Chapter 10

Test Equipment, Motors, and Controllers

Topics

To hear audio, click on the box.

Overview

In this chapter we will discuss installation, principle of operation, troubleshooting, and repair of motors and controllers. We will also discuss the principles of operation and use of test equipment. No matter what type of command you are assigned to, mobile construction battalion, public works, or construction battalion unit, you as a Construction Electrician (CE) will be called upon to install, troubleshoot, and repair various motors and controllers.

Throughout this chapter you will see references to the National Electrical Code© (NEC©). Look up each article and read it. More specific information is contained there than will be discussed in this chapter. You will need this specific information to do your job properly.

As a CE, you will encounter many pieces of electrical equipment and many appliances. A solid background in electrical theory and standards and a working knowledge of the components and of the machines themselves will allow you to install, maintain, troubleshoot, and repair a wide variety of equipment and appliances.

In one way or another, all machines use the same technologies. The differences are in the complexity of their operation and the tasks they perform. This chapter will not cover specific pieces of equipment or appliances but will concentrate on electrical components, motors, controllers, and circuitry that are common to most equipment and appliances.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the purpose and use of portable electrical tool testers.
2. Describe maintenance procedures of power tools.
3. Describe the purpose and use of test equipment.
4. Describe the different types of motors and controllers.
5. Identify the components of motors.
6. Identify the different components of a DC motor and controls.
7. Identify the different components of an AC motors and controllers.
8. Describe the construction of three phase motors.
9. Describe the functions of AC motor controllers.
10. Describe the different types and protection of motor branch circuits.
11. Describe the procedures associated with equipment grounding.
12. Describe the different types of control circuits.
13. Describe the procedures associated with troubleshooting and testing controllers.
14. Describe basic motor maintenance.
15. Describe the motor start up procedures.

Prerequisites

None

This course map shows all of the chapters in Construction Electrician Basic. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Test Equipment, Motors, and Controllers		C E
Communications and Lighting Systems		
Interior Wiring and Lighting		
Power Distribution		
Power Generation		
Basic Line Construction/Maintenance Vehicle Operations and Maintenance		B A
Pole Climbing and Rescue		S
Drawings and Specifications		I
Construction Support		C
Basic Electrical Theory and Mathematics		

Features of this Manual

This manual has several features which make it easier to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.
- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 PORTABLE ELECTRIC TOOL TESTERS

If you have ever had an encounter with an ungrounded electric drill while working in the rain, you have a feel for the importance of tool testing. You will also have gained a healthy respect for the person who tests tools at the battalion central tool room (CTR) or the Public Works Department (PWD) when he or she finds and corrects problems with portable electric power tools.

The tool tester shown in *Figure 10-1* is one that personnel from CTR or PWD might use.

The tool tester consists of a transformer, sensing relays, indicator lights, an audible warning buzzer, and leads suitable for tool or appliance connections.

The transformer passes approximately 30 amperes through the tool cord equipment ground, burning away any “burrs” that may be causing a poor equipment ground. If there is no equipment ground, the OPEN EQUIPMENT GROUND sensing relay is activated, and the OPEN EQUIPMENT GROUND light glows, giving the appropriate warning.

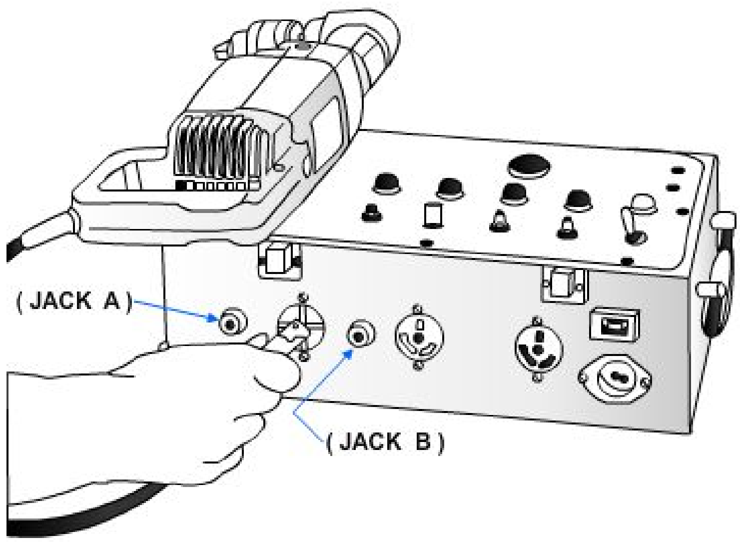

Figure 10-1 — Typical tool tester.

If the resistance of the ground on the equipment under test is approximately 0.2 to 1.5 ohms, the FAULTY EQUIPMENT GROUND sensing relay is activated Resistance in excess of this amount activates the OPEN EQUIPMENT GROUND sensing relay.

The range in length of extension cords the tester can test is from approximately 6 feet to 100 feet of 16-gauge wire. These lengths will be longer or shorter in other gauges. You can adjust the sensing circuit for different sensitivities.

Check the presence of a dangerous POWER GROUND, caused by carbon, moisture paths, or insulation breakdown, at a 500-volt ***potential*** or at a 120-volt potential by pressing the RF TEST button. Test the equipment, line cord, and switch for SHORT CIRCUIT.

A red light and buzzer indicate faulty conditions. You must correct one faulty condition before another one will be indicated.

Tests proceed only when the equipment ground is in a safe condition. Conduct all tests (except the power ground) at potentials less than 10 volts.

If you find no electrical defects, the tool operates at its proper voltage to reveal any mechanical faults.

Optional features are installed to simplify two-wire and double-insulated tool tests and provide for safely testing double-insulated tools for power grounds.

WARNING

The tool operates at the end of the test cycle. Be sure moving parts are faced away from the operator and have proper clearance to operate. Remove any removable cutting blade or bit before the tool is tested Do not come in physical contact with the tool during the test.

Test your Knowledge (Select the Correct Response)

1. How much amperage does the transformer of the tool tester pass through the tool cord equipment ground?

   A. 10
   B. 20
   C. 30
   D. 40

2.0.0 MAINTENANCE of POWER TOOLS

CEs have the task of ensuring the proper operation of all power tools within their realm of responsibility. The program itself will be formulated by higher authority. The best way to perform this task is to develop a good inspection and maintenance program. Periodically check all power tools for loose connections, ***pitted*** contacts, improper mounting of switches, and so forth.

