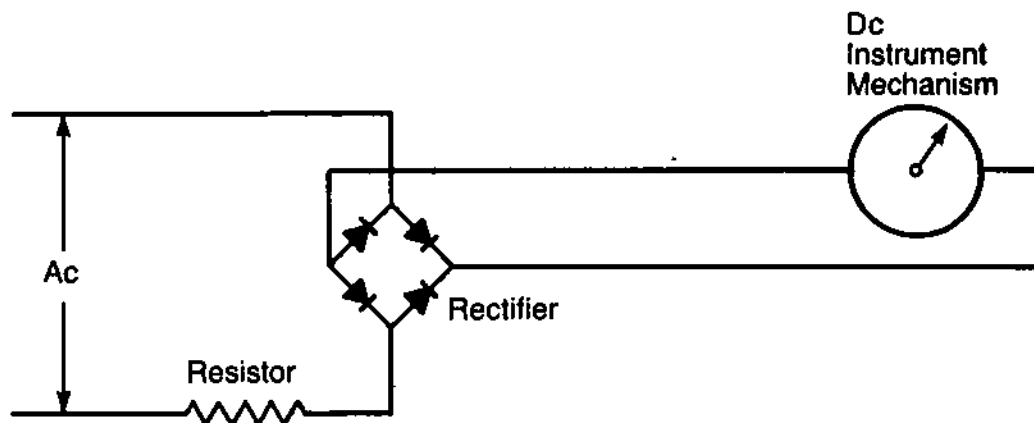


Fig. 49 – Inserting a Rectifier Ahead of the Instrument Coil Permits Using a Permanent Magnet, Moving-coil Mechanism to Measure Alternating Current

where high frequencies (through the audio range) are encountered. Tachometers of the a-c generator type all use rectifier indicators for these reasons.

The troubleshooting suggestions for d-c instruments are generally applicable to rectifier type instruments; the only added consideration is the rectifier itself. They are usually a full-wave bridge type but occasionally, they are single diodes used as half-wave rectifiers. If a rectifier has failed, it usually fails in open circuit mode, but they can also fail in short circuit condition. A short circuited rectifier is usually detected by a blown potential fuse and a continuous low resistance reading across the instrument terminals. An open half-wave rectifier, or a full-wave rectifier with at least two legs of the bridge open, will pass no current. Occasionally only one diode in a bridge array will fail; when this happens, the voltmeter reads about one-half of the correct value. Diodes can be replaced by a technician with commercial diodes rated at least twice the sine-wave full-scale voltage for a bridge, and four times sine-wave voltage for a half-wave diode. Where the measured wave is chopped, it is necessary to estimate, or measure, peak value and select a diode of the next higher peak inverse voltage capability. This point should be remembered in the event of a sudden rectifier failure in service, and immediate repair is necessary.

B. Dynamometer Type Instruments

Few voltmeters or ammeters are designed as dynamometers. Connections for these instruments are the same as for permanent magnet, iron-vane types. Troubleshooting is covered under 19.12.c. *Troubleshooting A-c Wattmeters*, below.

C. Use of Transducers

Current and voltage transducers convert a-c signals to d-c signals which can be read by a conventional d-c instrument. For complete information on application refer to the transducer manufacturer's literature.

Current and voltage transducers are the equivalent of the rectifying element in a rectifier instrument and have all the shortcomings of the average-responding rectifier instrument with respect to waveform error unless the transducer is equipped with approximate waveform compensation circuitry. Some transducers have amplifier circuitry to provide a high level signal output.

The basic current and voltage transducer circuits are shown in Figure 50.

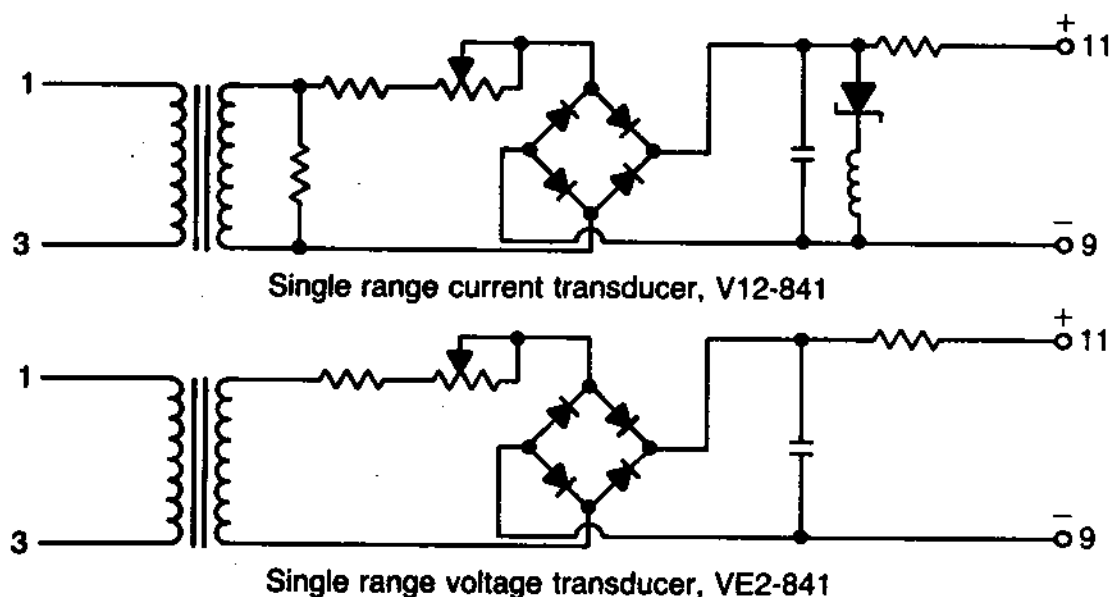


Fig. 50 – Basic Current and Voltage Transducer Circuits

The components on the output side of a transducer used as a rectifier are for waveform compensation and are not included in the simplest devices. These transducers are load-sensitive, they must be adjusted to compensate for load in a teleductor or they must be loaded to some specific value. The permissive loading is quite high compared to the terminal resistance of an indicating instrument and very long leads may be used between the transducer and the instrument. The most frequently encountered transducer is the constant current type which is load independent. This type incorporates a specialized amplifier which accommodates any load resistance up to 10,000 ohms without adjustment. The usual output is 1 milliamper.

Connections are the same as for conventional instruments. Troubleshooting techniques for the instrument are basically the same as those suggested for d-c current measuring instruments. See Manufacturer's Instruction Sheets. The procedure for troubleshooting transducers, external to the device, is similar to that employed for a-c ammeters and voltmeters. On external transducers, all that could be repaired in the field is the rectifier element, which is similar to those used on rectifier instruments. Transducers are so readily available and low in price that usually the most economical way to handle a defective or questionable unit is to replace it.

19.12 Alternating-Current Wattmeters

Traditionally and until development of taut-band design instruments, wattmeters were electrodynamicometers. Since the development of taut-band instruments, most wattmeters have used watt transducers feeding conventional taut-band d-c instruments. On switchboard instruments the transducer is usually inside the instrument case. Unless the international symbols are displayed on the case it is not always possible to tell at first glance whether the wattmeter is dynamometer or transducer type. These symbols are:

Dynamometer Type 

Transducer Type 

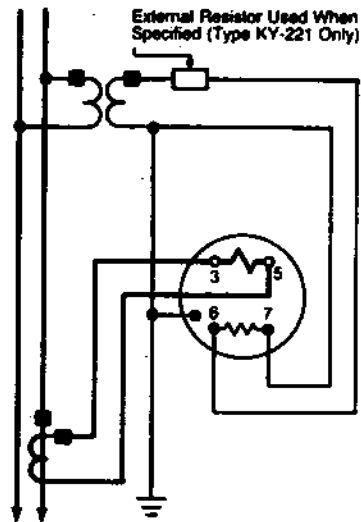
The number of wattmeters (or wattmeter elements) needed to measure power in a circuit is always equal to the number of wires in the circuit less one (Blondell's theorem). For single-phase, 2-wire circuits, one wattmeter element is needed and for single-phase, 3-wire or 3-phase 3-wire, two are needed. For 3-phase 4-wire circuits, three elements are required. Actually in the case of 4-wire circuits a compromise wattmeter is used called a $2\frac{1}{2}$ element. It is used because it is not practical to put three voltage elements on the moving element of a dynamometer.

If transducers are used there are savings in components that are not offset by lowered performance.

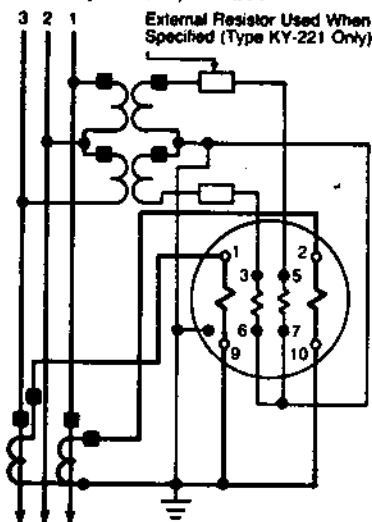
Three element transducers can be manufactured and are used to take care of those cases where exceptional conditions are to be met. It is often said that $2\frac{1}{2}$ element meters will read correctly only under balanced voltage conditions. This is true, however, neither electrical power systems or equipment will tolerate a degree of unbalance which would cause errors outside the accuracy rating of the instrument.

The three common connection schemes for a-c wattmeters are shown in Figure 51. The same basic diagrams apply to dynamometer wattmeters as well as transducer types.

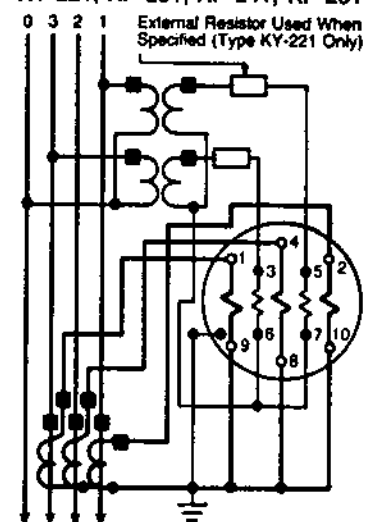
Wattmeter, Single-Phase, With Current Transformer and Potential Transformer, KY-221, KP-231, KP-241, KP-261



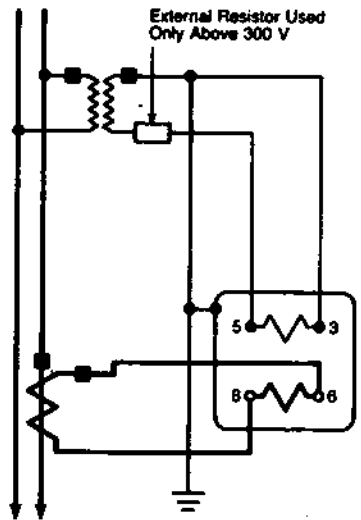
Wattmeter, Polyphase, 2 Current Coil, With Current Transformer and Potential Transformer, KY-221, KP-231, KP-241, KP-261



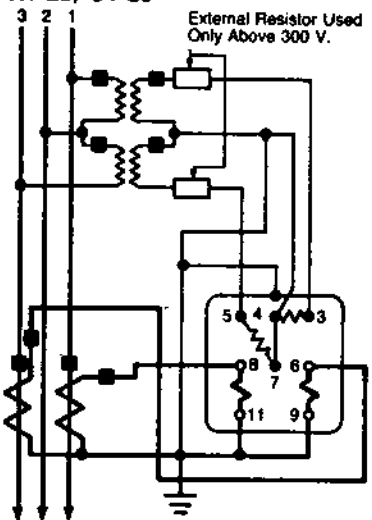
Wattmeter, Polyphase, 3 Current Coil, With Current Transformer and Potential Transformer, KY-221, KP-231, KP-241, KP-261



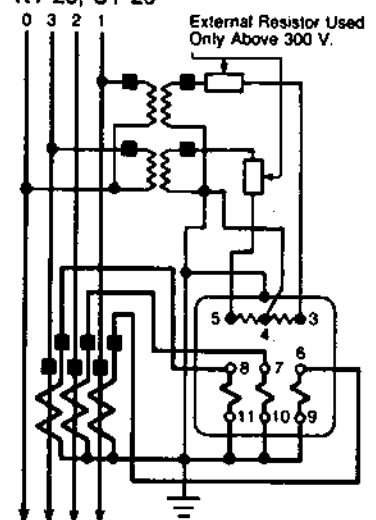
Wattmeter, Single-Phase, KY-25, UY-25



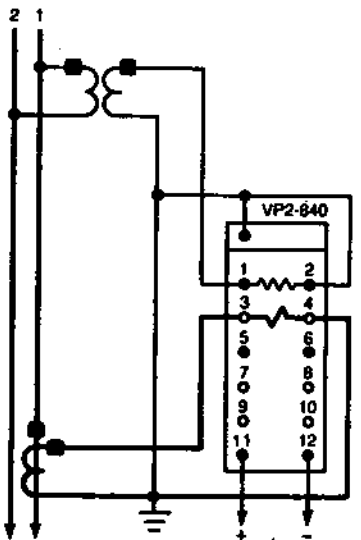
Wattmeter, 3-Phase, 3-Wire, KY-25, UY-25



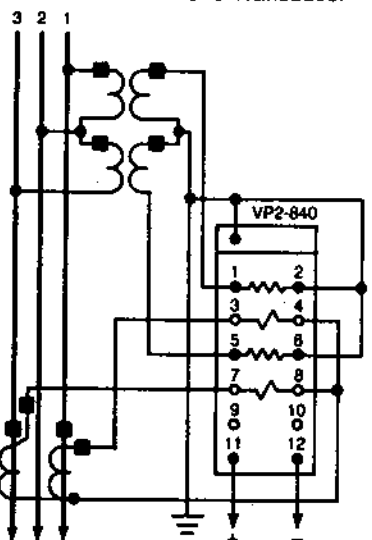
Wattmeter, 3-Phase, 4-Wire, KY-25, UY-25



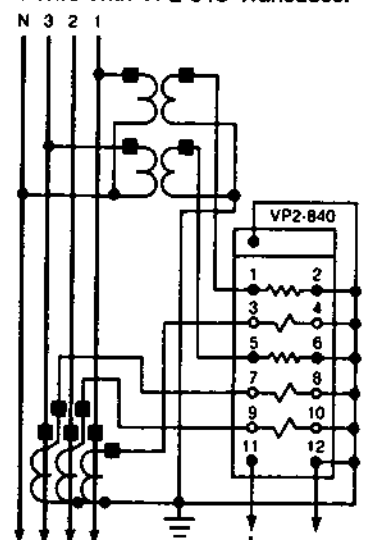
Wattmeter, 1 Element, Single-Phase, With VP-840 Transducer



Wattmeter, 2 Element, 3-Phase, 3-Wire With VP2-840 Transducer



Wattmeter, 2-1/2 Element, 3-Phase, 4-Wire With VP2-840 Transducer



Connect to terminals 1 (+) and 2 (-) on Westinghouse Edgewise Types V252 and H252 instrument.

Fig. 51 - A-C Wattmeter Connections

A. Transducer Type Wattmeters

The transducer elements used in wattmeters are of several types. One type of element uses the Hall generator employing a crystal in a magnetic circuit. The schematic is shown in Figure 52. When a Hall crystal is conducting a current and is placed in a magnetic field a potential difference is produced across the crystal. That potential difference is proportional to the product of the current through the crystal, the strength of the magnetic field, and the cosine of the angle between the current and flux. In a transducer the alternating current generates the flux and the a-c voltage produces the crystal current so a multiplying is produced with an output proportional to $EI \times \text{Cosine } \phi$ which by definition is watts.

The overload capability of wattmeters is shown in par. 19.10, Table 1, along with ammeters.

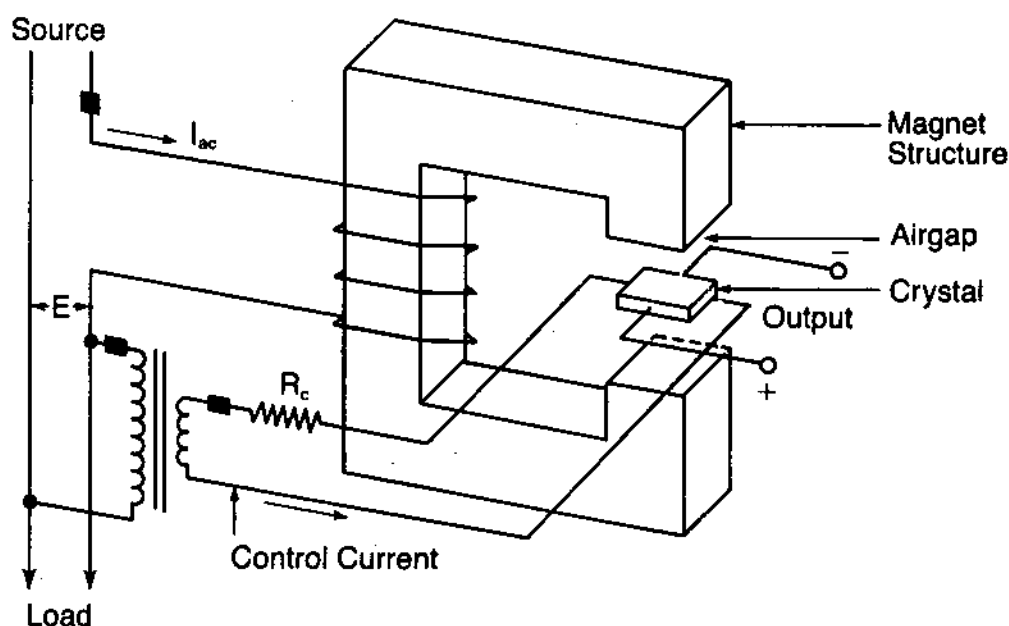


Fig. 52 – The Hall Generator Watt Transducer

B. Wattmeter Calibration

Wattmeter elements are rated nominally for 5 amperes at 120 volts but they are not calibrated for 600 watts (end scale). They are calibrated at a test wattage which, when multiplied by the product of the current and voltage transformer ratios and a constant (K), will produce the desired end scale value on the instrument. Wattmeters are calibrated single-phase with all current coils in series and voltage coils in parallel. Each wattmeter has a specified single-phase calibrating value in watts which will produce rated watts end-scale value in actual operation.

Rated end-scale value for a wattmeter is also referred to as the self-contained rating of the instrument. When instrument zero is not at the end, or at the electrical center, of the scale, the highest value is used, i.e., the value of the secondary end-scale watts which are applied to the instrument terminals in its operating connection.

The basic relationship formulas are:

$$\text{Rated End-scale Watts (Self-contained rating)} = \frac{\text{Full scale Watts}}{\text{CT ratio} \times \text{VT ratio}}$$

$$\text{(and) } 1\emptyset \text{ Calibrating Watts} = \frac{\text{Full Scale Watts}}{\text{CT ratio} \times \text{VT ratio} \times K}$$

Where K = 1 for 1 element
 2 for 2 element
 4 for 2½ element

Wattmeters have a limited range of current capacity. A five ampere instrument can be used from 4.00 amperes to 6.25 amperes. In most instrument catalogs there is a preferred scale tabulation showing minimum, nominal, and maximum value for the basic rating. The two-element wattmeter (5 ampere nominal) has a single-phase test range of 400 to 625 watts. This is 800 to 1250 watts self-contained. 120:1 voltage transformers and 400:5 (80:1) current transformers would produce:

9600 × 800 (to the next higher standard scale value) or 8000 kw as a minimum value.