The inspection and maintenance of power tools go hand in hand, and, in most cases, a problem discovered during inspection is corrected on the spot and requires no further work until the next inspection.

3.0.0 TEST EQUIPMENT

Test equipment and experienced CE's are not always needed to locate problems. Anyone who sees a ground wire dangling beneath a lightning arrester might suspect a problem. Little skill is required to consider an electrical service problem as a possible reason for the lack of power in a building.

Arcing, loud noises, and charred or burned electrical equipment sometimes indicate electrical faults; however, hidden, noiseless circuit problems are much more common and usually much harder to locate.

The right test equipment and a CE who knows how to use it are a valuable combination for solving electrical circuit problems.

No attempt will be made in this section to explain the internal workings of test equipment, such as meter movement or circuitry. Information on these subjects is covered in Navy Electricity and Electronics Training Series (NEETS) modules. This section introduces to you the types of test equipment used by the CE in the field.

WARNING

Naval Facilities Command (NAVFAC) requires that electrical equipment be tested under the supervision of qualified electrical personnel. If in-house personnel are not available for these tests, you may use the services of a qualified electrical testing contractor. If you do not know how to do certain required tests, go to your seniors (crew leader and/or project chief). Be certain that you can perform the test safely before starting the test procedure.

3.1.0 Ammeters

A meter that measures the flow of electric current is a current meter. Current meters that measure current in amperes are called ammeters. The ammeter is connected in series with the circuit source and load. Panel-mounted ammeters, such as those used in power plants, are permanently wired into the circuit. *Figure 10-2* shows two typical panel-mounted ammeters.

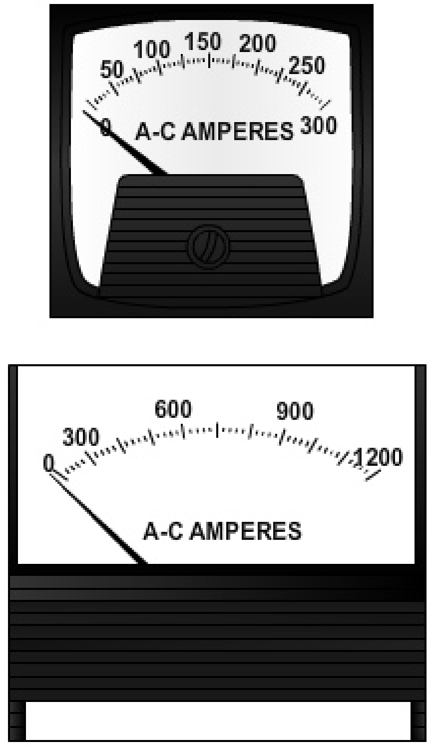

Figure 10-2 — Typical panel ammeters.

A clamp-on ammeter (*Figure 10-3*) is an exception to the rule requiring ammeters to be series-connected. The clamp-on ammeter consists in part of clamp-on transformer jaws that can be opened and placed around a conductor. The jaws are actually part of a laminated iron core. Around this core, inside the instrument enclosure is a coil winding that connects to the meter circuit. The complete core (including the jaws) and the coil winding are the core and secondary of a transformer. The conductor, carrying the current to be measured, is like a primary winding of a transformer. The transformer secondary is the source of power that drives the meter movement. The strength of the magnetic field surrounding the conductor determines the amount of secondary current. The amount of secondary current determines the indication of current being measured by the meter.

Figure 10-3 —Clamp-on ammeter.

All ammeters will have an adjustable scale. The function and range of the meter change as the scale changes.

To take a current measurement, turn the selector until the AMP scale you wish to use appears in the window. To take measurements of unknown amounts of current, rotate the scale to the highest amperage range. After taking the reading at the highest range, you may see that the amount of current is within the limits of a lower range. If so, change the scale to that lower range for a more accurate reading.

After choosing the scale you want, depress the handle to open the transformer jaws. Clamp the jaws around only one conductor. The split core must be free of any debris because it must close completely for an accurate reading.

To measure very low currents in a small flexible conductor, wrap the conductor one or more times around the clamp-on jaws of the meter. One loop will double the reading. Several loops will increase the reading even more. After taking the measurement, divide the reading by the appropriate number of loops to determine the actual current value.

The clamp-on ammeter is convenient and easy to use. To measure the current of a single-phase motor, for example, simply rotate the selector until the desired amp scale appears; clamp the jaws around one of the two motor conductors, and take the reading.

Some clamp-on instruments are capable of more than one function, for example, they are designed for use as an ohmmeter or a voltmeter when used with the appropriate adapter or test leads.

3.2.0 Voltmeters

The meter component (or voltage indicator) of a voltmeter is actually a ***milliammeter***, or ***micrometer***. This instrument is series-connected to a resistor (called a voltage multiplier) to operate as a voltmeter. The series resistance must be appropriate for the range of voltage to be measured. The scale of an instrument designed for use as a voltmeter is calibrated (marked off) for voltage measurements.

Panel voltmeters are similar in appearance to the ammeters shown in *Figure 10-2* except for the calibration of the scale. Examples of typical panel voltmeters are shown in *Figure 10-4*. Voltmeters are connected across a circuit or voltage source to measure voltage. Panel-mounted voltmeters are permanently wired into the circuit in which they are to be used.

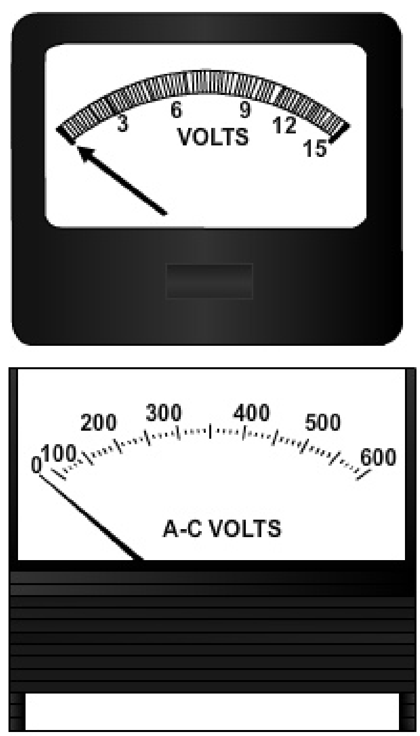

Figure 10-4 — Typical panel voltmeters.

Portable voltmeters are designed to measure one or more ranges of voltage. Those intended for measurement of more than one voltage range are provided with range selector switches. The range selector switch internally connects the appropriate multiplier resistor into the meter circuit for the range of voltage to be measured; for example, a voltmeter may be designed to use a O-I milliampere milliammeter as a voltage indicator. For each setting of the selector switch, a different multiplier resistor is connected into the meter circuit. For each selection, a particular resistor value is designed to limit the current through the milliammeter to a maximum of 1/1,000 of an ampere (1 milliampere) for a full-scale reading.

In a similar way, voltmeters designed to use a micrometer, for example, a 50-microampere meter, include multiplier resistors that limit the meter current to a maximum value of 50 microamperes. In this case, 50 microamperes are flowing through the meter for a full-scale deflection of the needle.

Voltmeters that use either a milliammeter or micrometer to indicate voltage have a scale calibrated to read directly in volts. The flow of current in either type of meter represents the electrical pressure (voltage) between two points in an electrical circuit; for example, the two points may be the hot (ungrounded) conductor and the neutral (grounded) conductor of a 125-volt circuit. In this case, the voltmeter is said to be connected across the line.

3.3.0 Line Voltage Indicators

The line voltage indicator (*Figure 10-5*) is much more durable than most voltmeters for rough construction work. Its durability is mainly due to its simple design and construction. It has no delicate meter movement inside the case as do the analog meters previously mentioned. The two test leads are permanently connected to a solenoid coil inside the molded case.

Figure 10-5 — Line voltage indicator.

An indicator, attached to the solenoid core, moves along a marked scale when the leads are connected across a voltage source. The movement of the core is resisted by a spring. The indicator comes to rest at a point along the scale that is determined by both the strength of the magnetic field around the solenoid and the pressure of the opposing spring. The strength of the magnetic field is in proportion to the amount of voltage being measured.

CAUTION

Do not use the line voltage indicator on voltages exceeding the capabilities of the indicator.

In the center of the tester is a neon lamp indicator. The lamp is used to indicate whether the circuit being tested is AC or DC.

When the tester is operated on AC, it produces light during a portion of each half-cycle, and both lamp electrodes are alternately surrounded with a glow. The eye cannot follow the rapidly changing alternations, so both electrodes appear to be continually glowing from AC current. Two other indications of AC voltage are an audible hum and a noticeable vibration you can feel when the instrument is hand-held.

When the tester is operated on DC, light is produced continuously, but only the negative electrode glows; therefore, the tester will indicate polarity on DC circuits. Both the test probes and the glow lamp enclosure are colored red and black. If, while you are testing a DC circuit, the electrode of the glow lamp on the side colored black is glowing, this glow indicates the black probe of the tester is on the negative side of the circuit; likewise, the opposite electrode glows when the red probe of the tester is on the negative side of the circuit.

The neon lamp is not the only method used on line voltage indicators to indicate DC polarity; for example, the Wigginton voltage tester, manufactured by the Square D Company, uses a permanent magnet mounted on a rotating shaft. The ends of the magnet are colored red and black. The magnet is viewed from a transparent cap located on top of the tester. When the red portion of the magnet is up, the red test prod is positive. When the black portion of the magnet is up, the black prod is positive. Neither type of line voltage indicator vibrates when measuring DC.

Be certain to read and understand the instructions for the particular instrument you use. As you can see from the example of polarity indicators, because of variations in similar instruments, you could easily misunderstand an indication from one instrument when thinking of the instructions for another.

The line voltage indicator does not determine the exact amount of circuit voltage. That presents no problem for most of the work CEs do. As you become proficient in the use of the solenoid type of voltage indicator, you can tell approximately what the voltage is by the location of the indicator within a voltage range on the scale.

3.4.0 Ohmmeters

You can determine the resistance of a component or circuit, in ohms, by using Ohm's law. With the instruments we just discussed, you can find circuit current and voltage. From electrical theory you already know that voltage divided by amperage equals resistance. But the fastest method of determining resistance is by taking a resistance reading directly from an ohmmeter.

The simplest type of ohmmeter consists of a housing that includes a milliammeter, a battery, and a resistor connected in series, as shown in *Figure 10-6*. The ohmmeter is designed so that the resistor R_1 limits the current though the milliammeter to a value that results in a full-scale deflection of the meter needle. The scale (*Figure 10-7*) is calibrated in ohms. By using several resistors, more than one battery, and a selector switch (to select one of the several resistors and batteries), you can make the ohmmeter include more than one resistance range.

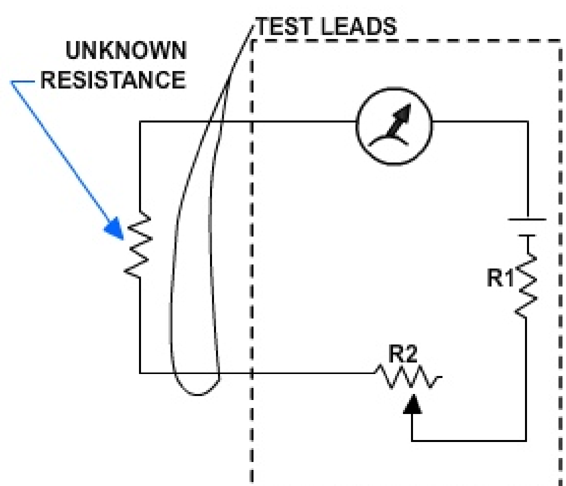

Figure 10-7 — Typical scale of a series type of ohmmeter.

You may use a ***variable resistor*** in the meter circuit (R_2 in *Figure 10-6*) to compensate for variations in battery voltage. Before using an ohmmeter for a precise resistance measurement, short the leads together and set the needle to zero by rotating the “zero ohms” (variable resistor) knob. The result is a full-scale reading at zero ohms.

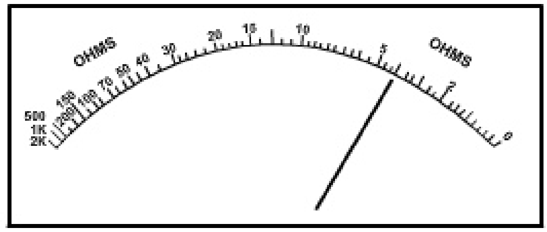

Figure 10-6 — A simple series ohmmeter circuit.