9600 × 1000 (to the next higher standard scale value) or 10 mw as nominal value.

9600 × 1250 (to the next higher standard scale value) or 12 mw as maximum value.

These are the preferred scales. 6000 or 15000 or other non-standard scales can be obtained, but the manufacturer would have to use other than a nominal five ampere chassis.

Wattmeters can be calibrated for an almost limitless variety of connections, the commonly used schemes are shown in Figure 51. If actual connections are unlike any standard diagram, they should be analyzed with an objective of reducing them to an equivalent circuit. Familiarity with vectors is almost a necessity in such cases.

When ordering replacement wattmeters it is wise to furnish the manufacturer with a sketch showing connections and transformer configuration if different from standard.

C. Troubleshooting Alternating-Current Wattmeters

In transducer type wattmeters the instrument portion is a direct-current milliammeter. Troubleshooting is the same as for a direct-current instrument. The transducer portion does not lend itself to field repair. In case of trouble it should be sent to an instrument service shop.

The dynamometer wattmeter is a pivot and jewel instrument with potential coils on the moving element and current coils on the stationary element. Mechanical problems within the instrument are much the same as for other jeweled instruments but there are some added ones:

- a) The pigtail connections from a moving-coil element can "ground" on the shaft causing a loss of torque.
- b) The air damping chamber may be dirty or the vane may be rubbing. Change in alignment occurs with pivot and jewel wear and parts can distort with age.
- c) Dynamometer instruments are especially susceptible to stray field errors.
- d) Moving coils may become displaced on the shaft.

1. *No Indication.* If there is no indication from the watt meter a check should be made for voltage across each voltage circuit and for current through each current circuit.

Warning: Do not open a current circuit under load, to do so can cause severe injury or death, and damage to property.

A small clamp-on ammeter is a good means for checking for the presence of current. If current and voltage are present the probable trouble is a reversed connection.

2. *Reversed Connections.* If a reversed connection is suspected, one current coil should be shorted. If this action makes an instrument read half load that had been reading zero, the polarity on the shorted coil should be reversed. If the shorting action causes the instrument to deflect forcefully down scale the opposite (unshorted) coil should be reversed. This coil should then be shorted. If half the load is registered its current leads should be reversed. The same procedure applies to 2½

element wattmeters except that each current coil when shorted will reduce deflection one-third.

3. Correct Readings But Connections Not Per Diagram. In conventional connection schemes, this is usually a matter of two wrongs making a right. A reversed potential on one element, and reversed current on another, will offset each other. To avoid future problems in tracing circuits such anomalies should be corrected and lead tags installed or corrected.

It is possible with some more involved connections to have validity only at one power factor. Correction will involve verification of the original connections with the system designer or reference to more detailed application information from the manufacturer.

4. Low Power Factor. Transducer type wattmeters are used satisfactorily only above .5 power factor; dynamometer types go somewhat lower. The limiting factor is the ability of the coils to carry the currents and of the magnetic parts inability to handle the fluxes associated with low power factors at normal watt levels. Generally wattmeters are able to handle low power factors only if the maximum scale watts are reduced as power factor goes down.

Maximum allowable currents vary with type and rating and should be checked out with the factory on any critical job. As a general rule, a 5a (nominal) transducer type wattmeter will take 7.5a (maximum) and a dynamometer 10a (maximum). For continuous operation at nominal voltage (full scale) the transducer type instrument would have to be kept above .66 power factor and the dynamometer type above .5 power factor.

5. Low-Voltage Operation. The same limitations apply if a wattmeter is used at low voltage. The maximum reading allowed should be reduced as voltage goes down to prevent exceeding the rated maximum current.

6. Bench Testing. When checking the instrument through connections is not successful, bench testing should be done. This requires that the instrument be removed from the circuit and connected on a bench test circuit. It should be connected with all potential coils in parallel and all current coils in series with special attention to polarity, see Figure 53. Instruments are usually symmetrical, meaning all voltages and currents should flow in the same direction, top to bottom, left to right, etc. If a phantom load box is available it should be used, if not a bank of incandescent lamps will meet the load requirement. A single-phase wattmeter should be used as a check instrument since it can verify calibration. An ammeter and a voltmeter will only suffice for checking proper operation

of the wattmeter. Test connections are shown in Figure 53. If an ammeter and a voltmeter are used instead of a wattmeter, an error of two or three percent can be expected because there is some inductance in a lamp bank load.

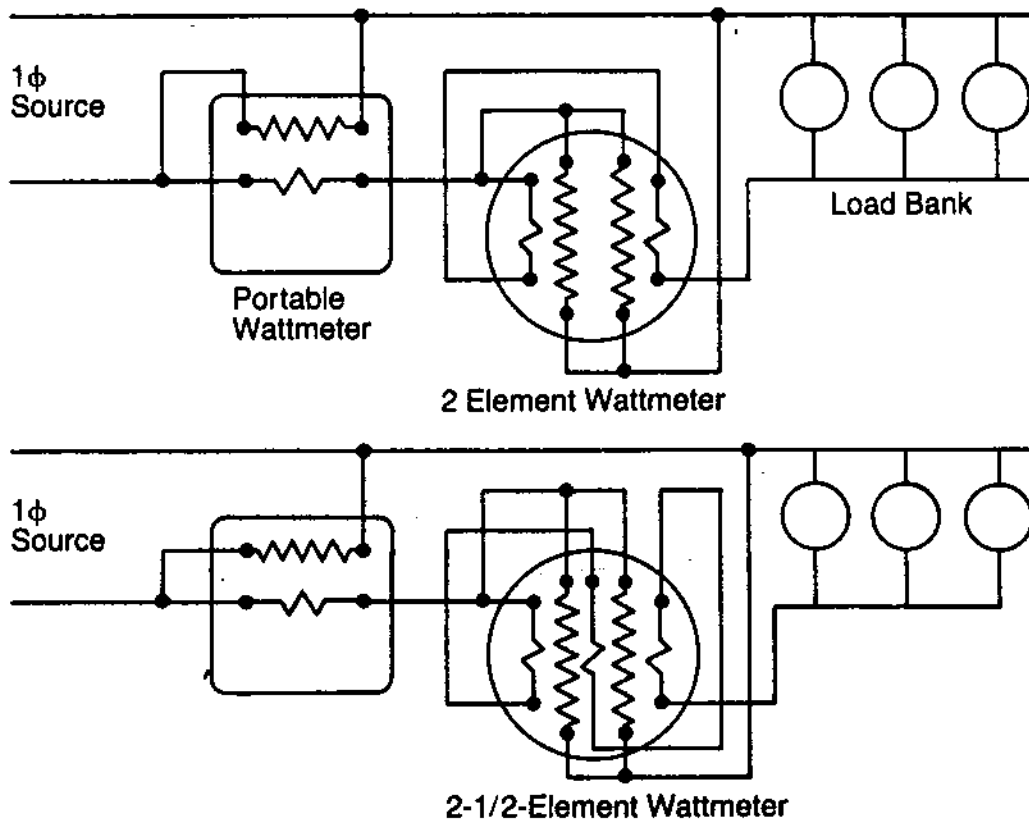


Fig. 53 – Test Connections for Watt Meters

After the bench test connections have been made, voltage and current are applied to the test circuit as close as practical to the nominal values. Voltage and current should be varied slightly to bring the test wattmeter up to the single-phase test watts of the instrument under test, the instrument should read full scale. If it is not convenient to use the exact value of test watts, some lesser value may be used with the reading on the instrument being reduced proportionately.

- (a) If the instrument registers correctly, the original problem had to be in the voltage and current transformer circuits. The transformer circuits should be checked with appropriate instruments. A phase-angle meter will verify polarities and phase relationships.
- (b) If the wattmeter does not read correctly, a check should be made for an open voltage circuit or a shorted current circuit. It might possibly be repaired in the field but generally accepted practice is to send the instrument to a repair shop.

D. Watt Transducers

The operating principle of the Hall generator transducer is covered under 19.12 A. *Transducer Type Wattmeters*, above. For greater detail refer to the manufacturer's literature on the subject. In addition to the Hall generator several other schemes are used for integrating, such as time-division multipliers, transistorized multipliers, and even thermopiles.

Watt transducers are available in all the configurations of wattmeters including 3-element types. They are connected the same way wattmeters are connected.

Outputs of watt transducers are not amplified when applied at 50mv or 100mv into a fixed resistance of 50 ohms or 100 ohms but they are amplified for a load-independent output of 1 ma into any resistance up to 10,000 ohms.

Troubleshooting for watt transducers is identical to the troubleshooting hints given for wattmeters insofar as connections are concerned, but in addition:

Non-amplified transducers are load-sensitive. If readings are incorrect load resistance should be checked.

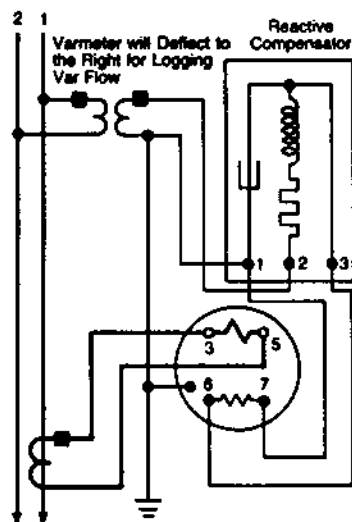
Amplified transducers have range and zero adjustments, if the output does not zero properly adjustment is simple. If the output is too high or too low at some point upscale but is correct at zero, it is probable that the calibration adjustment is off. The usual check is to put the transducer through the same single-phase test procedure prescribed for wattmeters.

If the transducer has no output the amplifier is usually at fault. It may not be properly connected to an external power source or the amplifier may be defective. These amplifiers are often socket mounted devices which can be replaced in the field. For any other difficulty shop repair is indicated.

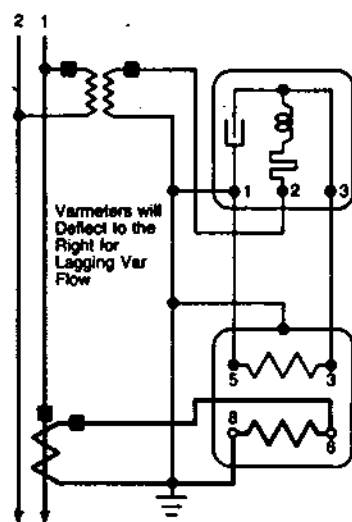
19.13 Varmeters

Wattmeters measure true power as the product of in-phase components of current and voltage. Varmeters measure reactive power as the product of voltage and current component which is 90° out of phase with the voltage. An ordinary wattmeter is conventionally connected on the current side through a phase shifting device on the potential side, in order to measure watts. There are also some self-contained varmeters which utilize internal phase shifting circuitry within the instrument case.

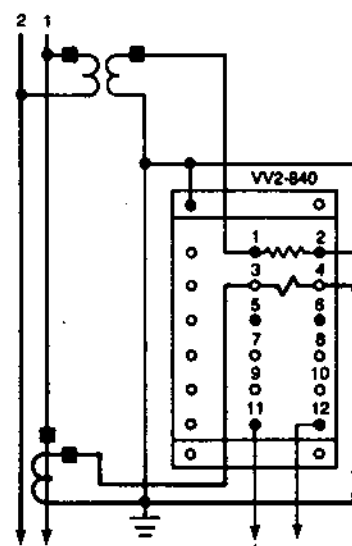
Varmeter, Single-Phase, With Current Transformer and Potential Transformer, KY-221, KP-231, KP-241, KP-261



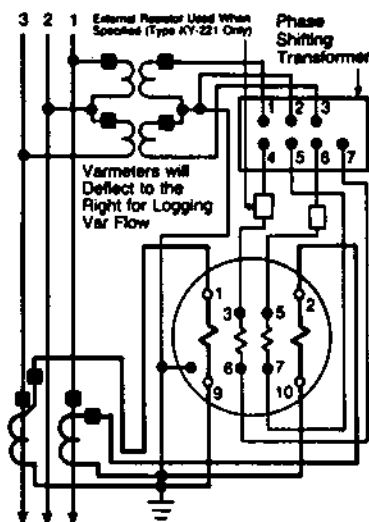
Varmeter, Single-Phase, 2-Wire, KY-25, UY-25



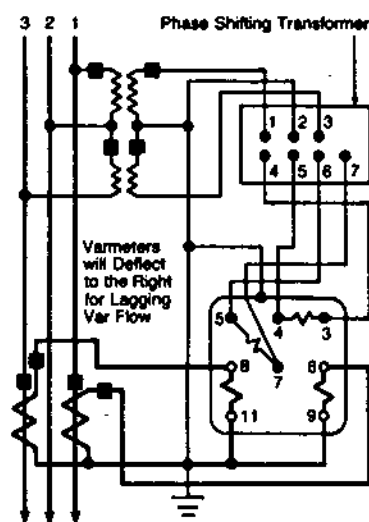
Varmeter, 1 Element, Single-Phase, With VV2-840 Transducer



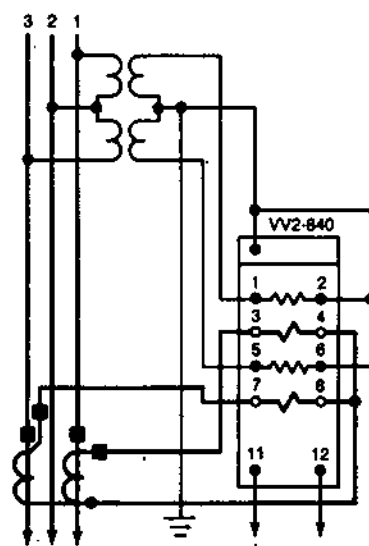
Varmeter, Polyphase, 2 Current Coll, With Current Transformer and Potential Transformer, KY-221, KP-231, KP-241, KP-261



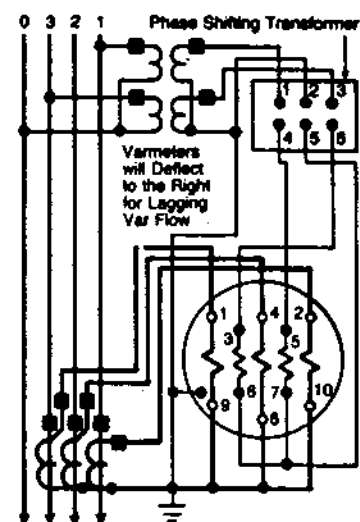
Varmeter, 3-Phase, 3-Wire, KY-25, UY-25



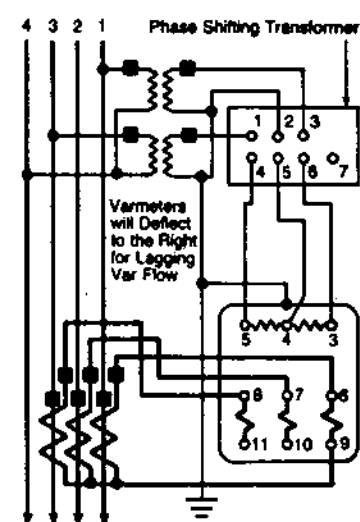
Varmeter, 2 Element, 3-Phase, 3-Wire, With VV2-840 Transducer



Varmeter, Polyphase, 3 Current Coil, With Current Transformer and Potential Transformer, KY-221, KP-231, KP-241, KP-261



Varmeter, 3-Phase, 4-Wire, KY-25, UY-25



Varmeter, 2-1/2 Element, 3-Phase, 4-Wire, With VV2-840 Transducer

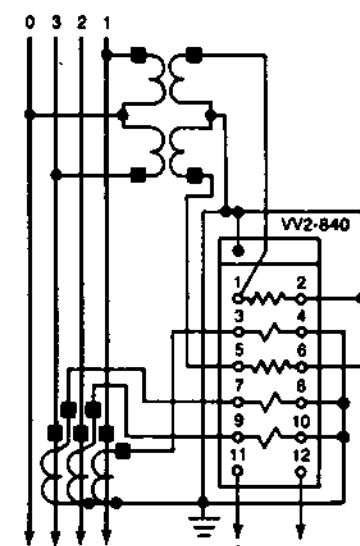


Fig. 54 - A-C Varmeter Connections

Connect to terminals 1 (+) and 2 (-) on V252 and H252 instrument.

The current coils of wattmeters and varmeters are usually connected in series. This places a limitation on the scale values of a varmeter in comparison to a wattmeter. Either instrument may have a left, center or offset zero but, the sum of the left and right end-scale values of the varmeter may not be less than the higher of the end-scale values of the wattmeter. The common connections for varmeters are shown in Figure 54.

It is possible to eliminate the phase shifter from a varmeter circuit by utilizing cross-phase connections. This involves using a current from one leg coupled with a voltage across the two remaining legs. This can be done on three-wire or four-wire systems with polyphase or single-phase meters calibrated to read three-phase. If a varmeter is to be connected in this manner it is best to submit wiring diagrams for the particular installation; they can be quite varied.

Calibration – Varmeter calibration is checked by removing the phase shifter and then following the same procedure as for wattmeters. The exception is self-contained varmeters; test procedures will be found in the instructions furnished by the manufacturer. A quick check can be made by taking ammeter and voltmeter readings and comparing them with the reading of the associated wattmeter using this formula:

$$\text{Vars} = 2 \sqrt{(\text{amps} \times \text{volts})^2 - \text{watts}^2}$$

Comparison by power factor meter is best made utilizing the chart under sub-chapter 19.14 on power factor meters.

Troubleshooting Varmeters – The troubleshooting procedures for wattmeters given in 19.12 *A-c Wattmeters*, above, apply to varmeters with these additions:

- a) The compensator used for phase shifting a single-phase varmeter is serialized and calibrated with a particular instrument; they must not be mixed.
- b) The phase-shifting transformer scheme used on polyphase varmeters is phase-rotation sensitive. Wiring diagrams are based on 1-2-3 rotation.
- c) If using a phase angle meter to verify connections, remember to check for the 90 degree lag on the voltage output of the phase shifter.

19.14 Power Factor Meters

By definition power factor is the ratio of watts to rms voltamperes; mathematically it is expressed as:

$$PF = \frac{\text{Watts}}{\text{rms Voltamperes}} = \frac{\text{Active Power}}{\text{Apparent Power}} = \frac{\text{kW}}{\text{kVA}}$$

In a sinusoidal single-phase circuit the above relationships hold, but in addition, $PF = \cos\phi$ where ϕ is the angle between the current and the voltage. In polyphase systems there can be different values of watts, voltamperes and $\cos\phi$ for each phase. Therefore the only truly valid method of measuring polyphase power factor is to measure each phase separately and then add vectorially as shown in Figure 55.

In Figure 55, the polyphase power factor is $\frac{AB}{AC}$; AB is the sum of three wattmeter readings and CB is the sum of three varmeter readings and AC is $\sqrt{CB^2 + AB^2}$. This calculation is quite an assignment for an electromechanical mechanism, so in practice some compromises have to be made. Usually the polyphase power factor meter assumes a sinusoidal waveform (and a balanced system) with respect to current and voltage. It measures the angle between a line to ground voltage, or the resultant of two line to line voltages and a line current. Therefore, there will be disagreement between the indication of a power factor meter and calculated values under less than ideal conditions.

The instrument mechanisms commonly used for power factor meters are the rotating iron-vane and the crossed coil electrodynamic types; the transducer types are now gaining in acceptance. The iron-vane and the dynamometer types measure the phase angle between the rms peak flux, due to current, and the rms peak flux due to voltage. Therefore they tend to minimize the effect of waveform abnormality on the readings. The transducer types, however, measure the angle between the current wave as it crosses zero and also the voltage wave as it crosses zero, and essentially ignore waveform.

Compensation is provided in the more expensive portable instruments. There is an advantage the transducer type has over others in that they can be built with almost any scale. A rotating iron-vane type rotates 180° for .5-1-.5 power factor whereas, a transducer type can rotate 250° .

The most accurate determination of polyphase power factor is based on the relationship between actual total watts and total vars at any instant. A close approximation may be derived from wattmeter and varmeter readings using the Figure 56 scale.

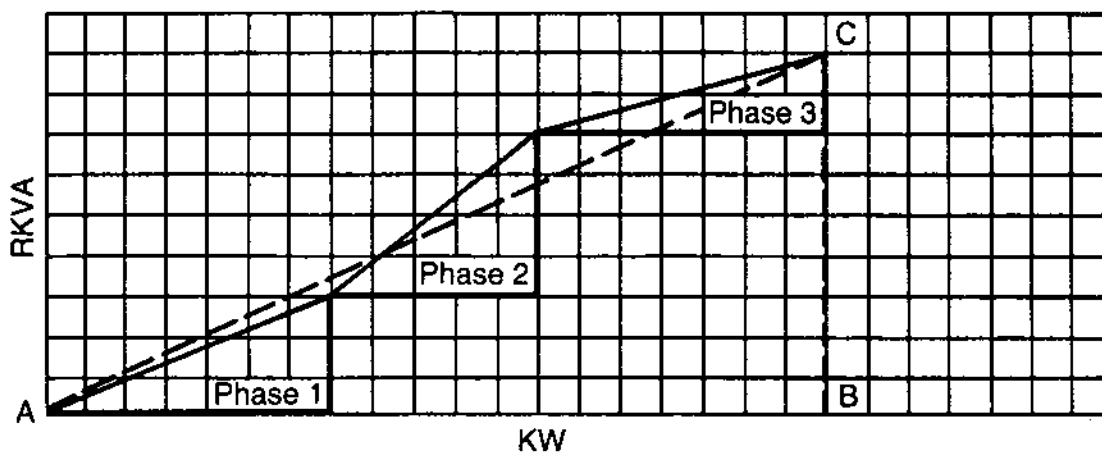


Fig. 55 - Vectorial Determination of Three-Phase Power Factor

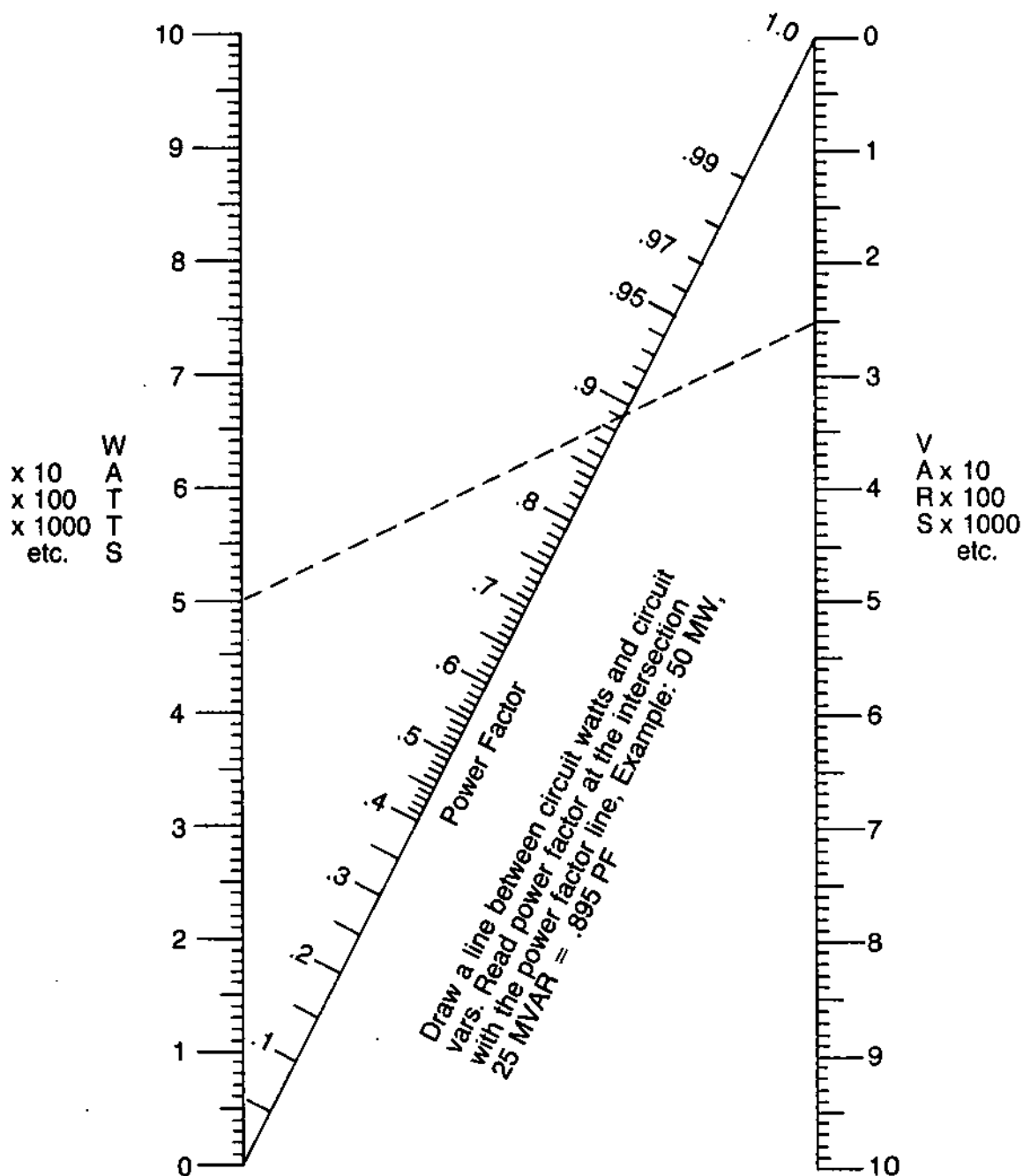


Fig. 56 - Determining Power Factor from Wattmeter and Varmeter Readings

A. Connections

The typical connections for power factor meters are shown in Figure 57. It is quite possible to use other connections and compensate for them by changing the instrument calibration to suit. Therefore, if any installation does not check with these diagrams or those in the manufacturers instruction sheets, it is not necessarily incorrect; a system designer should be consulted.

B. Troubleshooting Power Factor Meters

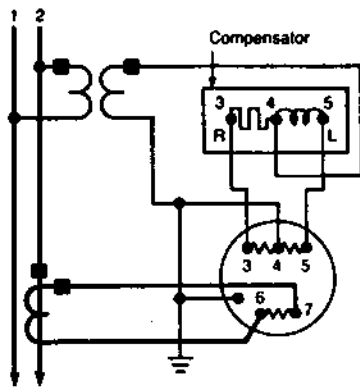
Troubleshoot dynamometer power factor meters the same as wattmeters. Their springs are of extremely low torque, intended only to conduct current to the moving element. When an instrument is de-energized the pointer will not return to any particular position; it should stay at the position it happens to be in at the moment. Balancing is more critical on a power factor meter than on any other type. The balancing method is conventional except that it is done with the instrument energized. The final test for correct balance is that the pointer stays in any position to which it is pushed.

The rotating iron-vane power factor meter is fairly sturdy. There are no conducting or torque springs so the pointer behaves like one on a dynamometer. Balancing is the same except that now, the pointer travel will be either 180 degree (2-quadrant) or 360 degree (4-quadrant). A source of trouble can be the damping disc, if pivot wear creates close clearances between the magnet and disc. A minute particle of dirt, under these conditions, can create drag.

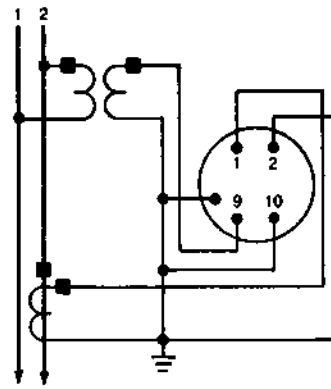
Power factor meters have additional trouble shooting procedures which are peculiar to this instrument:

1. For rated accuracy, the current must be at least 40% of rating. Between 20% and 40% current rating, probable error, (in power factor difference) may equal two electrical degrees. Below 20% current, the device does not give a reliable indication.
2. If the meter is off by 60° or 120° from the correct position (or if it reads 0.5 when the power factor is 1.0), it is virtually certain that the current is being taken from the wrong leg. The best way to correct the condition is by changing to the correct current. If no transformer is available, the voltage connections should be moved to a potential which is in proper phase relationship to the current.
3. If the two-quadrant 180 degree meter (or a 100 degree meter) hits hard against its stops a reversed current circuit is indicated, polarities should be checked. A four-quadrant meter will have a diametrically opposed reading with a reversed current polarity.

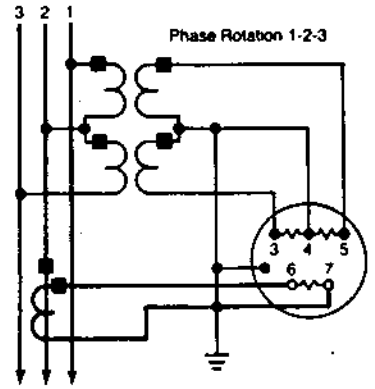
Power Factor Meter, Single-Phase, With External Reactor, KY-221



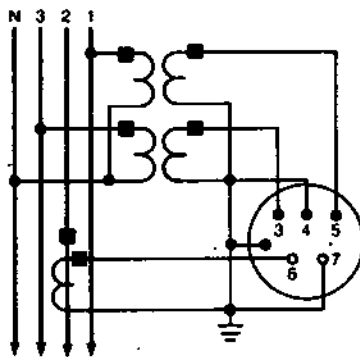
Power Factor Meter, Single-Phase, KI-231, KI-241, KI-261



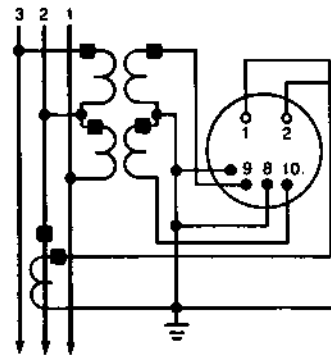
Power Factor Meter, 3-Phase, 3-Wire, KY-221



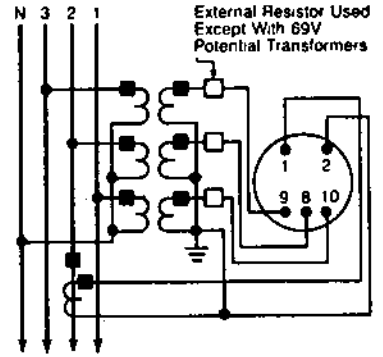
Power Factor Meter, 3-Phase, 4-Wire, KY-221



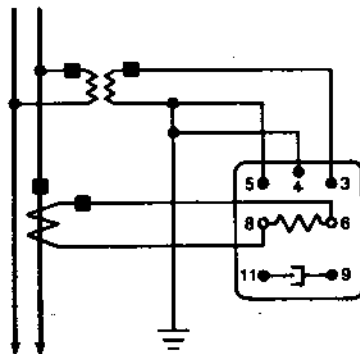
Power Factor Meter, Polyphase, KI-231, KI-241, KI-261



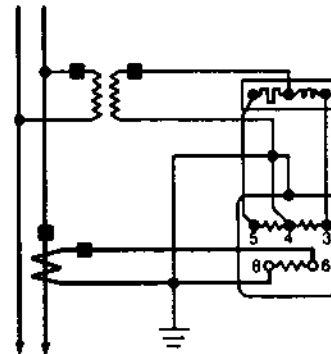
Power Factor Meter, 3-Phase, 4-Wire, KI-231, KI-241, KI-261



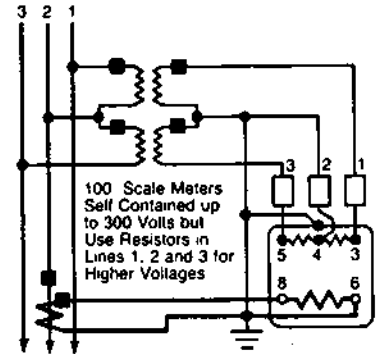
Power Factor Meter With External Capacitor, 60-4200 Hertz



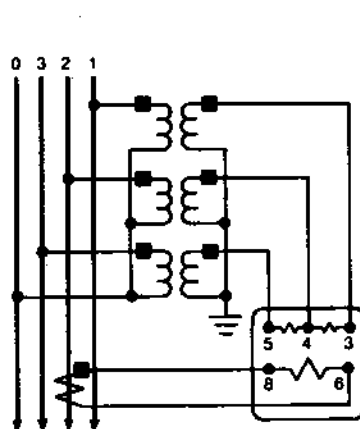
Power Factor Meter, Single-Phase, KY-25, UY-25



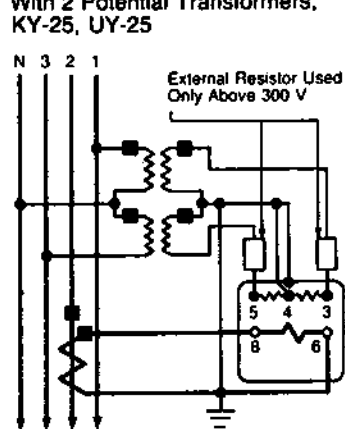
Power Factor Meter, 3-Phase, 3-Wire, KY-25, UY-25



Power Factor Meter, 3-Phase, 4-Wire, KY-25, UY-25



Power Factor Meter With Special Calibration For 3-Phase, 4-Wire, With 2 Potential Transformers, KY-25, UY-25



Power Factor Meter, Single-Phase, KI-25, UI-25

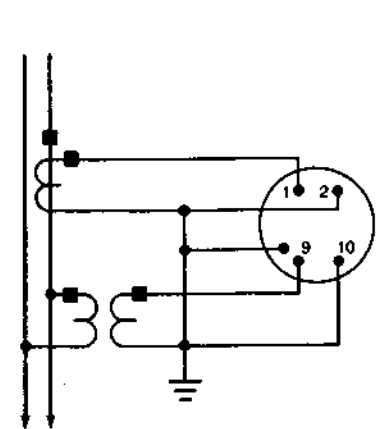
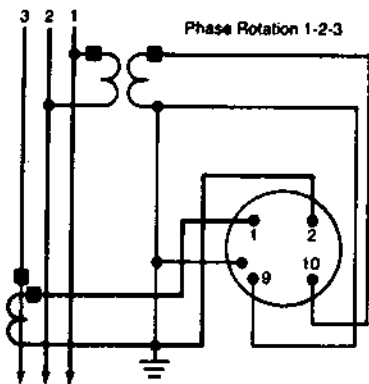
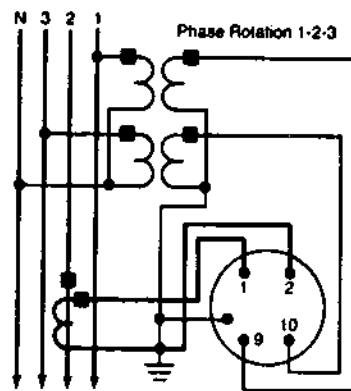


Fig. 57 - Typical Power Factor Meter Connections

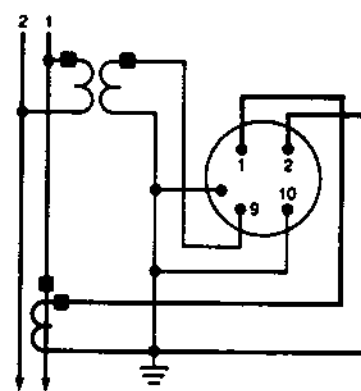
Power Factor Meter, 3-Phase,
3-Wire, KJ-231, KJ-241, KJ-261,
KJ-221



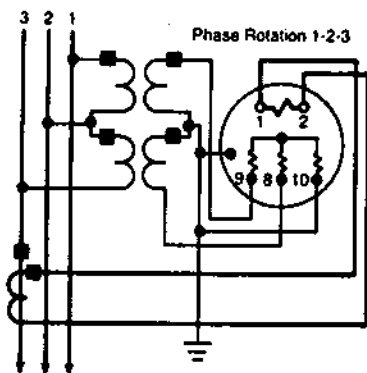
Power Factor Meter, 3-Phase,
4-Wire, KJ-231, KJ-241, KJ-261,
KJ-221



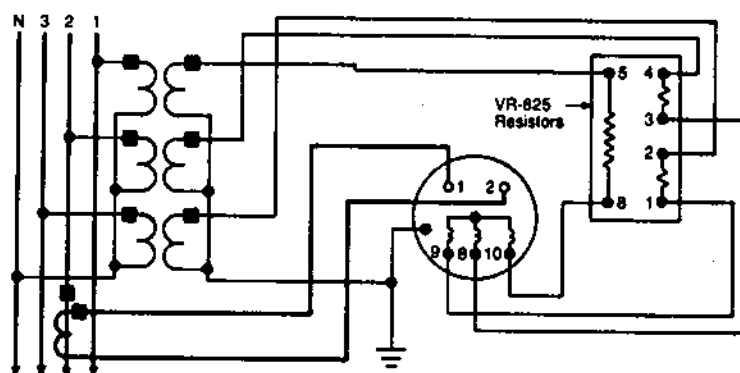
Power Factor Meter, Single-Phase,
KI-231, KI-241, KI-261, KJ-221,
KJ-231, KJ-241, KJ-261



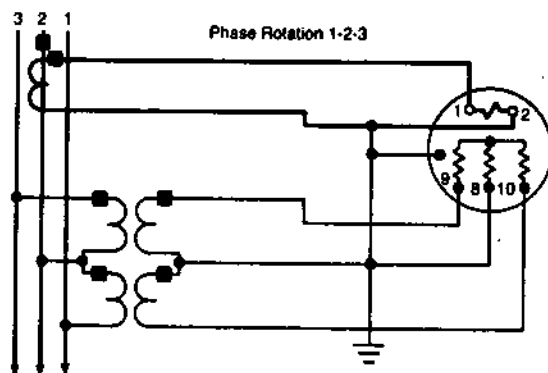
Power Factor Meter, 3-Phase,
3-Wire, KI-231, KI-241, KI-261
(For 120 V or 240 V only)



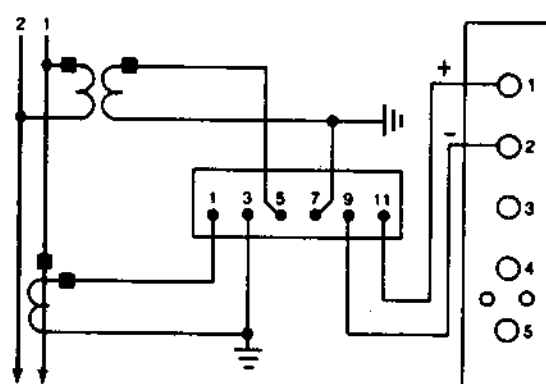
Power Factor Meter, 3 Phase, 4-Wire,
KJ-231, KJ-241, KJ-261



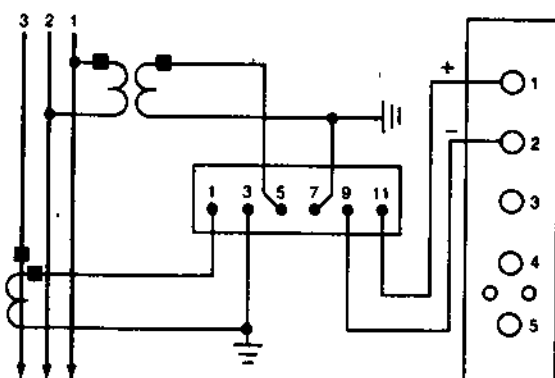
Power Factor Meter, Polyphase,
KI-25, UI-25



Power Factor Meter, Single-
Phase, 2 Wire V



Power Factor Meter, 3 Phase, 3
Wire (May Also Be Used For 3 Phase, 4 Wire
Where Line-Line Potential Is Available)



Power Factor Meter, 3 Phase,
4 Wire (Transducer Rated 208 Volts) V-252, H-252

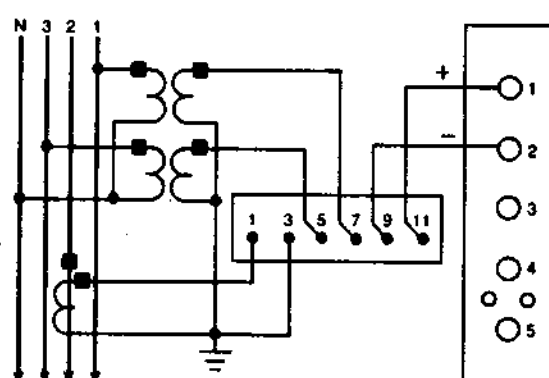


Fig. 57 (Continued) – Typical Power Factor Meter Connections

4. When a polyphase instrument reads backwards, lead instead of lag, or lag instead of lead the two potential leads should be interchanged. If then the reading is still incorrect, current polarity should be rechecked, see 2 and 3 above.