CAUTION

Be certain not to place the ohmmeter leads across an energized circuit or a charged capacitor. Ignoring this rule will likely result in damage to the test equipment. Always turn off the power on a circuit to be tested before making continuity or resistance tests. Before you test with an ohmmeter, bleed any capacitors that are included in the circuits under test. Use extreme care in testing solid-state components and equipment with an ohmmeter. The voltage from the internal batteries of the ohmmeter will severely damage many solid-state components. Always turn an ohmmeter off after you have completed your test to lengthen the life of the batteries.

After you zero the meter, place the leads across the circuit or component under test. The resistance of the unknown resistor between the ohmmeter leads limits the current through the meter, resulting in less than a full-scale deflection of the needle. The resistance reading may then be taken from the point along the scale at which the needle comes to rest

Accurate readings become progressively more difficult to take toward the high-resistance end of the scale. When the needle comes to rest at the high end of the scale and the ohmmeter has several resistance ranges, you may simply switch to a higher range for a reading closer to center scale. Read the resistance directly from the scale at the lowest range (for example, the R x 1 range on some ohmmeters). At the higher ranges multiply the reading by 100 or 10,000 (as on the R x 100 or R x 1,000 ranges). The higher resistance ranges in a multi-range ohmmeter use a higher voltage battery than do the lower ranges.

We will discuss multimeters (meters that perform more than one function) later in this section, but since we have already discussed the ammeter as a clamp-on ammeter, we will look at the same instrument as an ohmmeter.

To use the ammeter as an ohmmeter, plug a battery adapter into the jack on the side of the case (*Figure 10-8*). The battery in the adapter powers the ohmmeter function of this instrument. Use one of two test leads that may be plugged into the instrument (for voltage measurements) for the second lead of the ohmmeter. Plug this test lead into the jack marked “COMMON.” The ohmmeter scale is a fixed scale at the right side of the scale window opening. It is not part of the rotating scale mechanism. The rotating mechanism has no effect on the ohmmeter operation. The leads are applied to the circuit or component, and the reading is taken as with any ohmmeter.

Figure 10-8 — Clamp-on ammeter with ohmmeter battery adapter.

The series type of ohmmeter is only one type of instrument used for resistance measurements, but it is common in the design of ohmmeters used by CEs.

3.5.0 Multimeters

Up to this point, each of the instruments we have discussed, for the most part, performs only one function. The exception was the clamp-on ammeter/ohmmeter. In a similar way the analog meters and digital meters perform several (or multiple) functions and are therefore referred to as multimeters.

An analog instrument usually makes use of a needle to indicate a measured quantity on a scale. Digital meters indicate the quantity directly in figures. We will discuss both types here because you will use both types.

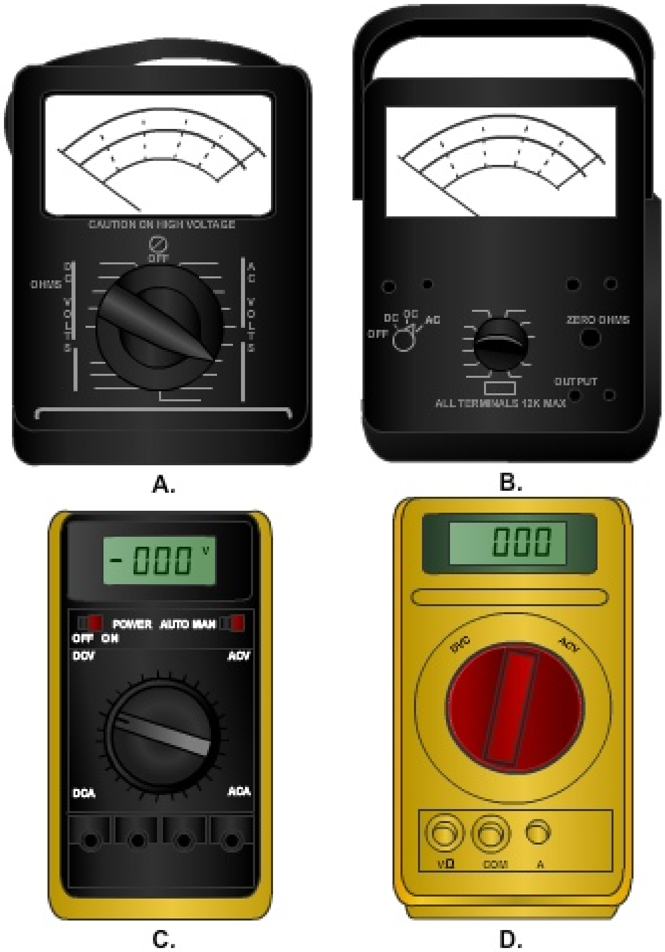

Figure 10-9 — Typical multimeters (analog types A and B and digital types C and D).

Notice that each multimeter in *Figure 10-9* (A, B, C, and D) consists of a case to enclose the indicating device, one or more functions and/or range switches, and internal circuitry and jacks for external connections.

3.5.1 Voltage Measurements

Before plugging the test leads into the jacks, set the switches for the measurement. Let's look at an example. You are about to measure the voltage at a standard wall outlet in an office. You already know from experience that the voltage should be in the area of 115 to 125 volts AC. You have one of two types of multimeters-an analog meter or a digital meter. Because you know the voltage to be tested, you would set the function switch to AC and the voltage to 250V. For the operation of the range and function switches on the particular meter, check the manufacture's literature.

What should you do if you have no idea what the voltage is? There are times when you should not get near the equipment; in this case, you should check with someone who knows (for example, a public works engineer or line crew supervisor). Check the highest range on your instrument. If you have a meter and know the voltage value should not exceed 1,000 volts AC, then set the range/function switch to 1,000 ACV.

Plug the test leads into the appropriate jacks for the test you are about to perform. When you have red and black test leads, get into the habit of using the black lead with the common or - (negative) jack, even when measuring AC volts. For either analog meter, plug the red lead into the + (positive) jack. With either of the digital meters, use the jack marked “V-O” (volts-ohms).

WARNING

The following sequence of steps is important for your safety. Stay alert and follow them carefully.

Connect the two test leads to the two conductors/terminals of the wall outlet while holding the insulated protectors on the test leads. Do not touch the probes or clips of the test leads. Take the reading. If you have the meter range switch at the highest setting and see that the voltage value is within a lower voltage range, set the range switch to the lower range that is still higher than the voltage reading you remember. When you take a reading at a higher range and switch to a lower range, the reading at the lower range will be more accurate. Be certain to read from the scale that matches the range setting of the switch, for example, when using the multimeter with the switch set to 300 AC VOLTS, read from the scale that has a maximum reading of 300 AC. Simply take the reading directly from either of the digital multimeters.

WARNING

Always be alert when taking voltage or amperage measurements if it is necessary to move the meter. If the instrument is moved in a way that causes tension on the test leads, one or both leads may be pulled from the jack(s). The leads will be energized just as the circuit to which they are connected, and they can be dangerous.

The positions of the jacks may differ for a particular measurement, from one meter to another. Notice how the jacks are labeled on the instrument you use, and follow the instructions from the manufacturer of the instrument.

3.5.2 Amperage Measurements

It is possible that you will never use a multimeter for amperage measurements. Most multimeters are designed with quite low current ranges. The clamp-on ammeter (discussed earlier) is the most convenient portable instrument for measuring AC amperes.

3.5.3 Resistance Measurements

As mentioned earlier, ohmmeters have their own voltage source. This circumstance is also true of the ohmmeter function of multimeters. The size and number of batteries for different instruments vary. Usually one or more 1 1/2- to 9-volt batteries are used for resistance measurements.

As you must set up the meter to measure voltage accurately, so you must set it up for measuring resistance. If you are to measure a 120-ohms resistor, for example, set the selector switch to ohms at the appropriate range. For the analog instruments, set the switch to the R x 1 or x 1 as appropriate. Read the value from the ohms scale directly. For higher values of resistance like 1,500 ohms, for example, use the R x 100 or x 100 range. In this case, multiply the reading from the ohms scale by 100.

For critical resistance measurements, always touch the leads together and set the indicator needle to zero with the appropriate adjustment knob. Do not let the leads touch your fingers or anything else while you are zeroing the meter.

On multimeters, use the common – (negative) and + (positive) jacks for resistance measurements.

Be certain that there is no power on the circuit or component you are to test when measuring resistance. Be sure also to discharge any capacitors associated with the circuit or component to be tested before connecting the instrument to the circuit or component.

For critical measurements, make sure that only the circuit or component you are to test touches the leads while you take the reading; otherwise, the reading may be inaccurate, especially on the higher resistance ranges.

Many times you will use the ohmmeter for continuity tests. All you will want to know is whether the circuit is complete or not. You do not have to zero the meter for noncritical continuity tests. You will touch the leads together to see where the needle comes to rest. If it stops at the same place when you place the leads across the circuit, you know the path has a low resistance. In other words you know there is continuity through the circuit.

CEs also use other instruments for different types of resistance measurements. We will discuss these instruments next.

3.6.0 Megohmmeters

The megohmmeter is a portable instrument consisting of an indicating ohmmeter and a source of DC voltage. The DC source can be a hand-cranked generator, a motor-driven generator, a battery-supplied power pack, or rectified DC.

The megohmmeter is commonly called a "megger" although Megger© is a registered trademark. The megger tester shown in *Figure 10-10* is an example of a dual-operated megohmmeter that has both a hand cranked generator and a built-in line power supply in the same module.

Figure 10-10 — Typical megohmmeter tester.

Any one of the ohmmeters shown in *Figure 10-9* will measure several megaohms. You may wonder why they are not called megohmmeters. What is the difference between the megger and the typical ohmmeter? Does not each of them have an indicator and a DC voltage source within the instrument enclosure? The megger is capable of applying a much higher value of DC voltage to the circuit or component under test than is the typical ohmmeter. Meggers that will supply a test potential of 500 volts are common in the Navy. The megger (*Figure 10-10*) is capable of several test voltages up to 1,000 volts, depending on the setting of the selector switch. Ohmmeters are generally designed to include batteries as voltage sources. These batteries apply approximately 1/2 to 9 volts to the circuit under test.

The megger is designed so that the needle floats freely until the generator is operated. When the generator is not operating, the needle may come to rest at any point on the scale. This characteristic is due to internal design, unlike that used in the typical ohmmeter.

3.7.0 Insulation Resistance Testers

The megger is used to measure high-insulation resistance. The high resistance may be between windings of a transformer or motor or between the conductor in a cable and the ***conduit*** or sheath surrounding the cable (*Figure 10-11*).

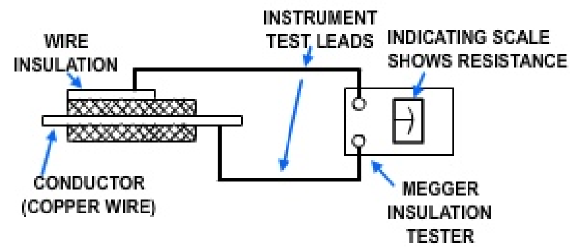

Figure 10-11 — Typical megger test instrument hooked up to measure insulation resistance.

If the test leads connected to the line and earth terminals are open-circuited (as when they are not allowed to touch anything) and the hand-cranked generator is operated, the needle is deflected to ***infinity*** (*Figure 10-12*). "Infinity" means that the resistance is too high for the instrument to measure. The symbol for infinity on the scale of the megger (*Figure 10-10*) is similar to a horizontal figure eight. During a test, a reading at or near infinity means either that the insulation is in excellent shape or the test leads are not making contact with the component being tested.

If the test leads are connected to each other while the hand crank is turned, the pointer will deflect to zero, indicating no resistance between the test leads. A zero deflection in the above-mentioned test (*Figure 10-11*) can mean that the conductor under test is touching the sheath or conduit surrounding it. This deflection could also be an indication that the insulation is worn or broken somewhere close to the test point. Any reading near the low end of the scale may mean faulty or wet insulation.

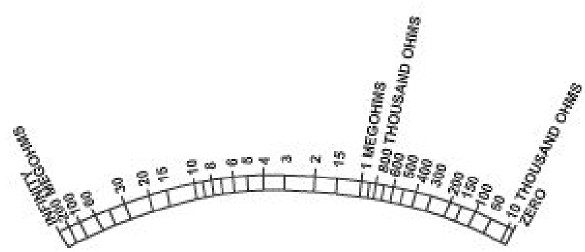

Figure 10-12 — Typical indicating scale on the megger insulation tester.