If the instrument is a single-phase type using a resistor-reactor, the outside leads should be reversed. The leads that are common to the resistor and the reactor elements should not be interchanged.

5. There can be a gross discrepancy between the power factor calculated from current, voltage, and wattmeter readings on polyphase systems, particularly three-phase four wire. If the system is known to be unbalanced in any respect, this is the probable reason. The only check on this conclusion is to make tests on each phase and make a vector addition as illustrated in Figure 55. This is relatively easy to do on a three-phase, four-wire system where the problem is most likely to occur. On a delta system it requires measuring wattmeter currents inside the delta. There are usually no current transformers at this point but a clamp-on wattmeter and ammeter will provide a rough check and verify the cause of any gross error.

19.15 Frequency Meters

Frequency meters can be either mechanical, electrical, or electro-mechanical. The mechanical frequency meters use a group of vibrating reeds, each tuned to a different frequency. Natural machine vibrations cause the reed to oscillate in harmony with the vibration. In the electrical type the reed assembly may be excited by an alternating circuit coil for improved sensitivity and immunity to spurious vibrations. Each reed begins to vibrate at about two percent above or below its tuned frequency on a seven reed instrument, and reaches maximum amplitude at tuned frequency. This means that intermediate frequencies can be read by observing the pattern traced by the reeds. See Figure 58.

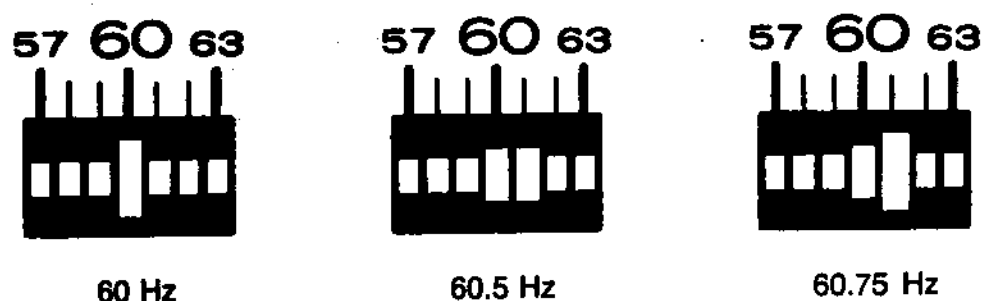


Fig. 58 – Reading the Vibrating Reed Frequency Meter

In addition to the vibrating reed frequency meter there are in use designs using transducers, and induction disc, dynamometer bridge, dynamometer resonant circuit, moving iron and other types.

The most commonly encountered is the tuned circuit transducer type, and some tuned circuit types are linear with respect to frequency. These can have the de-energized indication off-scale on either the high or low side.

The more modern types use a nulling transducer which has a zero output somewhere on the scale. They have a rising voltage characteristic with one polarity at frequencies below null and change polarity when frequencies are above the null point. When this instrument is de-energized the pointer seeks the null point.

Standard nulling type frequency meters are made with frequency spans as small as 2 Hz and as broad as 20 kHz. The narrow range devices are extremely accurate in absolute terms, (± 0.061 Hz for 59-61 range and ± 0.35 Hz for 50-70 range for switchboard instruments) accuracy is about double that of panel types. Frequency transducers can be adjusted in the field but self-contained transducer types must be adjusted in a meter laboratory as the resistors are wound to specific values. The adjustment procedures are somewhat complicated so precise instructions should be obtained from the manufacturer for the specific transducer before attempting adjustment.

A. Connections

Frequency meters are connected to any system voltage source of the proper level. Typical diagrams are shown in Figure 59.

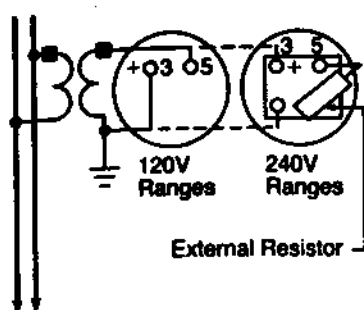
B. Troubleshooting the Frequency Meter

General instructions pertaining to dc milliammeters apply. Beyond that, any troubles will likely be in the transducer circuitry and aside from the adjustment requirements mentioned previously, the instrument does not lend itself to field repair.

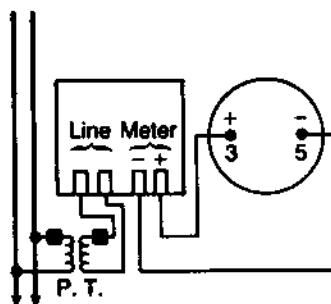
19.16 Synchrosopes

A synchroscope is a variant of a single-phase power factor or phase angle meter of the continuously rotating type. It reads the phase relationship between two voltages whereas the power factor meter reads the

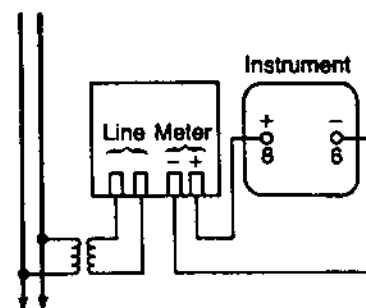
Frequency Meter, Self-Contained,
KR3-221, KR3-231, KR3-241,
KR3-261



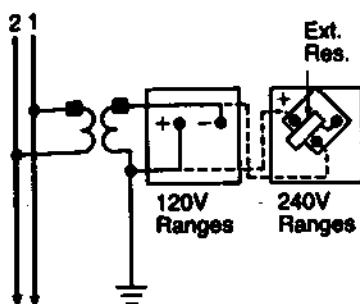
Frequency Meter, With External
Transducer, KW-221, KX-231,
KX-241, KX-261



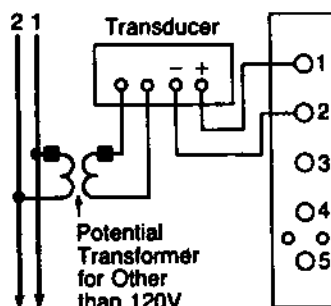
Frequency Meter, Transducer Type,
KX-251, UX-251



Frequency Meter, Self-Contained,
KR3-251, UR3-251



Frequency Meter With VC-841
Transducer



Frequency Meter With VC2-841
Transducer

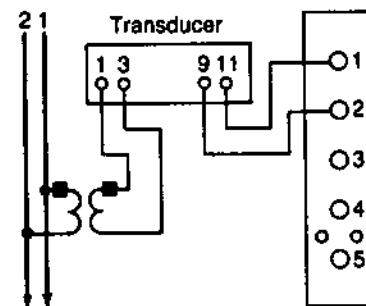


Fig. 59 - Typical Frequency Meter Connections

vectorial angle between line current and voltage. Earlier models were electrodynamic instruments, but for many years the standard has been the moving iron type. They are preferably called rotating iron-vane types to distinguish them from other moving iron instruments which perform an entirely different function.

The motor-like stator is connected to one phase of the bus, or running side, through either a separate or built-in phase splitting network which generates a rotating magnetic field. The polarizing coil of the rotating vane is connected to the other incoming source of power. In use, after frequencies and voltages have been carefully matched between the house bus and incoming power from another source, the operator observes the behavior of the synchroscope. Continuous rotation in the fast direction indicates that the incoming line frequency is out of phase with the house bus. The operator must not attempt to synchronize while there is constant rotation. Eventually, rotation will stop or even reverse. Then the pointer will begin to drift toward the 12:00 o'clock position. When the pointer reaches the 12:00 o'clock position on the synchroscope, the incoming frequency is in synchronism with the house bus and the breaker may be closed. This is an over-simplification because different

techniques are employed, depending on circumstances. Usually, when synchronizing two machines, the operator is familiar with the rotative speed of the synchroscope and the closing time of the tie line breaker; he may close the incoming breaker some time ahead of the 12:00 o'clock position on the synchroscope.

A synchroscope is not a reliable frequency difference indicator except for very small variations. In operation, a synchroscope is expected to start to rotate when the frequency of the incoming machine is within 1.5 Hz of the bus, and to stop rotating when the difference is more than 3 Hz. The bus frequency must be within 2 Hz of the synchroscope frequency rating. Outside these limits, or with only one side of the synchroscope energized, the pointer could come to rest anywhere. However, the manufacturers inject an "unbalance condition" to throw the pointer into an approximate 1:30 or 10:30 o'clock position under these conditions; this is why the rotation of the pointer tends to be erratic. The instruments are deliberately unbalanced for a static position 45 degree away from 12:00 o'clock when de-energized.

A. Connections

Synchscopes are connected to voltage sources having a zero phase angle between them under normal conditions. Serious damage may be caused to generators if an error is made in synchronizing. Connections are as shown in Figure 60.

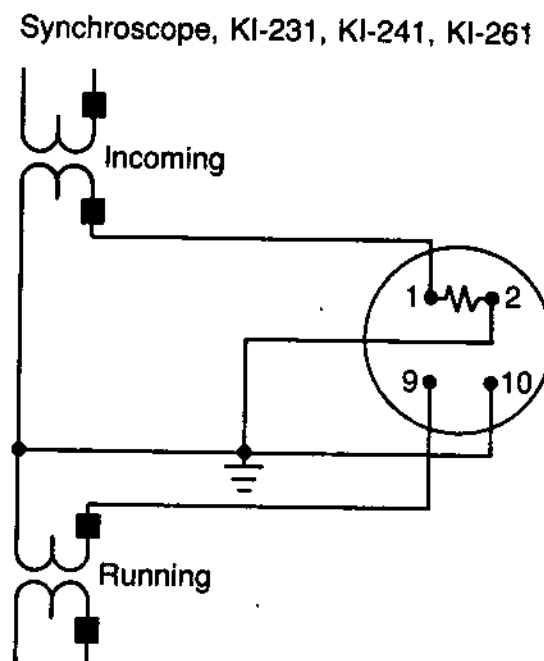


Fig. 60 - Synchroscope Schematic

B. Troubleshooting Synchrosopes

The mechanism of a synchroscope requires the same maintenance procedures as a power factor meter except for balancing. There are certain characteristics of synchrosopes which require additional comment; they are:

1. A synchroscope must be disconnected from the line once the circuit breaker has closed. The synchroscope switch should disconnect both the stator and the rotor simultaneously. With only the stator energized, the rotating field may drag the rotating vane along with it because of eddy currents; this can cause premature wearing out of bearings. The synchroscope will not rotate once the two systems are tied together but, it is not as practical to disconnect it when one machine is tripped off.
2. Before placing a synchroscope in service, it is wise to verify correct pointer position by connecting both sides of the instrument to the same source. It should move to the 12:00 o'clock position where there is an arrow, or vertical mark, on the dial.
3. If rotation is backwards, it indicates that the rotating field is incorrect. If there is an external capacitor-reactor, the non-common leads should be reversed. If only a capacitor is used, the polarity of the associated winding is incorrect and the instrument requires skilled repair.
4. If there is no rotation when there is a frequency difference of less than 1.5 Hz, voltage should be checked; the device will tolerate $\pm 10\%$.
5. If pulsation in rotative speed is excessive, the balance of the instrument rotor and applied voltage on both sides of the meter should be checked. There could also be an unbalance in the reactor-capacitor network. The currents in each side should be equal.

19.17 Special Purpose Instruments

A. Tachometers

Speed measuring systems using conventional electrical instruments as readout devices fall into three categories, alternating-current tachometers, direct-current tachometers, and pulse tachometers.

1. *A-c tachometers* utilize a permanent-magnet generator which produces a voltage and frequency proportional to rpm which is usually 10 volts per 1000 rpm or 60 Hz at 360 rpm. The upper speed limit is 5000 rpm due to a limitation on the bearings of the generator and the lower

speed limit is 90 rpm. At low speed, the instrument pointer begins to follow the sine wave and fans too broadly to follow.

A readout instrument is a rectifier indicating or recording type instrument. It requires 1000 ohms/volt, 10 volts per 1000 rpm. Troubleshooting the instrument is not difficult. The generator may require periodic replacement of bearings but the frequency of replacement depends primarily upon speed. The replacement procedure is the same as for small motors. There is a calibration adjuster under the hex cap on the front end bell; it varies the magnetic flux passing through the windings and can change the output voltage about $\pm 5\%$. The only limitation on the generator output is to keep it at 1 ma or less since output signal is not load sensitive below that level.

2. *D-c tachometers* are similar to the a-c type except that the generator puts out a d-c signal and the instrument is a conventional d-c voltmeter calibrated in rpm.

These instruments are serviced as a conventional d-c voltmeter. There is usually a rheostat built into the rear of the instrument case for calibration adjustment.

3. *Pulse tachometers* take many forms but they are all basically the same device. They utilize a notched wheel which rotates in close proximity to a magnetic reluctance pickup which generates a pulse as each notch passes by. The pulses are fed into a transducer circuitry which converts pulse rate into a proportional d-c output, see Figure 61.

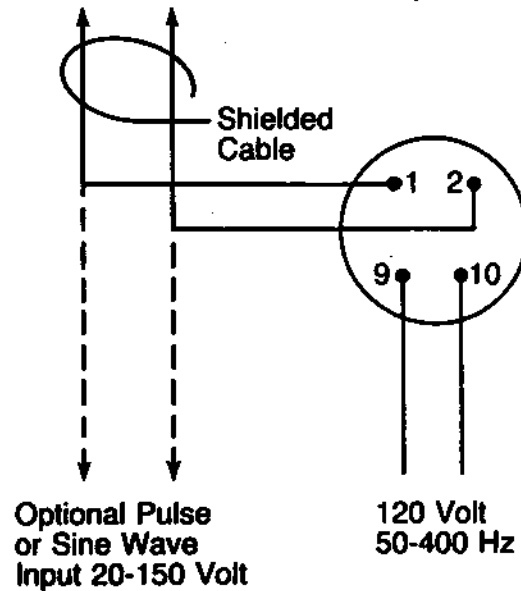
B. The Readout Instrument

The readout instrument is a conventional d-c analog indicator or recorder. Its transducer is load sensitive, so the resistance of the instruments must be matched to the load resistance specified on the transducer. When rheostats are furnished in either the transducer or the instrument, they are for lead length compensation but they can also be used for a very limited calibration adjustment. Change in basic instrument calibration requires shop work. Here are some pointers on troubleshooting pulse tachometers:

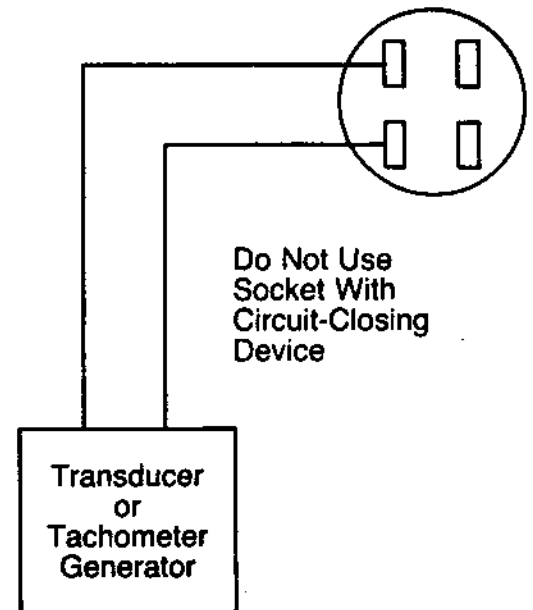
- a) The air gap between pickup and toothed wheel is critical at 0.01 ± 0.002 inches.
- b) The lead from pickup to transducer must be shielded and shield grounded at the pickup end only.
- c) The input voltage must be between 0.2 and 20 volts peak. The voltage level is affected by the air gap and the rpm.

Speed Indicator

To Variable Reluctance Pickup 0.1-2 Volts



D-c Instrument Used With Transducer or Tachometer Generator



Speed Indicator With Transducer

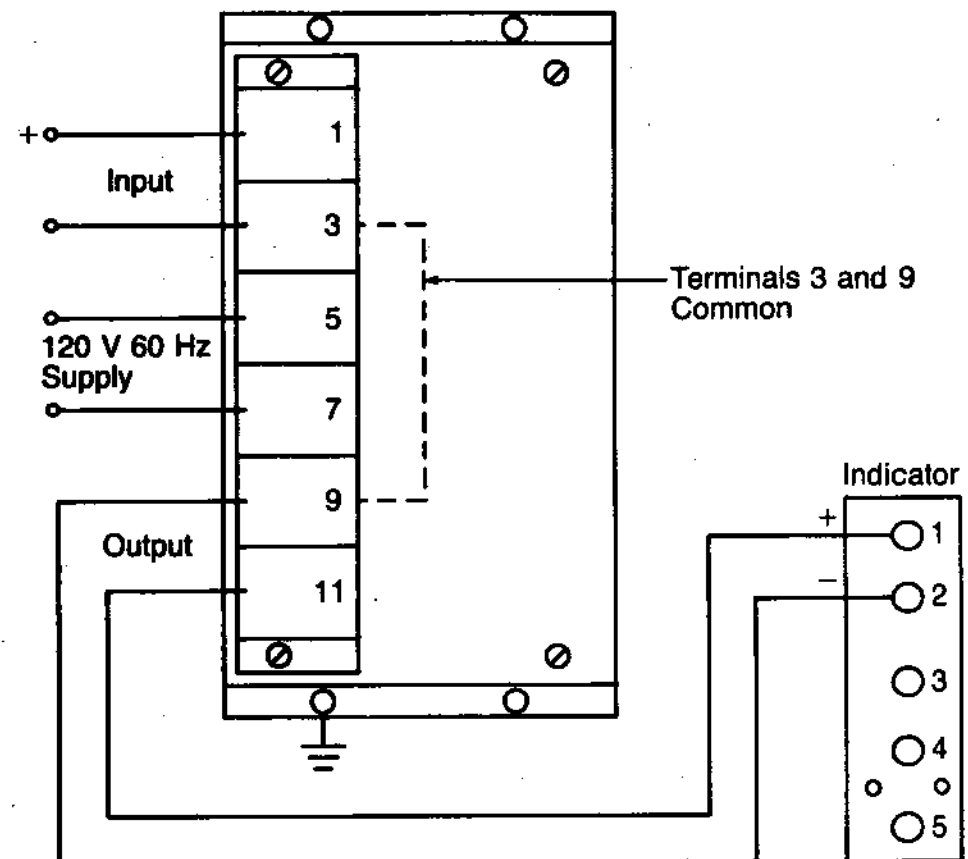


Fig. 61 - Speed Indicators - Pulse Type

d) The only wearing parts on the pulse generator are the bearings. These are removed by taking off the end cap and the pulse disc. This exposes a front bearing plate held in place with cap screws. Removing this cover permits withdrawing the shaft and bearing assembly.