The megger serves well as an insulation tester because of the high-test voltage it produces. The low voltage of an ohmmeter may not produce enough leakage current through poor insulation to cause the meter to indicate a problem even when one exists. But the relatively high voltage of the megger will likely cause enough leakage current to reveal an insulation problem by a lower than normal resistance indication on the meter scale.

How low is the resistance of bad insulation? How high must the insulation resistance reading be before you can be sure the insulation is good?

Here are some general observations (See *Table 10-1*) about how you can interpret periodic insulation resistance tests, and what you should do with the results.

Table 10-1 — Insulation resistance problems and fixes.

CONDITION	WHAT TO DO
Fair to high values and well maintained	No cause for concern
Fair to high values, but showing a constant tendency towards lower values	Locate and remedy the cause and check the downward trend
Low but well maintained	Condition is probably all right, but the cause of the low values should be checked
So low as to be unsafe	Clean, dry out, or otherwise raise the values before placing equipment in service (test wet equipment while drying it out)
Fair or high values, previously well maintained but showing sudden lowering	Make tests at frequent intervals until the cause of low values is located and remedied or until the values become steady at a level that is lower but safe for operation or until values become so low that it is unsafe to keep the equipment in operation

3.7.1 Short Time or Spot Reading Tests

Several test methods are commonly used to test insulation.. We will discuss the short-time or spot-reading tests.

In this method, simply connect the megger across the insulation to be tested and operate it for a short, specific time period (60 seconds usually is recommended). As shown in *Figure 10-13*, you have picked a point (to take the reading) on a curve of increasing resistance values; quite often the value will be less for 30 seconds, more for 60 seconds. Bear in mind also that temperature and humidity, as well as condition of the insulation, affect your reading.

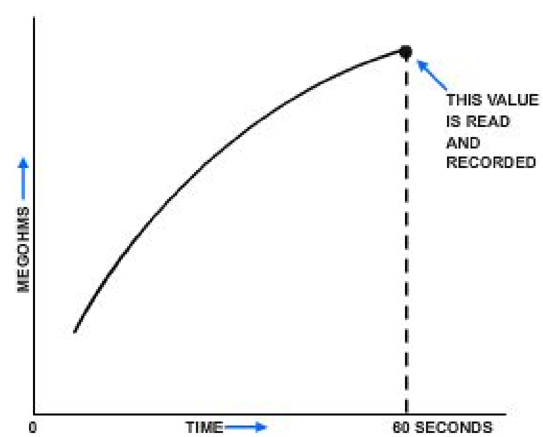

Figure 10-13 — Typical curve of insulation resistance (in megaohms) with time.

If the apparatus you are testing has low capacitance, such as a short run of type NM cable (Romex), the spot reading test is all that is necessary; however, most equipment is capacitive, so your first spot reading on equipment in your work area, with no prior tests can be only a rough guide as to how “good” or “bad” the insulation is. For many years, maintenance personnel have used the 1-megohm rule to establish the allowable lower limit for insulation resistance. The rule may be stated thus: **Insulation resistance should be approximately 1 megohm for each 1,000 volts of operating voltage with a minimum value of 1 megohm**. For example, a motor rotated at 2,400 volts should have a minimum insulation resistance of 2.4 megohms. In practice, megohm readings normally are considerably above this minimum value in new equipment or when insulation is in good condition.

By taking readings periodically and recording them, you have a better basis for judging the actual insulation condition. Any persistent downward trend is usually fair warning of trouble ahead, even though the readings may be higher than the suggested minimum safe values. Equally true, as long as your periodic readings are consistent, they may be all right even though lower than the recommended minimum values.

3.7.2 Common Test Voltages

Commonly used DC test voltages for routine maintenance are as follows:

Table 10-2 — Common DC voltages used.

EQUIPMENT AC RATING	DC TEST VOLTAGE
Up to 100 volts	100 and 250 volts
440 to 550 volts	500 and 1,000 volts
2,400 volts	1,000 to 2,500 volts or higher
4,160 volts and above	1,000 to 5,000 volts or higher

CAUTION

Use care in applying test voltage to the component to be tested. Do not use a high-test voltage on low-voltage equipment or components.

Do not exceed the commonly used test voltages mentioned above unless you are following the equipment manufacturer's instructions to do so. On the other hand, a test voltage lower than the operating voltage of the component to be tested may not reveal a problem that the test should indicate. If the test voltage is too low, you may get no more than a resistance reading such as you would get with an ohmmeter.

3.7.3 Causes of Low Insulation Resistance Readings

Insulation resistance varies with the temperature. The effect of temperature depends on the type of insulation, the amount of moisture in and on the insulation surface, and the condition of the surface.

The amount of moisture in insulation has a great effect on its resistance. For meaningful results, tests of insulation resistance should be made under as nearly similar conditions as practical. Long cables can be exposed to a variety of conditions along the cable route at the same time. A comparison of readings may not indicate a change in insulation condition.

An accumulation of things like dust, dirt, and moisture can cause low-resistance readings. A motor stored or kept idle for a while may have to be cleaned and dried out before being installed and placed in service.

3.7.4 Record Keeping

Keep records where tests are performed periodically. The frequency of the tests should be based on the importance of the circuit. One test each year is usually adequate. Compare records of each circuit or component. Trends may indicate a future problem, and corrections may be made in time to prevent future problems in cables or components like motors or transformers.

3.7.5 Effects of Temperature

If you want to make reliable comparisons between readings, correct the readings to a base temperature, such as 20°C (68°F), or take all your readings at approximately the same temperature (usually not difficult to do). We will cover some general guidelines to temperature correction.

One rule of thumb is that for every 10°C (50°F) increase in temperature, halve the resistance; or for every 10°C (50°F) decrease, double the resistance; for example, a 2-megohm resistance at 20°C (68°F) reduces to 1/2 megohm at 40°C (104°F).

Each type of insulating material will have a different degree of resistance change with temperature variation. Factors have been developed, however, to simplify the correction of resistance values. *Table 10-3* gives such factors for rotating equipment, transformers, and cable. Multiply the reading you get by the factor corresponding to the temperature (which you need to measure).

For example, assume you have a motor with Class A insulation and you get a reading of 3.0 megohms at a temperature (in the windings) of 131°F (55°C). From *Table 10-3*, read across at 131°F to the next column (for Class A) and obtain the factor 15.50. Your correct value of resistance is then

3.0 megohms X 15.50 = 46.5 megohms

Note that the resistance is 14.5 times greater at 68°F (20°C) than the reading taken at 131°F. The reference temperature for cable is given as 60°F (15.6°C), but the important point is to be consistent-correcting to the same base before making comparisons between readings.

Table 10-3 — Temperature Correction Factors (Corrected to 20°C for rotating equipment and transformers; 15.6°C for cable)

Temp.		Rotating Equip.		Oil filled XFMRs	Cables							
°C	°F	Class A	Class B		Code Nat	Code GR-S	Perf Nat	Heat Res Nat	Heat Res & Perf GR-S	Ozone Res Nat GR-S	Varn Cambric	Impreg Paper
0	32	.21	.4	.25	.25	.12	.47	.42	.22	.14	.1	.28
5	41	.31	.5	.36	.4	.23	.6	.56	.37	.26	.2	.43
10	50	.45	.63	.5	.61	.46	.76	.73	.58	.49	.43	.64
15.6	60	.71	.81	.74	1	1	1	1	1	1	1	1
20	68	1	1	1	1.47	1.83	1.24	1.28	1.53	1.75	1.94	1.43
25	77	1.48	1.25	1.4	2.27	3.67	1.58	1.68	2.48	3.29	4.08	2.17
30	86	2.20	1.58	1.98	3.52	7.32	2	2.24	4.03	6.2	8.62	3.2
35	95	3.24	2	2.8	5.45	14.6	2.55	2.93	6.53	11.65	18.2	4.77
40	104	4.8	2.5	3.95	8.45	29.2	3.26	3.85	10.7	25	38.5	7.15
45	113	7.1	3.15	5.6	13.1	54	4.15	5.08	17.1	41.4	81.0	10.7
50	122	10.45	3.98	7.85	20	116	5.29	6.72	27.85	78	170	16
55	131	15.5	5	11.2			6.72	8.83	45		345	24
60	140	22.8	6.3	15.85			8.58	11.62	73		775	36
65	149	34	7.9	22.4				15.4	118			
70	158	50	10	31.75				20.3	193			
75	167	74	12.6	44.7				26.6	313			

Legend:

- XFMR – Transformer
- Nat – Natural
- Perf – Performance
- Res - Resistance
- Varn - Varnished
- Impreg - Impregnated

3.7.6 Effects of Humidity

We mentioned in this section the marked effect of the presence of moisture in insulation upon resistance values. You might expect that increasing humidity (moisture content) in the surrounding (ambient) air could affect insulation resistance. And it can, to varying degrees.

If your equipment operates regularly above what is called the “dew-point” temperature (that is, the temperature at which the moisture vapor in air condenses as a liquid), the test reading normally will not be affected much by the humidity. This stability is true even if the equipment to be tested is idle, so long as its temperature is kept above the dew point. In making this point, we are assuming that the insulation surfaces are free of contaminants, such as certain lints and acids or salts that have the property of absorbing moisture (chemists call them "***hygroscopic,***" or "***deliquescent,***" materials). Their presence could unpredictably affect your readings; remove them before making tests.

In electrical equipment we are concerned primarily with the conditions on the exposed surfaces where moisture condenses and affects the overall resistance of the insulation. Studies show, however, that dew will form in the cracks and crevices of insulation before it is visibly evident on the surface. Dew-point measurements will give you a clue as to whether such invisible conditions may exist, altering the test results.

As a part of your maintenance records, make note at least of whether the surrounding air is dry or humid when the test is made and whether the temperature is above or below the ambient. When you test vital equipment, record the ambient wet- and dry bulb temperatures, from which dew point and percent relative or absolute humidity can be obtained.

3.7.7 Preparation of Apparatus for Test

Before interrupting any power, be certain to check with your seniors (crew leader, project chief, or engineering officer, as appropriate) so that they can make any necessary notification of the power outage. Critical circuits and systems may require several days or even weeks advance notice before authorization for a power outage may be granted.

3.7.7.1 Take Out of Service

Shut down the apparatus you intend to work on. Open the switches to de-energize the apparatus. Disconnect it from other equipment and circuits, including neutral and protective (workmen’s temporary) ground connections. See the safety precautions that follow in this section.

3.7.7.2 Test Inclusion Requirements

Inspect the installation carefully to determine just what equipment is connected and will be included in the test, especially if it is difficult or expensive to disconnect associated apparatus and circuits. Pay particular attention to conductors that lead away from the installation. That is important, because the more equipment that is included in a test, the lower the reading will be, and the true insulation resistance of the apparatus in question may be masked by that of the associated equipment.

WARNING

Take care in making electrical insulation tests to avoid the danger of electric shock. Read and understand the manufacturer’s safety precautions before using any megohmmeter. As with the ohmmeter, never connect a megger to energized lines or apparatus. Never use a megger or its leads or accessories for any purpose not described in the manufacturer’s literature. If in doubt about any safety aspects of testing, ask for help. Other safety precautions will follow in this section.

3.7.8 Safety Precautions

WARNING

Observe all safety rules when taking equipment out of service:

- Block out disconnected switches.

- Be sure equipment is not live.
- Test for foreign or induced voltages.
- Ensure that all equipment is and remains grounded, both equipment that you are working on and other related equipment.
- Use rubber gloves when required.
- Discharge capacitance fully.
- Do not use the megger insulation tester in an explosive atmosphere.

When you are working around high-voltage equipment, remember that because of proximity to energized high-voltage equipment, there is always a possibility of voltages being induced in the apparatus under test or lines to which it is connected; therefore, rather than removing a workmen's ground to make a test, disconnect the apparatus, such as a transformer or circuit breaker, from the exposed bus or line, leaving the latter grounded. Use rubber gloves when connecting the test leads to the apparatus and when operating the megger.

3.7.8.1 Apparatus Under Test Must Not be Live

If neutral or other ground connections have to be disconnected, make sure that they are not carrying current at the time and that when they are disconnected, no other equipment will lack protection normally provided by the ground.