C. Thermometers

Electrical temperature measuring instruments fall into two categories – pyrometers and resistance thermometers. Pyrometers are simply low-reading millivoltmeters which measure the output of thermocouples.

On large rotating apparatus, electrical thermometers are usually of the resistance type. They use coils of copper, called resistance temperature detectors (RTDs) in contact with the windings, bearings, or oil of the apparatus. The change in resistance of these RTDs is proportional to temperature. The thermometer employs a bridge circuit to measure resistance and the output of the bridge goes to a milliammeter calibrated in temperature, see Figure 62.

Electrical Resistance Thermometer, Self-Contained

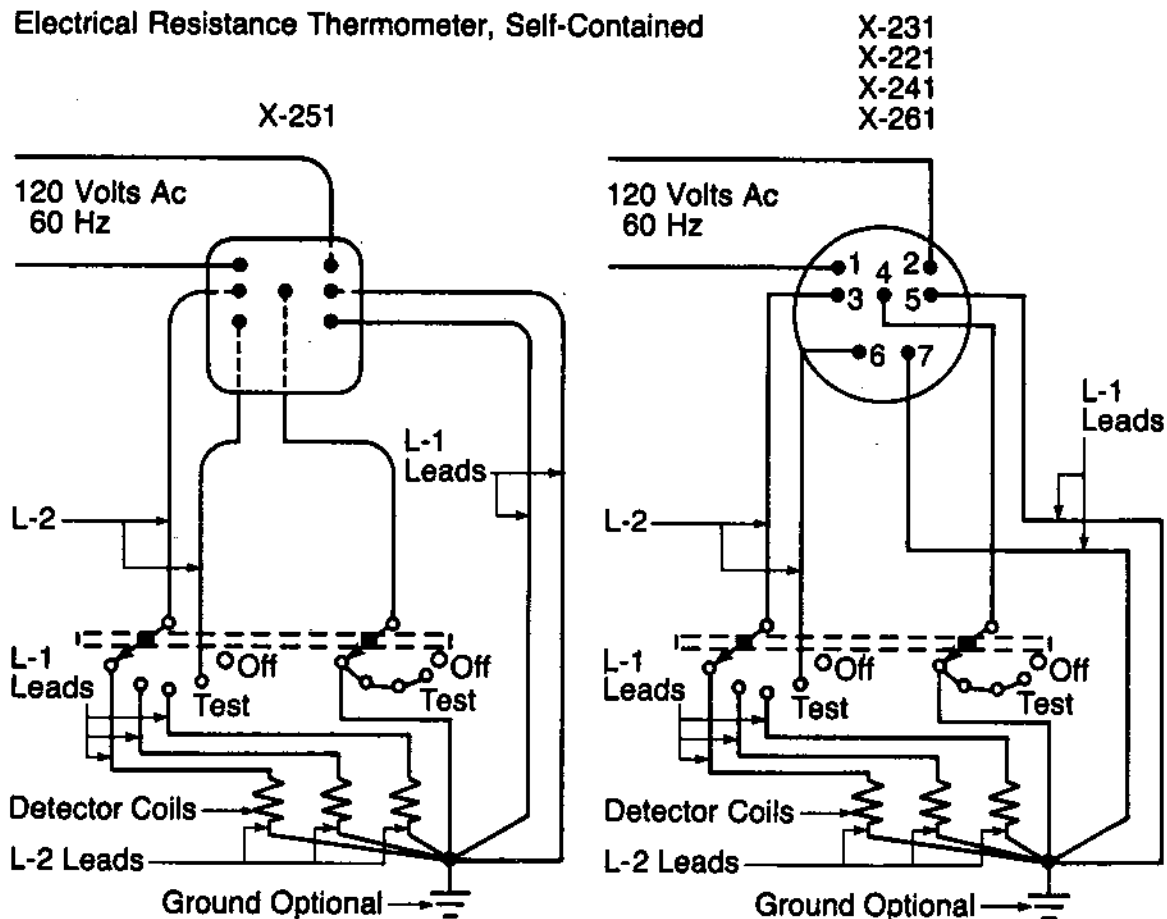


Fig. 62 – Electrical Resistance Thermometer

Troubleshooting a resistance thermometer calls for a number of special considerations.

1. Voltage and frequency are fairly critical. The 120V 60 Hz supply should be within $\pm 10\%$ on voltage and $+1\%$ on frequency. Within the range a self-regulating circuit will function.
2. Leads become part of the bridge resistance circuit; they must be carefully measured for resistance. "Switch-to-RTD" lead resistance must be within 0.02 ohms of balance and a total resistance under 0.3 ohms for each lead. Instrument to switch leads should measure less than 0.02 ohms each. The lead resistance measurement from several RTDs connected to a common return should also be under 0.02 ohms. Note: On special application the RTD leads can be as much as 3.0 ohms.
3. When switching between RTDs "switch" contacts must "make-before-break", or the instrument pointer will "peg" during switching and be damaged after repeated switching.
4. The switch must be a very high quality component, like a switchgear control switch. High contact resistance will cause an erroneous reading.
5. Part of the instrument is a test resistor. With the switch turned to "test", the pointer should move to a green test line on the dial. If it does not, set to zero with the zero adjuster.
6. RTDs themselves can be partially shorted. A Wheatstone bridge should be used to check them. For copper coils the resistances should be:

Temperature Degrees C	Resistance in Ohms
0	9.037
25	10.00
50	10.962
100	12.887
150	14.812
200	16.737
300	20.587

D. Ground Detectors

A ground detector is an array of voltmeters or resistors and a milliammeter arranged to indicate any abnormal relationship between lines and ground on a system which is normally grounded.

The following are examples of the application of ground detector voltmeters:

1. For D-c 2-Wire Ungrounded System – Figure 63

Under normal conditions both instruments will read approximately the same. If a ground occurs on either line, the corresponding instrument will read lower than the other. Instruments are 0-1 d-c milliammeters with dials marked in volts. For example: for 125 volts use a 0-150 volt dial. External resistor from center to either end has resistance of 1000 ohms per volt of dial rating. (Two standard d-c voltmeters may be used, omitting the external resistor.)

2. For D-c 2-Wire Ungrounded System – Figure 64

Under normal conditions instrument indicates zero. It will deflect to right (viewed from front) if ground occurs on positive line and left if on negative line. Instrument is 0.5-0-0.5 dc milliammeter with dial marked in volts. For example: for 125 volts use a 150-0-150 volt dial. External resistor from center to either end has resistance of 2000 ohms per volt of dial rating. For example: for 150-0-150 volt dial use 300,000-300,000 ohm external resistor.

3. For D-c 3-Wire System With Ungrounded Neutral – Figure 65

Under normal conditions both instruments will read approximately the same. With switch open they indicate zero. If a ground occurs on line A or B, the corresponding instrument will read lower than the other. If the neutral is grounded and the switch is opened, instrument A will read zero and B reads the voltage to ground. Instruments are 0-1 d-c milliammeters with dials marked in volts. For example, for 125-250 volts use a 0-300 volt dial. External resistor from center to either end has resistance of 1000 ohms per volt of dial rating. (Two standard d-c voltmeters may be used, omitting the external resistor.)

4. For D-c 3-Wire System With Ungrounded Neutral – Figure 66

Under normal conditions instrument indicates zero. It will deflect to the right (viewed from the front) if ground occurs on positive line and to left if on negative line. If ground is on neutral line, instrument will deflect to left when switch is open. Instrument is 0.5-0-0.5 d-c milliammeter with dial marked in volts. For example: for 125-250 volts use a 300-0-300 volt dial. External resistor from center to either end has resistance of 2000 ohms per volt of dial rating. For example: for 300-0-300 volt dial use 600,000-600,000 ohm external resistor.

5. *For A-c Single-Phase 2-Wire Ungrounded System – Figure 67*

Under normal conditions both instruments will read approximately the same. If a ground occurs on either line, the corresponding instrument will read lower than the other instrument. Each external resistor has 20 ohms resistance per volt of instrument dial rating minus 150 ohms. Instruments are 0-50 a-c milliammeters with approximately 150 ohms terminal resistance and dial marking in volts. For example: for 120 volts use 0-150 volt dial. (Standard a-c voltmeters may be used, omitting the external resistors. Sensitivity to high resistance grounds will be increased.)

6. *For A-c Single-Phase 2-Wire Ungrounded System – Figure 68*

Under normal conditions the instrument indicates zero. If a ground occurs the instrument will indicate the approximate voltage between the ungrounded line and ground. Ground is in line to correspond to switch which, when opened, causes instrument to indicate the lower voltage. Instrument is 0-50 a-c milliammeter with approximately 150 ohms terminal resistance and dial marking in volts. For example: for 120 volts use 0-150 volt dial. Each external resistor has 20 ohms resistance per volt of instrument dial rating minus 150 ohms.

7. *For A-c Three-Phase 3-Wire Ungrounded System – Figure 69*

Under normal conditions instrument indicates zero. If ground occurs, instrument will indicate approximate voltage between ungrounded lines and ground. Ground is in line to correspond to switch which, when opened, causes instrument to indicate the highest voltage. Instrument is 0-50 a-c milliammeter with approximately 150 ohms terminal resistance and dial marking in volts. For example: for 120 volts use 0-150 volt dial. Each external resistor has 34.64 ohms resistance per volt of instrument dial rating minus 150 ohms.

8. *For A-c Single-Phase 3-Wire System With Ungrounded Neutral – Figure 70*

Under normal conditions the instruments indicate approximately the same and with switch open they indicate zero. If a ground occurs in A or B the corresponding instrument will read lower than the other. If the neutral is grounded and the switch is opened, instrument A will read zero and B will read the voltage to ground. Instruments are 0-50 a-c milliammeters with approximately 150 ohms terminal resistance and dial marking in volts. For example: for 120-240 volts use 0-300 volt dial. Each external resistor has 20 ohms resistance per volt of instrument dial rating minus 150 ohms. (Standard a-c voltmeters may be used, omitting the external resistors. Sensitivity to high resistance grounds will be increased.)

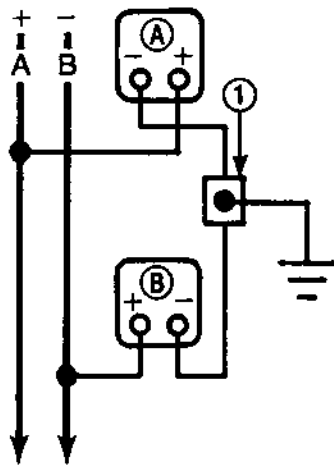


Fig. 63 - Ground Detector D-C, 2-Wire Ungrounded System

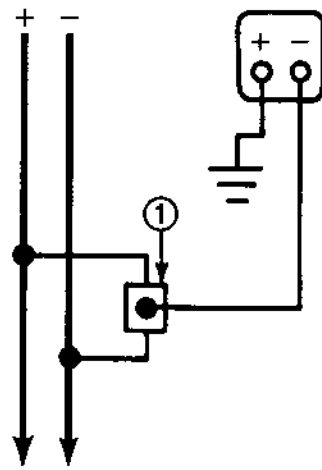


Fig. 64 - Ground Detector D-C, 2-Wire Ungrounded System

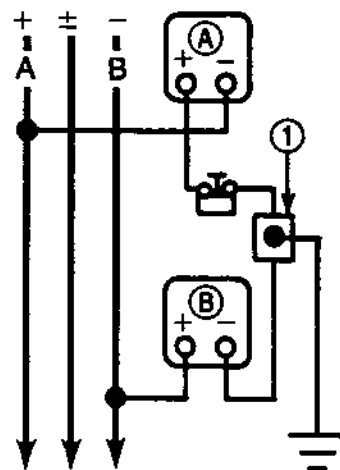


Fig. 65 - Ground Detector D-C, 3-Wire System with Ungrounded Neutral

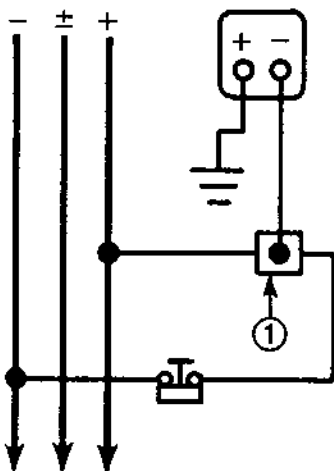


Fig. 66 - Ground Detector D-C, 3-Wire System with Ungrounded Neutral

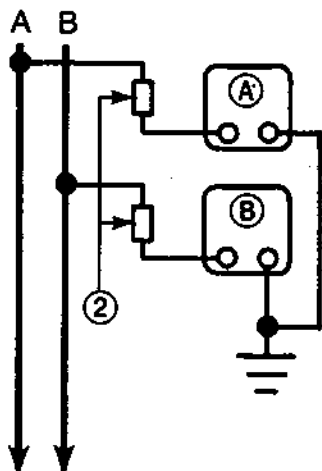


Fig. 67 - Ground Detector A-C, Single-Phase, 2-Wire Ungrounded System

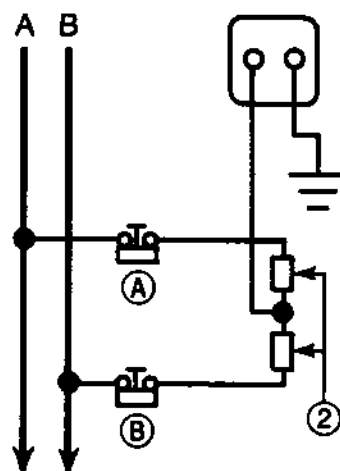


Fig. 68 - Ground Detector A-C, Single-Phase, 2-Wire Ungrounded System

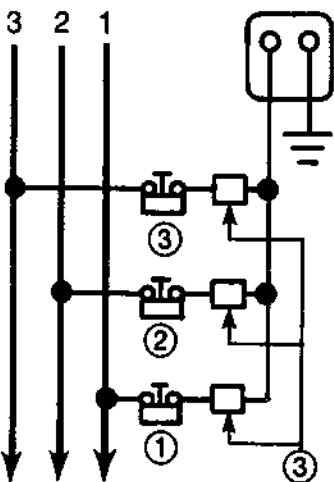


Fig. 69 - Ground Detector A-C, Three-Phase, 3-Wire Ungrounded System

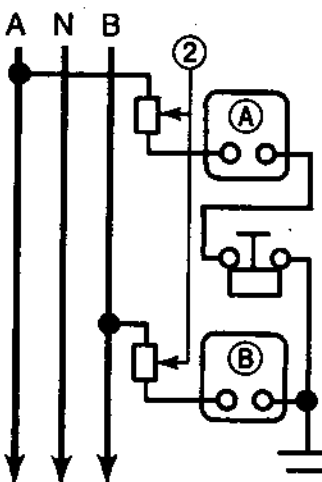


Fig. 70 - Ground Detector A-C, Single-Phase, 3-Wire System with Ungrounded Neutral

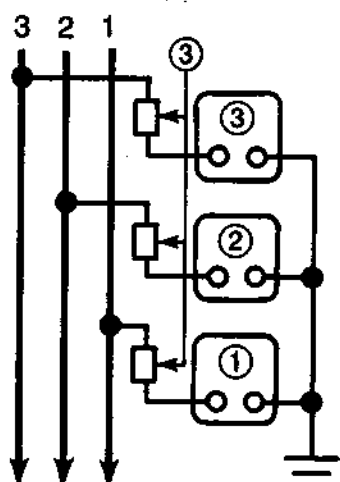


Fig. 71 - Ground Detector A-C, Three-Phase, 3-Wire Ungrounded System

- ① External Resistor, 1 Required.
- ② External Resistor, 2 Required.
- ③ External Resistor, 3 Required.

9. For A-c Three-Phase 3-Wire Ungrounded System – Figure 71

Under normal conditions and with balanced phases all instruments will read approximately the same. If a ground occurs the corresponding instrument will read lower than the others. Instruments are 0-50 a-c milliammeters with approximately 150 ohms terminal resistance and dial markings in volts. For example: for 120 volts use 0-150 volt dial. Each external resistor has 20 ohms resistance per volt of instrument dial rating minus 150 ohms. (Standard a-c voltmeters may be used, omitting the external resistors. Sensitivity to high resistance grounds will be increased.)

E. Position Indicators

These devices are not in the strictest sense instruments but they are closely related. Typically, a position indicator consists of a pair of self-synchronous motors. One motor is coupled to a rotating shaft with 360 degrees rotation and the other remotely located operates a pointer in a 360 degree instrument case. The motors are connected to each other by secondary wiring. Both are connected to the same alternating-current source for primary excitation. Any rotation of the first or transmitter motor is repeated identically by the second motor, the receiver. See Figure 72 for schematic.

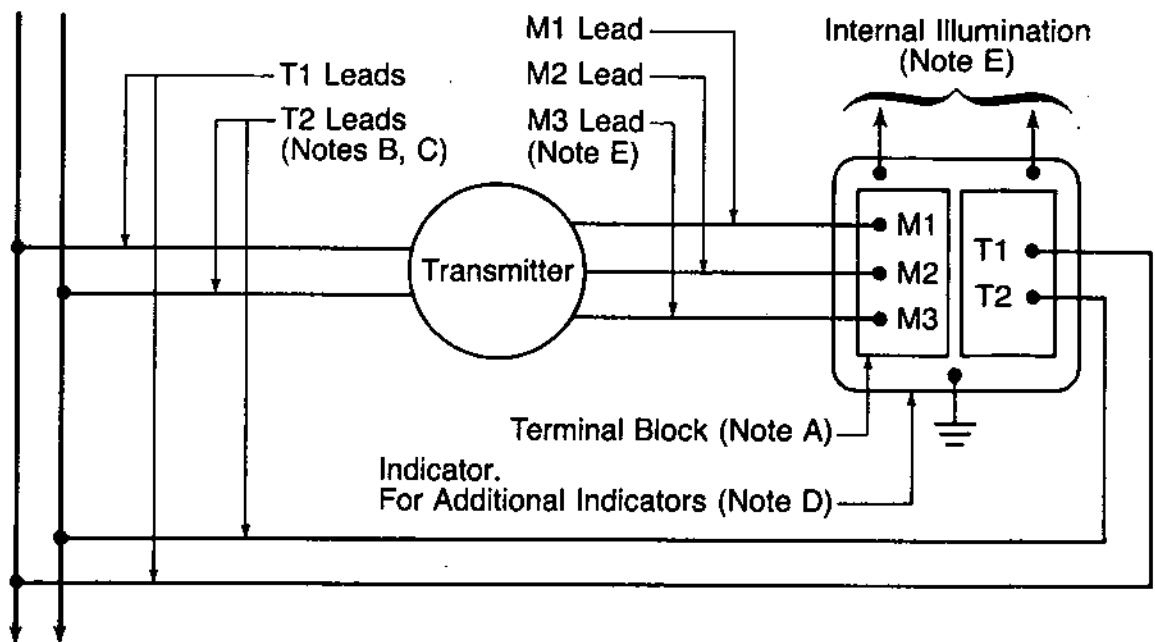


Fig. 72 – Synchrotite Position Indicator

Troubleshooting considerations are the same as for a small motor. The ability of the receiver to track the transmitter is affected by several factors:

A 180 degree error is due to a reversal of the single-phase supply line to one of the motors.

Reversed rotation is due to incorrect phase sequence on the rotor connections to the receiver.

Lag errors are caused by too much resistance in the rotor connecting circuit. 50 ohms per leg will add one degree of lag.

Supply voltage has a similar effect. A drop of 10 volts creates an added 0.25 degree error.

The torque reduces as the number of receivers per transmitter increases. This is a broad variable, but three or four receivers should not add more than a degree of lag.

Bearing friction, concentricity of shaft to dial and the general condition of brushes and slip rings could also affect accuracy.

In a properly made and maintained installation, operation within a 2½ percent error is to be expected.

F. Socket Instruments

A 100 degree taut-band switchboard instrument can be modified and installed in an outdoor watthour meter base making it weather, dust, and splash proof. The socket used is a standard four prong type.

Maintenance of socket type instruments is the same as for their switchboard counterparts. However, sockets for watthour meters are wired for straight through (top-to-bottom) connection but socket instruments may come in any configuration. Most problems are due to the failure to use circuit closing devices (where continuity is required with meters removed) or, where circuit closing devices were used on a meter fed from a transducer. Standard connection diagrams are usually supplied with the instrument. If there is any doubt about connections consult the instrument manufacturer.

19.18 Portable Instruments

ANSI Standard C39.1 recognizes portable analog instruments in accuracy classes 0.25, 0.5 and 1.0% but as a practical matter the 0.5% instrument is the maintenance man's most reliable tool. Westinghouse (0.5%) portable type instruments are noted for their versatility, ruggedness and accuracy in field service and test work.

Maintenance work requires measurements at two accuracy levels. For routine circuit tracing, circuit identification and approximate measurements of circuit loading there is a broad range of universal test sets and single purpose instruments; commercial type VOMs, clamp-on ammeters etc., are adequate for routine work but, their fundamental deficiency is basic inaccuracy and lack of (rms) response on alternating-current. Even the popular types of digital VOMs fall into this classification for a-c measurement but, they are generally very good on direct-current. Where it is necessary to measure under dynamic conditions, or where absolute values of alternating-current are required, the 0.5% accuracy class portable instrument is needed. Testing for performance guarantee purposes, acceptance testing, voltage setting, and adjustment of control circuits requires absolute values. These are the jobs for the 0.5% portables, with performance guaranteed to meet the standards of the American National Standards Institute and acceptability by the Bureau of Standards. With this type of certification both the supplier and the user are talking about the same values.

A. Certification of Portable Instruments

To be deserving of a high degree of credibility all absolute electrical measurements should be traceable to the National Bureau of Standards. This organization is the custodian of the primary standards and they maintain reference standards derived from the primary standards. These reference standards are, in turn, used to verify the calibration of secondary standards which are used to calibrate working instruments. Industry, instrument manufacturers, testing laboratories, and the like can obtain verification of devices at the reference standard level or lower. They are then permitted to manufacture, recalibrate, and certify their instruments as having traceability to the National Bureau of Standards.

The American National Standards Institute standard ANSI C39.1 defines the minimum performance and general requirements level for electrical instruments. ANSI standards should assure that an instrument, when calibrated to NBS traceable standards, is capable of transferring that quality of measurement to field conditions within specified limits. In practice, portable instruments are checked periodically against standards of the next higher order. The frequency of such checking depends upon the criticality of the instrument readings, the environment and handling

to which instruments are subjected, and the type of personnel using them.

A record should be made up for each instrument by serial number showing dates of inspection, calibration data as received, and the date when it should be recalled from the field and a recalibration check made; also any interim repairs it required should be noted. After a few years, it will become obvious what time cycle needs to be established for check-out of each instrument.

B. Use and Application of Portable Instruments

For maximum accuracy a portable instrument should be operated with the dial in a horizontal position unless it has been calibrated for use in some other position and is so marked. Failure to observe this requirement may result in indication errors due to possible effect upon accuracy from changes in the moving element balance.

Before energizing an instrument, the pointer "zero" position should be checked; if necessary, reset it with the zero adjuster. Other precautions which should be observed and practiced are:

Check circuit to the instrument. The instrument range must be higher than the maximum value of any quantity to be measured. Multiple range instruments should always be connected or switched to the highest range.

Use direct-current instruments only on direct-current circuits. Permanent-magnet, moving coil instruments do not respond to alternating-current and if connected to alternating-current can be overloaded or damaged with no deflection of the pointer.

A-c instruments of the iron-vane type will indicate on direct-current but at reduced accuracy. For purposes expediency this type of instrument can be used on direct-current by taking the average of reversed readings.

A-c instruments using an internal transformer, such as multiple range ammeters, cannot be used on direct-current.

A-c rectifier type instruments read within their accuracy rating only when used in a-c circuits having good sinusoidal wave forms. Instrument readings will be in error by an amount dependent upon the degree and type of deviation from sine wave. Due to the infinite possible variations of wave form distortion, it is not a simple matter to relate an instrument error to wave form distortion.

Rectifier instruments should not be used in d-c circuits; they will read incorrectly, or not at all. Instruments with full-wave rectification will read approximately 11% high on d-c while those with half-wave rectification will read approximately 120% high on one polarity and zero with reverse polarity.

Flux-Volts – voltmeters, used in transformer testing, are simply full-wave rectifier instruments; as such, they can be used in the same manner as any other rectifier voltmeter for measuring a-c voltages.

To eliminate instrument reading errors due to parallax between pointer and scale, portable instruments are furnished with knife-edge pointers and mirror dials. Parallax error is eliminated when the pointer is superimposed over its mirror image during scale reading.

Westinghouse portable instruments are designed with the intent that the + terminal on direct-current and the + terminal on alternating-current be connected to the grounded side of the external circuit being measured. Failure to observe this requirement for connections may result in instrument indication errors, particularly on voltages near 800 volts or above where electrostatic forces begin to act on the pointer.

If an instrument is designed for use with an auxiliary device, such as a shunt or transformer to extend its range; the proper (serialized or rated) auxiliary device must be included in the circuit to avoid instrument overload and damage. In Figure 73 a current measuring instrument is connected in series with the load. The self-contained instruments require no auxiliary shunts but often a separate externally connected shunt, or load box, must be used to handle higher current, see Figure 74.

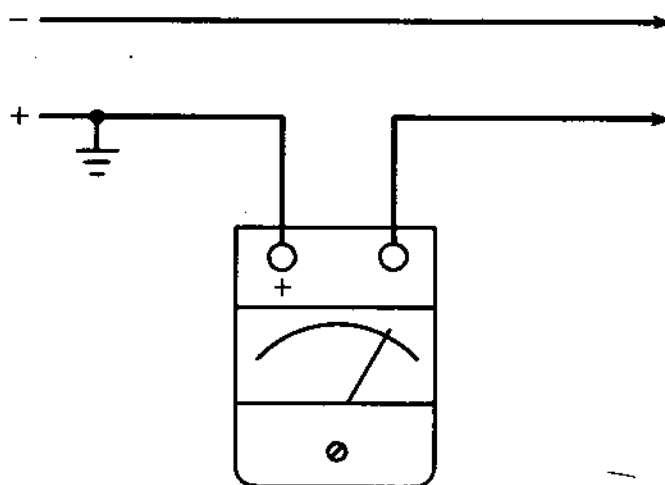


Fig. 73 – D-C Microammeter, Milliammeter, and Self-Contained Ammeter

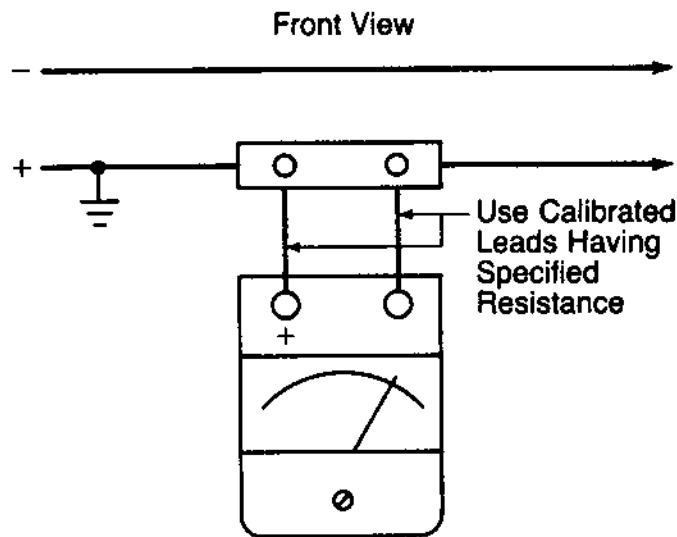


Fig. 74 – D-C Millivoltmeter with Shunt for Measuring Current

Shunts are marked with a current and millivolt rating. Millivoltmeters usually have a full scale millivolt rating corresponding to that of the shunts with which they are to be used. Since the millivolt drop measured across a shunt is proportional to the current through it, the actual line current may be readily calculated as follows:

Assume the shunt is rated 8000 Amp. 50 mV.

Assume the millivoltmeter range is 50 mV (full scale).

Assume the millivoltmeter reads 43 mV and you want to know the actual line current. Using this formula, the actual line current is determined by this mathematical method:

$$\frac{\text{mV reading on instrument}}{\text{mV rating of shunt}} = \text{current rating of shunt}$$

Using the assumed values given above:

$$\text{the actual line current} = \frac{43}{50} \times 8000 = 6880 \text{ amperes}$$

Since millivoltmeters can be applied to shunts of every possible current rating it is sometimes useful to three scales on these instruments; instruments are available with 0-50, 0-100, and 0-150 millivolt scales. The extra scales facilitate direct reading of currents in shunts rated at 15, 30, 150, 300 amperes and higher, using the same millivoltmeter.

For operator safety, shunts should always be connected in the grounded side of a circuit. If the circuit is grounded at more than one point, the shunt must be located so that the total line or load current flows thru it. If this condition cannot be established, it may be necessary to connect the shunt and instrument to the high voltage side of the circuit. If this must be done, recognize and respect the hazards involved by properly insulating and isolating the measuring circuit and devices from operating personnel. Use of any instrument in the high potential side of circuits over 800 volts requires special consideration to assure instrument accuracy and operator safety. Be sure they are properly connected.

1. Voltage measuring instruments are connected in shunt or across the points whose potential difference (voltage) is to be measured, see Figure 75.

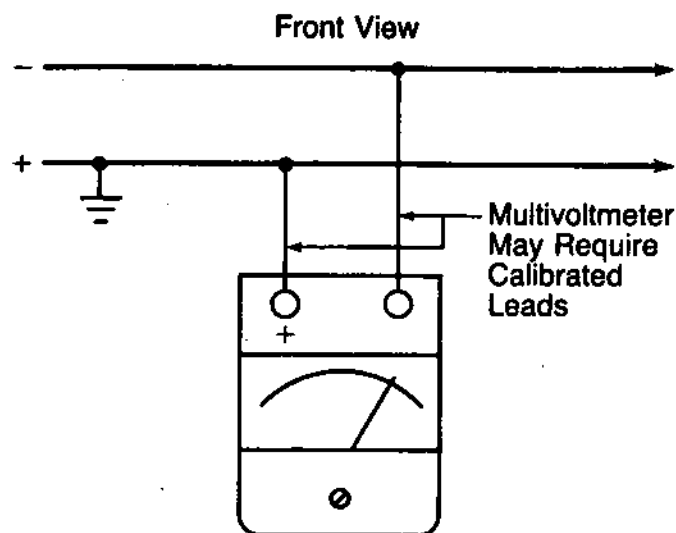


Fig. 75 – D-C Voltmeter and Millivoltmeter Used without Shunt

2. Millivoltmeters, designed for use with shunts, may also be used to measure low voltages within their scale ranges. However, on high resistance circuits, they may unbalance the circuits and the instruments may be underdamped but, the accuracy of the instrument readings will not be impaired.

3. High resistance millivoltmeters are generally designed with higher internal damping. Their use will minimize circuit unbalance and give a truer picture of circuit conditions. High resistance millivoltmeters may also be used in conjunction with shunts. Damping may be high, but accuracy of readings is not impaired.

4. The positive (+) terminal of a voltmeter is internally connected directly to the measuring coil. This terminal should be connected to the

grounded side of the circuit being measured. Failure to keep the (+) terminal at ground potential, particularly when measuring high voltages, may result in instrument indication errors.

Current measuring instruments are connected in series with the circuit or load whose current is to be measured, see Figure 76. They should be connected in the grounded side of the circuit for maximum operator safety.

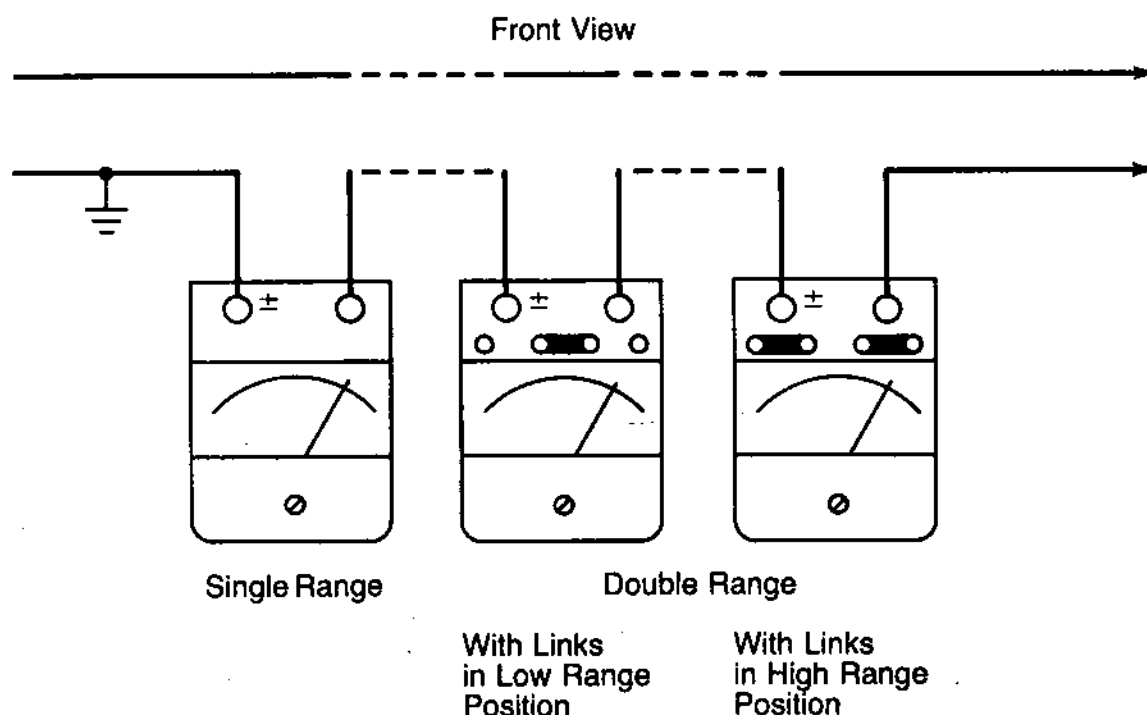


Fig. 76 – A-C Milliammeter and Self-contained Ammeter

Double range ammeters are furnished with links whose position determines the full scale range of the instrument.

Multiple range ammeters with internal transformers cannot be used on direct-current.

Warning: Do not energize a current transformer primary circuit if the secondary is open-circuited. The high voltage induced can cause severe personal injury or death, and damage to the transformer and any connected apparatus. To safeguard against this possibility use a switch as shown in Figure 70.

Figures 77 and 78 are schematics of instruments connected with transformers.

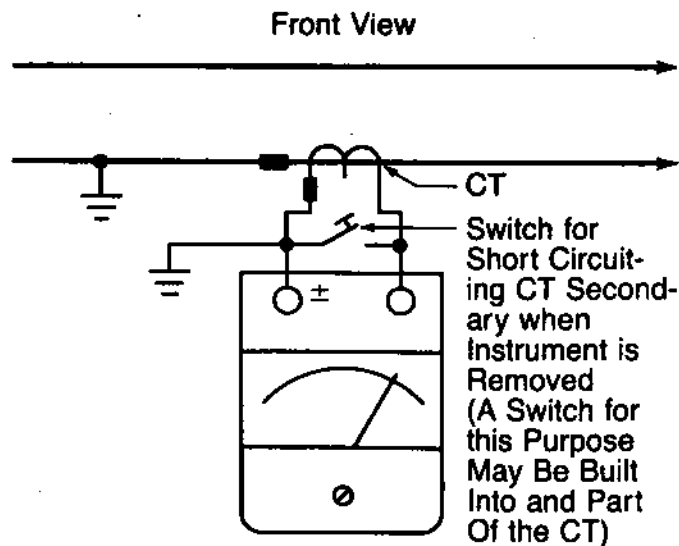


Fig. 77 – A-C Ammeter with Current Transformer

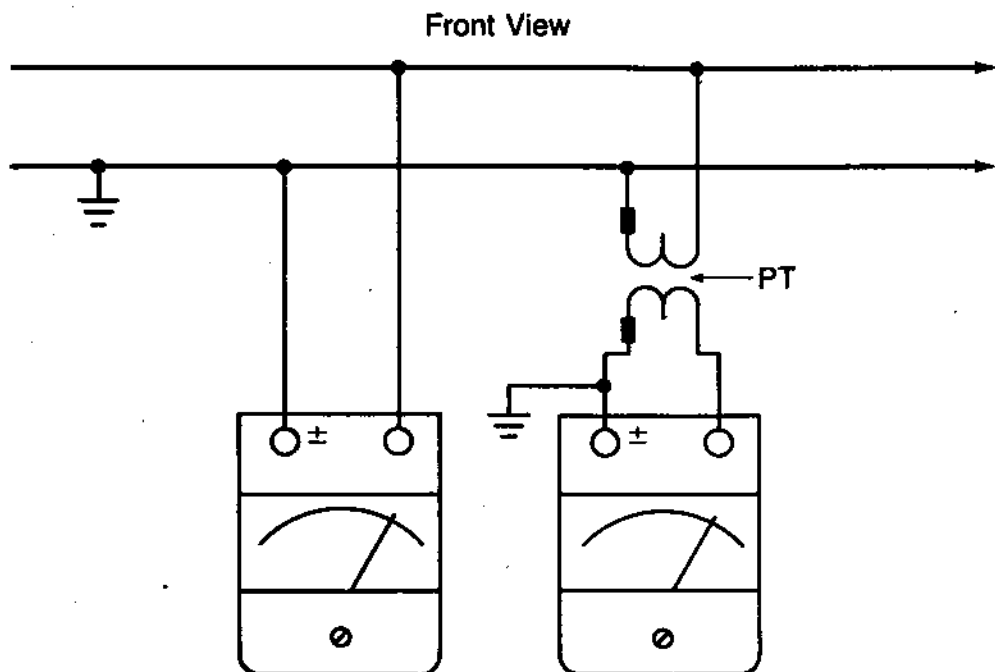


Fig. 78 – A-C Voltmeter with and without Potential Transformer

The line current is the product of instrument indication and current transformer ratio, the following are possible influences:

1. The (+) terminal of a voltmeter is internally connected directly to the measuring element coil. This terminal should be connected to the grounded side of the circuit being measured. When a potential transformer is used with the instrument, the transformer lead connected to the ($\pm$) meter terminal should be grounded. Failure to keep the $\pm$ terminal at ground potential, particularly when measuring high voltages, may result in instrument indication errors.

2. The voltage across the voltage transformer primary is the product of the voltmeter reading and the voltage transformer ratio.
3. A-c voltmeters designated type (PA) utilize a moving iron-vane mechanism and they respond to the true rms value of an applied a-c wave.
4. A-c voltmeters designated type (PC) utilize diode rectifiers and a d-c mechanism. Since its d-c mechanism responds to the average value of applied wave, the combination is calibrated on a pure sine wave and the scale is calibrated for the rms value of applied voltage. This type of instrument reads accurately only on pure sine wave voltage. Its use on non-sinusoidal wave shapes will introduce reading errors depending on the degree of wave shape distortion. Type (PC), multi-range voltmeters, are generally designed with an internal resistive network that establishes a common scale distribution for all ranges. Use of this network requires a switch for range selection and eliminates the option of multiple terminals.

19.19 Recording Instruments

The records made by recording instruments are either strip charts or circular charts. The recording mechanism may be direct acting, galvanometric, pneumatic, potentiometric, or oscillographic. The record may be drawn in ink, on pressure-sensitive, or heat sensitive, or light sensitive paper. Sensitivities, speeds of response vary widely. There is also a wide variety of magnetic recorders, and printers, and electronic units in increasingly common use. Probably the type most frequently of concern to the maintenance department is the direct-acting analog type.

A. Circular Chart Recorders

Circular chart recorders are used for short term recording of current or voltage. These instruments are available as panel mounted or portable devices. Figure 79 shows a typical portable circular-chart recorder.

Chart drives are synchronous motors, hand-wound clock mechanisms, or carry-over clock types. The synchronous motor drive may be changed from one to seven days with gearing supplied with the drive. Clock motor voltages are changed on dual-voltage instruments by a range changing switch. Hand-wound clocks have spring-driven escape-ment mechanisms. Shifting from one day to seven day operation is done with a gear change lever.

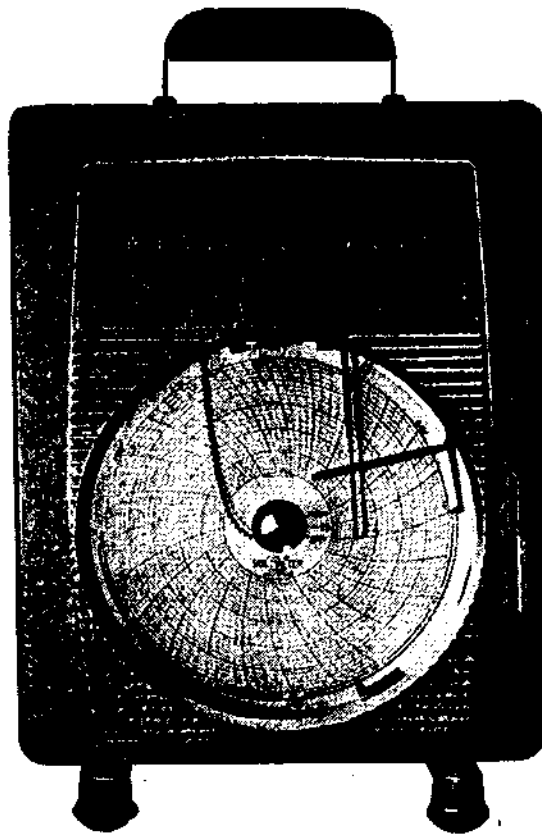


Fig. 79 - Typical Chart Recorder-Circular

A carry-over clock is used when the drive is expected to continue during a power outage. This drive has a basic synchronous motor drive with a back-up self-winding clock that takes over when the synchronous drive fails or when power is off. Following an outage the clock will automatically rewind to store reserve to make up for the time it operated or the replacement will be at a ratio greater than the expenditure.

The ink supply system will be an ink sac feeding the pen through a flexible tube, the sealed ink system, preferred for switchboard instruments, or it may be an eye dropper type of reservoir feeding a V-pen, commonly used on portable recorders.

Most standard inks are suitable for use in a temperature range of +30F to +90F (-1.11C to +32.22C). At temperatures lower than +30F, extreme temperature inks should be used, suitable to -40F (-40C). Low temperature inks should not be used at temperatures above +50F (+10C) because of rapid evaporation.

B. Strip-Chart Recorders

Strip-chart recording instruments are used for long term recording where the length of the strip roll permits prolonged continuous operation. Most strip-chart recorders are electrically driven but some hand-wound clock

mechanisms may be encountered. Chart speeds are rated at inches per hour. The total running time in days is shown in parentheses, thus $\frac{3}{4}$ " (71), $1\frac{1}{2}$ " (35), 3" (17), 6" (8) and 12" (4) means that at $\frac{3}{4}$ inch per hour the meter will run for 71 days, at $1\frac{1}{2}$ " per hour for 35 days, etc. Figure 80 shows a typical strip-chart panel recorder.

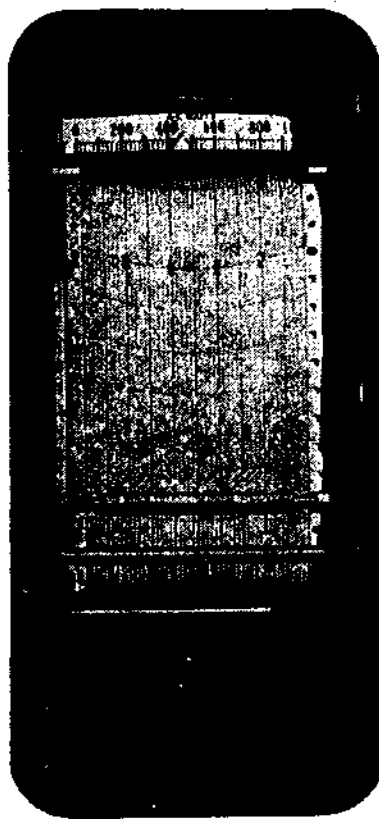


Fig. 80 – Typical Chart Recorder-Strip

C. Maintenance of Recording Instruments

1. Calibration Adjustment

To check and adjust calibration the instrument must be in its normal vertical operating position.

- a. Connect the instrument to the calibrating circuit with a reference standard instrument; (ammeters in series with the reference standard and voltmeters in parallel with the reference standard).
- b. On ammeters and left-zero voltmeters, calibration is adjusted by setting the pen to zero (unenergized) and adjusting "effective torque" of the spring by moving the clamping position (at the outer convolution) until the instrument tracks the scale properly. Shortening the effective spring length increases the spring torque and vice versa.

c. Suppressed-zero voltmeters have a combination of two calibration adjustments.

Degree of suppression, by rotating the set screw.

Spread of the scale, by shortening, or lengthening, the effective length of the torque spring.

A trial reading should be made by energizing the voltmeter and noting the voltages required for the left end of the scale and for the major scale division below full scale. Adjust suppression and spread as necessary for the pen to track over the scale.

2. *Mechanical Balance*

Moving elements are mechanically balanced to minimize position influence which is a change in indication resulting from the instrument not being in a perfectly vertical position. Balance weights are usually provided on the damping vane. When making calibration adjustments it may be necessary to change the position of the balance weights to attain scale tracking at all points.

3. *Damping*

Instruments with magnetic damping are usually adjusted to overshoot on sudden load changes. This damping is adjustable by changing the position of the damping magnet poles relative to the damping vane. Care should be taken to secure the damping magnets in place after adjustment has been made.

4. *Sealed Inking Systems*

These systems consist of an ink sac, plastic tubing, a pen which is of fine metal tubing, with the pen pressure supplied by the adjusted lateral displacement of the plastic tubing. This pressure should be as light as possible and still provide continuous contact.

Ink feed tubes must be replaced with great care to assure free flow of ink and proper pen pressure. Careful fitting of the tubing should be from the pen back to the ink sac avoiding any kinks, and assuring sufficient clearance of all operating mechanisms. After the supply tube is fully adjusted, excess tubing at the ink sac should be cut off and the final connection of the supply tubing to the ink sac should be made.

If a pen becomes clogged and stops inking a pen cleaning wire may be used to clear the channel. There is a danger that the wire will push the

plug of dried ink and paper fibers back up the tube only to have it descend and plug the pen again. A reverse flushing procedure is more effective and more certain. Reverse flushing requires a pen syringe, which can be obtained from the instrument manufacturer. The syringe should be filled with water. The pen should be detached from the supply tube, removed from the recorder, and cleared by means of the cleaning wire. The pen writing tip should then be inserted into the syringe hole and bulb pressure applied until water flows freely out of the pen inlet. The pen should then be reversed, the inlet end inserted into the syringe hole, and bulb pressure applied. A clean pen will emit a fine solid stream. The pen should then be remounted. This procedure is recommended at each time the ink sac is replaced.

5. *Charts and Ink*

The paper used for the charts is a special type developed for this specific application, with special dimensional stability, moisture absorption characteristics, and specific inking properties. Only papers recommended by the instrument manufacturer for the particular instrument should be used.

Inks for recording instruments are especially formulated for the instrument, the type of recording, and the inking system. Only the ink recommended by the recorder manufacturer should be used.

If a recorder has been out of service long enough for ink to dry in the system, the ink reservoir, tubing, and pen should be washed with the proper solvent for the ink involved, usually water or alcohol, and the reservoir refilled. A flushing of the inking system with the proper ink solvent once a month is recommended.

6. *Chart Mechanism*

The chart mechanism includes the chart roll compartment, a driving drum, re-roll spool, re-roll drive mechanism, and chart drive.

The re-roll drive mechanism may be a spring driven device wound either manually or by the timing mechanism. In either case the spring stores sufficient energy to re-roll well over a full roll of chart paper. Synchronous motor chart drives are self-starting and do not require regulation. Bearings in chart drives and re-roll drive mechanisms should be cleaned and lubricated on an established schedule. Bearings should be removed and cleaned by dipping in clock cleaning fluid and after drying, lubricated with high grade clock oil.

7. Calibration

The accuracy of recording instruments can be checked by comparing them with known standards in the same manner as for indicating instruments.

The calibration of recording voltmeters, ammeters, and wattmeters can be adjusted over a range of plus or minus 5% by changing the location of the outer end of the spring in the spring clamp. Increasing the active length of the spring increases the reading for a given setting of the standard. For specific instructions consult the manufacturers' instrument manual.

The calibration of d-c recording instruments can be performed by adjusting either (or both) of the two magnetic shunts as follows: With the magnetic shield removed, loosen the set screws in the shunt bar clamps located at the top of the lamination stack assembly. Now, the shunt bars can be raised, or lowered, (as desired) by application of firm forefinger pressure on the bar. Final precise settings can be obtained by adjusting the shunt bar with the chart mechanism and pen in normal position. The ends of the shunt bars are accessible for hand adjustment through the opening under the chart mechanism. When the desired instrument calibration is attained, the set screws in the shunt bar clamps must be retightened to lock the shunt bars in position.

In general, calibration is performed in the same manner as for indicating instruments. Use portable standards of known accuracy. When recording mechanisms are removed for repair, the original angles between the pen and the moving elements must be restored as follows:

- a. On a-c ammeters, the axis of the rotor is 36 degrees in advance of the pen axis.
- b. On a-c voltmeters, the axis of the rotor is 34 degrees in advance of the pen axis.
- c. On a-c wattmeters, the axis of the moving coils is approximately in line with the pen axis.
- d. On d-c instruments, the axis of the pen is approximately 26 degrees in advance of the moving coil axis.

When replacing a moving element, the moving coils or rotor must be centered in the air gap by means of the adjustable jewel screw mounts.

The calibration of voltmeters and wattmeters can also be varied by adjusting the series resistors, but this method is not recommended

except in special cases. Resistance values are chosen to give the best accuracy under varying temperature, or polyphase unbalancing conditions. If it ever becomes necessary to change the rating or full scale capacity of an instrument, the instrument should be returned to the factory.

Shunted type d-c recording ammeters are generally calibrated as 50 mv (full scale) millivoltmeters by applying rated millivolts to the outer ends of the calibrated leads furnished with the instrument. When calibrating these instruments for use with shunts below 100 ampere capacity, allowance should be made for the shunted current taken by the instrument; (approximately 0.2 ampere). For example, for a 25 ampere 50 mv shunt, $I = (25 \text{ minus } 0.2) \text{ or } 24.8 \text{ amperes}$.

Polyphase recording wattmeters are calibrated on single phase circuits with the current coils in series and the potential coils in parallel. When used with transformers, the calibration constant (K) is equal to the product of the current transformer and voltage transformer ratios.

Recording varmeters (volt-ampere reactive) are ordinary voltampere meters. The calibration is the same as that of the standard wattmeter. In some cases the zero is placed in the center of the scale instead of at the left end to record lagging and leading reactive power.

Recording type portable utility wattmeters are specially calibrated for both alternating-current and direct-current operation by adjusting the full scale current to be 5 amperes at nominal watts d-c input, (for example, 500 w), and adjusting the resistance of the current coil and shunt leads to take 5 amperes when 100 millivolts are applied.

Accuracy Ratings – Recording instrument accuracy ratings are expressed in terms of full scale capacity ANSI standard 39.2. Ratings of specific instruments should be obtained from the manufacturers.

8. *Variation in Chart Records*

Sluggishness of action is indicated by the record not showing actual variations in the quantity measured and may be due to friction in either the meter element, or in the pen system.

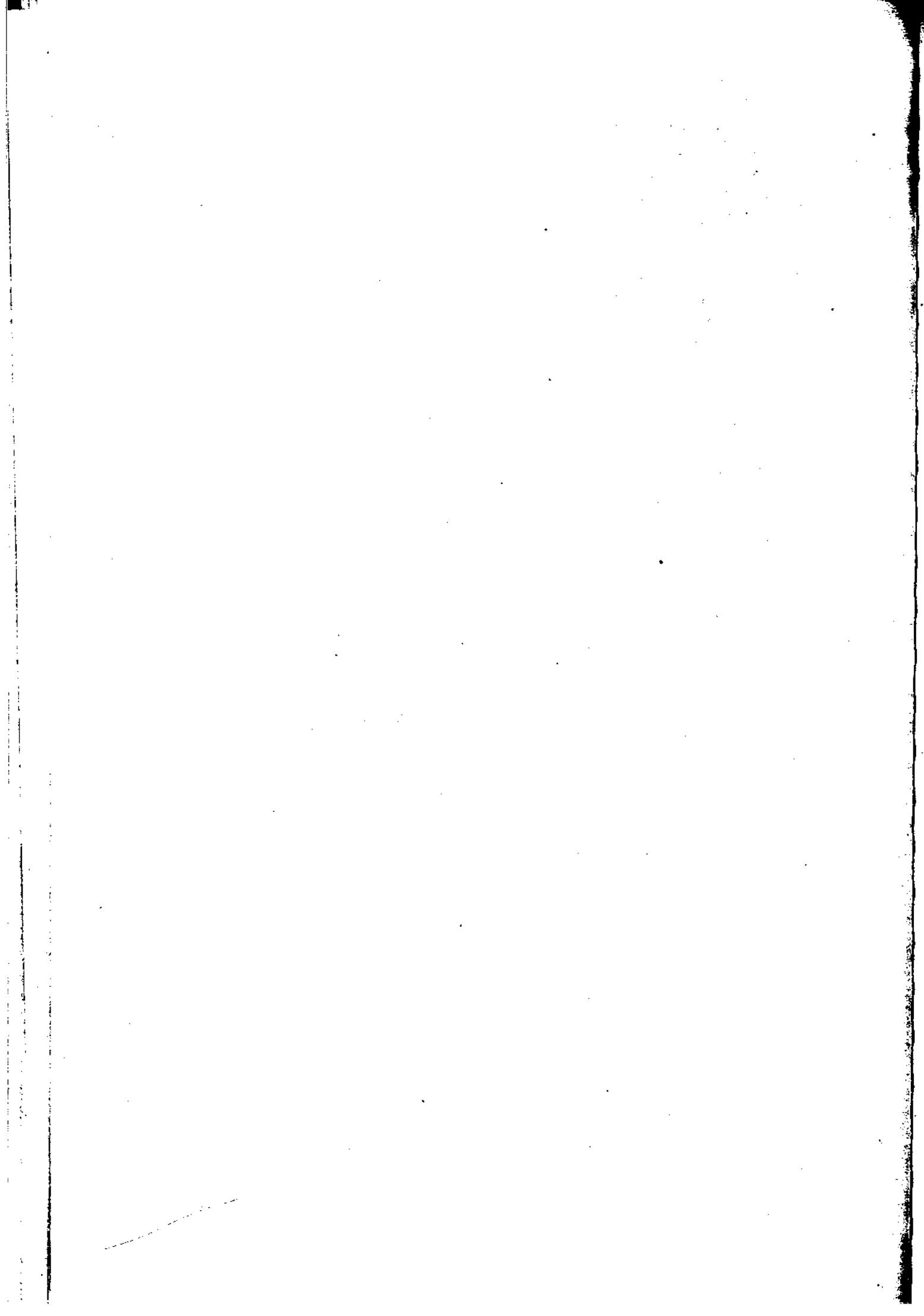
Friction in the moving element can be detected by removing the pen and tilting the chart mechanism forward. If the pen arm does not return to position after slight lateral displacement there is a friction problem. Friction in the moving element may be due to dirt or magnetic particles in the air gaps, or to a damaged jewel or pivot.

If the friction exists only when the pen is in action, with the ink flowing correctly, it is due to the pen tip bearing too heavily on the paper. This may be caused by excessive pen tip pressure or, to an improper clearance adjustment between the pen and the pen bearings. The former condition can be corrected by rebalancing the pen, the latter by adjusting the bearing supports to allow a total clearance of .005 to .010 inches between the pen and the bearings.

The quality of the record obtained depends on the speed of the chart paper and the nature of the circuit. The choice of a chart speed depends upon the nature of the load and the accuracy which is desired at the time. On loads which are subject to large swings and oscillations, higher chart speeds should be used, otherwise, the ink will soak through the paper, and no distinct record will be obtained since the pen traverses the same line several times. At higher speeds, the paper will move perceptibly between successive oscillations of the pen, and the record will be legible.

9. Damping Adjustment

Magnetic damping is provided in all mechanisms; the degree of overshoot is adjustable by turning the screw identified in the service manual, after removing the mechanism shield for access. Turning the screw clockwise decreases damping, turning it counterclockwise increases damping.



Protective Relays

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- Design Preference 2:20.1
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Warning: Follow the safety instructions given in Volume 1 Chapter 5, and throughout the book. Failure to do so can result in severe personal injury or death, and substantial damage to property.

Protective Relays

The function of a protective relay is to detect abnormal operation of system components and initiate appropriate action to protect the system. Relays are used to protect such apparatus as generators, motors, transformers, busway, distribution feeders, or transmission lines, usually by initiating breaker or recloser trip to isolate the apparatus. As with any protective equipment, periodic inspection and test should be conducted in order that the relays may perform properly when called upon. Relays are available in electromechanical designs and in designs using solid state components. Electromechanical types of relays are by far the most frequently encountered.

20.1 Apparatus Covered

This material will cover the maintenance of electromechanical relays only. Solid State relays should be maintained using normal techniques and equipment for solid state devices, supplemented by manufacturers information concerning the specific relay or system. Many solid state systems and some individual units have built in test provisions and special test units. It is not practical to cover these in a general purpose publication.

20.2 Design Preference

Electromechanical protective relay designs have been favored by users from a test and maintenance viewpoint, as well as the following reasons:

1. Greater familiarity resulting from years of service.
2. Simpler circuitry and fewer components.
3. Sturdy construction and durable parts.
4. Simplicity of maintenance, test, and change out.
5. Comparatively low cost of replacement parts.

Solid state designs are usually specified when there is a need for higher operating speed and sensitivity.

Discussion here will be confined to electromechanical relays. ①

① For more complete basic understanding of relays refer to *Westinghouse Applied Protective Relaying* published by Westinghouse Printing Division, Trafford, PA 15085.

20.3 Relay Servicing Tools and Instruments

Tools needed to service electromechanical relays should include the following:

- 1 Each, curved and straight heavy duty tweezers.
- 3 Thin, open end wrenches, $\frac{3}{16}$ ", $\frac{1}{32}$ ", and $\frac{3}{8}$ ".
- 1 Small screw-holding screwdriver.
- 1 Thin blade screwdriver, $\frac{3}{16}$ " blade, 6" shank.
- 1 Short screwdriver, $\frac{1}{4}$ " blade, $1\frac{1}{2}$ " or 2" shank.
- 1 Standard screwdriver, $\frac{1}{4}$ " blade, 4" or 6" shank.
- 1 Set Phillips screwdrivers, 6" shank.
- 1 Set jeweller's or optician's screwdrivers.
- 1 Pair, needle nose pliers, straight.
- 1 Pair, needle nose pliers, curved.
- 1 Pair, duck bill pliers.
- 1 Contact burnishing tool.
- 1 Magnet cleaner, magnetized.
- 1 Set, spin-tite wrenches, insulated handles to fit $\frac{3}{16}$ ", $\frac{5}{16}$ ", $\frac{1}{32}$ ", and $\frac{3}{8}$ " nuts.
- 1 Inspection or dental mirror.
- 1 Loupe or pocket magnifying glass. An illuminated magnifying glass is more useful.
- 1 Bulb syringe.
- 1 Contact file, fine.
- 1 Magnet brush, stiff bristle, non-metallic.
- 1 Artist's paint brush, insulated shank, 1" camel hair.
- 1 Flashlight, insulated case.
- 1 Pen-light.

20.4 Bench Test Equipment

Notice: Reliable, steady state, power sources must be used to obtain accurate test results. Non-sinusoidal wave form will introduce significant errors in some cases.

Warning: Avoid direct contact with energized relays or related circuits. Failure to heed this warning can cause severe injury or death from electric shock.

When circumstances will not permit testing in place, the relay must be removed and testing performed on a test bench. Test instruments should have a high accuracy, 0.5 percent portable standards type. Any non-calibrated device should be checked before use, including potentiometers, resistors, variacs, load banks, and similar instruments.

Care should be taken in handling relays, to avoid exposure to dirt, lint, moisture, or other contaminants. Handling should be with lint-free gloves or tweezers. Relays should be tested and re-installed one at a time to avoid possible interchange of units.

The relay manufacturer's instruction literature should be studied and recommendations followed exactly.

List of Bench Test Apparatus

Alternating-current, single and 3 phase sources.

Direct-current sources.

Oscilloscope, dual trace.

A-c ammeters and voltmeters, including VTVM.

D-c ammeters and voltmeters.

Ohmmeter or Wheatstone bridge.

Phase shifter.

Variacs.

Phase angle meter.

Electronic timer.

Electronic frequency counter.

Frequency generator and power amplifier.

Load banks.

Precision resistance load box.

Module card extenders.

Miscellaneous auxiliary relays, switches, indicating lights, clip leads, and extension cords.

20.5 Relay Inspection and Test Preliminaries

Test and inspection report forms are a useful tool to assure no important items are overlooked and to provide a record of individual devices. In making tests and inspections all information called for on the form should be carefully checked. Relays and associated equipment may be changed out between inspections and the inspection check will reveal the condition. Some sample test and inspection forms are shown in *Westinghouse Electrical Maintenance Hints, Volume 4 Chapter 3*.

Relay Inspection Procedure

See Figures 1 through 8.

1. Use care in removing relay cover. It is possible in some cases to activate the instantaneous trip with the operation indicator, reset device, or with the finger when removing the cover.



Fig. 1



Fig. 2



Fig. 3



Fig. 4

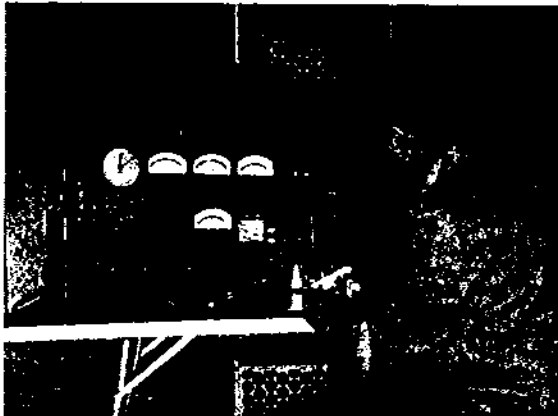


Fig. 5



Fig. 6

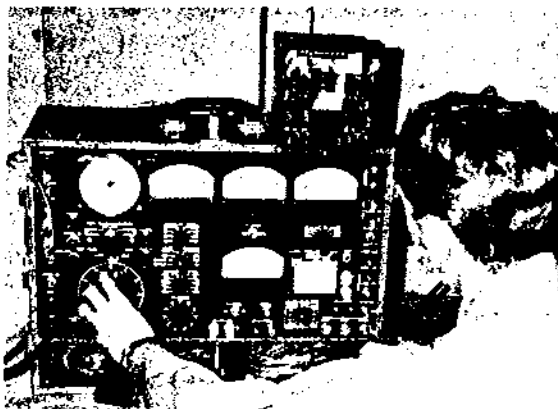


Fig. 7



Fig. 8

2. Inspect the cover for broken glass and a tight gasket seal; replace the gasket when necessary. Glass must be tight and should be cleaned during inspection.

3. On Westinghouse relays equipped with Flexitest cases, a relay test block will be used when testing. Before this block can be used, or the relay removed from its case for servicing, the test switches must be sequentially opened.

Be sure you follow this recommended safety procedure:

a. Open the Trip Circuit — this is the red handled switch in the row of switches.

b. Open all remaining switches on the relay.

c. Be certain that the removal of the connection block, or opening of the current circuit test switches actually shorts out the current transformer secondary.

d. Open the latches that hold the relay in its case and carefully remove the relay from the case.

Warning: Avoid touching the sliding contacts in the relay case. At this stage they are still energized and can cause severe personal injury or death from electric shock, tripping, or short circuiting.

Fig. 1 – Make Certain Relay Identification and Existing Records Agree.

Fig. 2 – If Defects are Visible Consider Necessary Repair or Replacement and Possible Shutdown.

Fig. 3 – Remove Covers One at a Time and Replace Promptly when Inspection is Complete.

Fig. 4 – Clean and Inspect the Relay.

Fig. 5 – Use Extreme Care When Dismantling or Making Repairs.

Fig. 6 – Check the Quality of the Service Work Before Making Calibration Checks.

Fig. 7 – Relay Accuracy is Based on Repeatability. Make Two or More Checks at Significant Points on the Operating Curve to Arrive at an Accurate Value of Current or Voltage.

Fig. 8 – Make Certain All Units Are Operational and Functioning Electrically and Mechanically Before Leaving the Job.

e. Having removed the relay mechanism, inspect the relay case for dirt, foreign material, filings, and other contamination. Blow out relay case with low pressure dry air or a bulb syringe. Check all accessible hardware for tightness and stripped threads.

Danger: Use insulated probes and extreme care in checking connections inside the case, they are energized at this point and will cause severe injury if touched. Replace the case cover when checking is completed.

f. Inspect the relay and its moving parts as follows:

1. Remove any rust or filings from the disc and magnet poles with a magnet cleaner or brush.
2. Inspect the relay for friction, its disc should not be warped or bent. It must have adequate clearance between magnet poles and it must not rub when rotated.
3. Inspect for evidence of moisture or rust on iron parts and corrosion or discoloration on brass or aluminum. If free moisture is present, or rust or corrosion is noted, report this condition. It may indicate the relay is being used in an improper atmosphere or there is a design problem.
4. Check all connections in the relay for tightness; especially taps. Check the hardware holding the relay element in its frame.
5. Check disc rotation by hand. It should move freely and reset smoothly. If its action is sluggish, bearings may be worn, dirty, or defective. On an instantaneous plunger type relay, a burr or groove may have developed on the plunger. This can cause the relay to hang up.
6. Bearings should be cleaned and inspected. Inspect with an optical magnifier to determine condition of jewels. Pivots should be straight and clean. Replace cracked jewels and bent pivots.
7. To clean jewels and pivots, soak in a solution of benzine or a jewelers cleaning solution for 5 to 10 minutes. Remove from solution, blow off with air and inspect. Use an orange wood stick or soft eraser to polish jewel surfaces. An ordinary bottle cork can be used to clean pivots. Stick the pivot into the cork and rotate to polish all sides of the pin. Never use any abrasives, cloth, or polish.

8. When replacing jewels and pivots, exercise care to insure proper disc alignment before tightening.
9. Relay contacts must be clean and tight.
10. Burned or pitted contacts should be cleaned with a burnishing tool or a contact file.

Notice: Do not use solvent on contacts and do not touch the contact surfaces with the fingers. The oily residue left on the contact could cause improper relay operation.

11. If the relay has auxiliary target devices or contact annunciator coils, check these items for friction and freedom of moving parts. They are normally magnetically sealed-in but may be a latch-type device triggered by contact opening or closing.

Notice: Before making any electrical tests on relays make certain the device is not damaged or inoperative due to lack of proper prior maintenance.

High Current Relays

Test apparatus must be employed to determine the minimum pick-up current which will cause the relay to function. Refer to the manufacturer's instruction literature for time/current curves and tolerances. A manual trip operation should be a part of every test to insure there is proper electrical continuity and the relay will operate under simulated electrical response calling for a trip operation. A check should also be made to insure that the proper position indicators function, and while still energized, determine if they are quiet in operation.

When checking the pick-up value of current on plunger and solenoid type relays, note the ammeter reading at the instant the relay operates. The pick-up current value should be within 5% of the calibrated or tap setting value. This check is made with the relay in its normal operating position. With the pick-up current value established the applied current should be slowly decreased until the relay drops-out. The current value at this point should be within 90% to 95% of the pick-up current. The tests for pick-up and drop-out should be repeated several times to arrive at an average value which is then recorded.

All time current and voltage relays should be inspected at two year intervals and recalibrated. If performance is unsatisfactory or environmental conditions are adverse, inspection and recalibration should be performed at more frequent intervals. A copy of inspection and test data

should be kept on location or in a log book at the switchgear location for operator reference. A permanent record should be maintained in the plant Engineering or Maintenance department.

Test Preliminaries

Measures applicable when altering the setting of any adjustable device performing a protective function in an electrical system:

Self-contained and portable test sets save time in setting up test circuits and provide fairly reliable, easily interpreted test results but, they seldom use meters rated for extreme accuracy. Built-in timers and multi-scale instruments often eliminate the need of accessory instrumentation or devices.

To be effective, field testing of apparatus and devices should, as much as possible, duplicate actual operating conditions for the equipment being tested.

The purpose of testing and rechecking protective devices is to prove that the device will consistently and accurately perform the job assigned to it.

The importance of accuracy in test data cannot be over-emphasized; test results can vary with conditions and type of instrumentation employed. The accuracy of test equipment should never be taken for granted. It can change depending on the frequency with which it is used and recalibrated. Instrument errors can be injected which may be significant to the degree that adjustment of a device will be made based on inaccurate readings.

Recorded data is vital to the evaluation of subsequent test results and decisions for recalibration, adjustment and replacement.

Records of all changes in plant load which show increases or decreases in system requirements are necessary to calculate effects on coordination of protective devices. Power requirements and load characteristics seldom remain constant. Due to this fact, hazardous conditions can result from an indiscriminate readjustment of protective devices and relays.

Warning: Do not re-set tripping devices or protective relays to meet varying load conditions. Re-setting can cause system coordination distortion and reduce protection function, which can cause severe personal injury or death, and property damage. System engineers should establish coordinated system settings.

The following should constitute the basic requirements for any inspection or test procedure:

- a. The test should be complete enough to establish that the apparatus or device will perform its specific function when operating conditions are simulated or duplicated on test operation.
- b. An as-found test run should be made before any cleanup, adjustment, repair or recalibration functions are performed.
- c. The as-found test results should be recorded and compared with earlier data or manufacturer's performance curves.
- d. The manufacturer's performance data and instruction books should be available for reference. Any published information should have precedence over alternate test procedures, practices, or performance evaluations. Each manufacturer's product should be treated individually.
- e. Having established the method and test procedures, the engineer should determine the safest and most efficient manner for conducting the tests under prevailing conditions.

Safety Recommendations

- A. Always protect the test personnel and others in the vicinity of the testing operation.
- B. Wherever possible, testing of live apparatus must be avoided. If temporary circuits must be maintained, all possible safeguards should be employed to prevent contact with energized equipment, bus runs, or apparatus still in service.
- C. Equipment under test should be isolated from control or feedback circuits which are still energized. Preliminary checks should be made to insure that the apparatus is fully de-energized. Sneak circuits or added circuitry not appearing on original drawings may be present.
- D. Grounding and safety requirements for use of the test equipment should be observed. Grounds should be checked for effectiveness before any test is begun.
- E. All bus runs that have been disconnected for test purposes should be grounded to prevent feedback from test voltages. If not practical or possible to ground these conductors, protect personnel and others by proper safeguards and warning signs or lights.

Warning: Exclude unnecessary and unauthorized personnel from the test area and equipment being tested. Test currents and voltages can be deadly. Failure to heed this warning can cause severe personal injury or death, and damage to property.

Capacitive circuits and those devices capable of storing energy received from test voltages are a significant hazard. They should be grounded after each application of test voltage as part of the test. Only adequately insulated tools should be used when working on electrical equipment, even on de-energized circuits.

The use of a rubber floor mat is required when operating the test equipment. Another rubber mat is required for the safety of anyone assisting the test engineer and making adjustments at the location of the device or apparatus being tested.

A third person to relay signals to others assisting with the test should not be used and equipment test should never be left energized and unattended. If it becomes necessary to leave the test equipment (even momentarily) to check or confer with others assisting in the test, it should be shut off.

Rings, watches, tie clasps, or other conducting articles of jewelry should be removed when performing electrical tests. Test personnel should wear only approved non-conducting hard hats. They should also wear safety goggles and use recently tested rubber safety gloves, protected with dry outer gloves, whenever the situation requires their use.

Personnel should be trained in first aid and resuscitation techniques and be prepared for any emergency involving injury or electrical shock. First aid equipment and fire extinguishers suitable for use on electrical fires should be present during test operations.

Refer to *Westinghouse Electrical Maintenance Hints, Volume 1, Chapter 5* for more safety and first aid information.

20.6 Typical Checks and Calibrations

Each manufacturer of relays has established test and service procedures for the great variety of relays offered. It is therefore impractical to attempt a discussion of specific techniques. The manufacturer's instruction literature should be used as a guide for the relay inspection and test being performed. Never schedule more relay work than can be completed in a normal working day. Relays that have been only partially checked-out can contain hazardous voltages.

Test and service procedure for the Westinghouse CO relay is typical:

1. Stationary Contact — Standard adjustment provides a contact follow. By turning the time dial located at the lower left of the stationary contact block on relays identified with T, the index mark on the movement frame will coincide with the O mark on the time dial when the stationary contact has moved through approximately half its normal deflection. With the stationary contact resting against the backstop, the index mark is offset to the right of the O mark approximately 0.02 inches. The placement of the various time dial positions in line with the index mark will give operating times as shown on the time/current curves. For double trip relays the follow on the stationary contacts should be approximately $\frac{1}{32}$ inch.

Where a circuit breaker closing will be initiated immediately after a trip by the relay contact, the contact follow should be eliminated by loosening the stationary contact mounting screw, removing the contact plate and replacing it with the bent end resting against the contact spring.

2. Minimum Operating Current — To obtain the best view of any movement of the moving contact, the time dial should be set at position 6. The moving contact should leave the backstop at tap value current plus three percent and should return to the backstop at tap value minus three percent, see Table 1.

If this check shows that calibration is necessary the damping magnet should be removed. The control spring tension should be adjusted so the moving contact will leave the backstop at tap value plus one percent and return to the backstop at tap value minus one percent.

3. Time Curve Calibration — The relay operating time for certain values of current should be as shown on the time current curves, plus or minus five percent. For a more accurate check, the current conditions outlined in Table 1 should be applied to the relay and the operating times should be within plus or minus five percent of the values shown.

If the operating time is not within the tolerance for the low values of applied current, two times tap value, the permanent magnet keeper should be adjusted until this operating time is correct.

If the operating time is not within the tolerance of the high values of applied current, twenty times tap value, the electromagnet screw plugs require adjustment. For calibrating purposes, one of the two electromagnet screw plugs should always be screwed all the way in and the other screwed in or out to obtain the correct operating time. Withdrawing the

left plug (viewed from the front) decreases the operating time, screwing the plug inward increases the operating time.

If these adjustments fail to bring the relay's performance within acceptable limits the relay should be returned to the factory for repair and calibration. A brief description of the tests made and the trouble encountered should be placed in the relay case when returning it to the factory.

Table 1 Time Curve Calibration Data — 50 and 60 Hertz

Relay Type	Permanent Magnet Adjustment			Electromagnet Plugs	
	Time Dial Position	Current (Multiples of Tap Value)	Operating Time Seconds	Current (Multiples of Tap Value)	Operating Time Seconds
CO-2	6	3	0.57	20	0.22
CO-5	6	2	37.80	10	14.30
CO-6	6	2	2.46	20	1.19
CO-7	6	2	4.27	20	1.11
CO-8	6	2	13.25	20	1.11
CO-9	6	2	8.87	20	0.65
CO-11	6	2	11.27	20	0.24 [ⓐ]

[ⓐ]For 50 Hertz CO-11 relay 20 times operating time limits = 0.24 + 10% - 5%.

20.7 Final Inspection and Operational Checks

After completion of electrical tests and servicing, the relays should be replaced in their original compartments and power restored. A check of wiring continuity can be made by mechanically operating the relay to assure it will trip the protective device. The relay operation should be checked under load conditions, using its associated potential or current transformer, if possible. This test will determine the electrical accuracy and proper relay operation.

Warning: Relays checked under load contain hazardous voltage which can cause severe personal injury or death, and damage to property. Follow the manufacturer's procedures when checking relays under load.

A final check should be made to assure that all test leads and jumpers have been removed and the device is left in working order. All wiring connections removed for test purposes should be re-inspected to assure proper reconnection and tight connections.

Warning: Relays partially checked-out can contain hazardous voltages which can cause severe personal injury or death, and damage to property. Never leave partially checked relays unattended.