Pay particular attention to conductors that lead away from the circuit being tested and make sure that they have been properly disconnected from any source of voltage.

3.7.8.2 Shock Hazard from Test Voltage

Observe the voltage rating of the megger and regard it with appropriate caution. Large electrical equipment and cables usually have sufficient capacitance to store up a dangerous amount of energy from the test current. Be sure to discharge this capacitance after the test and before you handle the test leads.

3.7.8.3 Discharge of Capacitance

It is very important that capacitance be discharged, both before and after an insulation resistance test. It should be discharged for a period about four times as long as test voltage was applied in a previous test.

Megger instruments are frequently equipped with discharge switches for this purpose. If no discharge position is provided, use a discharge stick. Leave high capacitive apparatus (for instance, capacitors, large windings, etc.) short circuited until you are ready to re-energize them.

3.7.8.4 Explosion and Fire Hazard

So far as is known, there is no fire hazard in the normal use of a megger insulation tester. There is, however, a hazard when your test equipment is located in a flammable or explosive atmosphere. You may encounter slight sparking (1) when you are attaching the test leads to equipment in which the capacitance has not been completely discharged, (2) through the occurrence of arcing through or over faulty insulation during a test, and (3) during the discharge of capacitance following a test. Therefore:

WARNING

Do NOT use the megger insulation tester in an explosive atmosphere.

Suggestions: For (1) and (3) in the above paragraph, arrange permanently installed grounding facilities and test leads to a point where instrument connections can be made in a safe atmosphere.

For (2): Use low-voltage testing instruments or a series resistance.

For (3): To allow time for capacitance discharge, do not disconnect the test leads for at least 30 to 60 seconds following a test.

Test your Knowledge (Select the Correct Response)

2. Which of the following safety precautions is NOT necessary when dealing with the insulation resistance tester?

   A. Discharge capacitance fully
   B. Do not use tester in an explosive environment
   C. Use face shield when using tester
   D. Test for induced voltages

4.0.0 MOTORS and CONTROLS

As a Construction Electrician, you must understand the principles of operation and construction of electrical motors and controllers. This knowledge is necessary so you can perform troubleshooting, maintenance, and repair of this equipment. You must be able to determine why the motor or controller is inoperative, if it can be repaired without removing it from service, or if it must be replaced. You must know what equipment substitutions or replacements to make and how to make the proper lead connections. The various types of motors and controllers have many elements in common; therefore, maintenance is fairly uniform. Once a motor or controller has been installed and the proper maintenance performed, you will have very little trouble. However, if something should go wrong, you must understand motors and controllers and how they operate to determine what troubleshooting steps to take and repairs to make. Remember, YOU are the repairman.

The checklist should include, but is not limited to, the following:

5.0.0 MOTORS

Motors operate on the principle that two magnetic fields within certain prescribed areas react upon each other. Pole pieces, frame, and field coils form one field, and current sent through the ***armature*** windings sets up another magnetic field. The units of a motor, then, are the poles and the armature. The poles are ordinarily the static part, and the armature is the rotating part.

The poles are formed by placing magnetized bars so that the north pole of one is placed directly opposite the south pole of the other. The air gap between these poles contains the magnetic field. Just as a conductor must be insulated to prevent its electrical charge from being grounded, so the magnetic field must be shielded from the earth’s magnetic field and from the field of nearby generators or motors. This shielding is usually accomplished by surrounding the field with a shell of soft iron. The armature carries the coils which cut the lines of force in the field.

6.0.0 DC MOTORS and CONTROLS

Direct-current motors and controls are seldom installed, maintained, or serviced by CEs unless they are assigned to special units, such as the State Department, where they will receive special training on this type of equipment. Therefore, we will not go into the depth on DC motors and controls as we will with AC. For information on direct-current motors and controls refer to the Navy Electricity and Electronics Training Series (NEETS) modules and the *Electrician's Mate* Training Manual, NAVEDTRA 12164.

7.0.0 AC MOTORS

Most of your work with motors, at shore stations especially, will be with AC motors. DC motors have certain advantages, but AC power is more widely used, and AC motors are less expensive and, on the whole, more reliable.

For example, sparking at the brushes of a DC motor can be very dangerous if there is explosive gas or dust in the surrounding air. Most AC motors do not use brushes and commutators and require little maintenance. They are suited to constant speed applications and designed to operate at a different number of phases and voltages.

AC motors are designed in various sizes, shapes, and types such as the induction, series, and synchronous, but as a CE in the U. S. Navy, you will be concerned primarily with the induction motors. This type of motor includes, among others, the split-phase, capacitor, repulsion-induction, and polyphase motors.

7.1.0 Split - Phase Motors

A split-phase motor is usually of fractional horsepower. It is used to operate such devices as small pumps, oil burners, and washing machines. It has four main parts. These are the rotor, the stator, end plates (or end bells, as they are sometimes called), and a centrifugal switch

The rotor consists of three parts. One of these parts is the core which is made up of sheets of sheet steel called laminations. Another part is a shaft on which these laminations are pressed. The third part is a squirrel-cage winding consisting of copper bars which are placed in slots in the iron core and connected to each other by means of copper rings located on both ends of the core. In some motors the rotor has a one-piece cast aluminum winding.

The stator of a split-phase motor consists of a laminated iron core with semi closed slots, a steel frame into which the core is pressed, and two windings of insulated copper wire, called the running and starting windings, that are placed into the slots.

End bells, which are fastened to the motor frame by means of bolts or screws, serve to keep the rotor in perfect alignment. These end bells are equipped with bores or wells in the center, and are fitted with either sleeve or ball bearings to support the weight of the rotor and thus permit it to rotate without rubbing on the stator.

The centrifugal switch is located inside the motor on one of the end bells. It is used to disconnect the starting winding after the rotor has reached a predetermined speed, usually 75 percent of the full load speed. The action of the centrifugal switch is as follows: the contacts on the stationary part of the switch (the stationary part is mounted on the end bell) are closed when the motor is not in motion and make contact with the starting winding. When the motor is energized and reaches approximately 75 percent of full load speed, the rotating part of the switch (mounted on the rotor) is forced by centrifugal force against the stationary arm, thereby breaking the contact and disconnecting the starting winding from the circuit. The motor is then operating on the running winding as an induction motor. *Figure 10-14* shows the two major parts of a centrifugal switch.

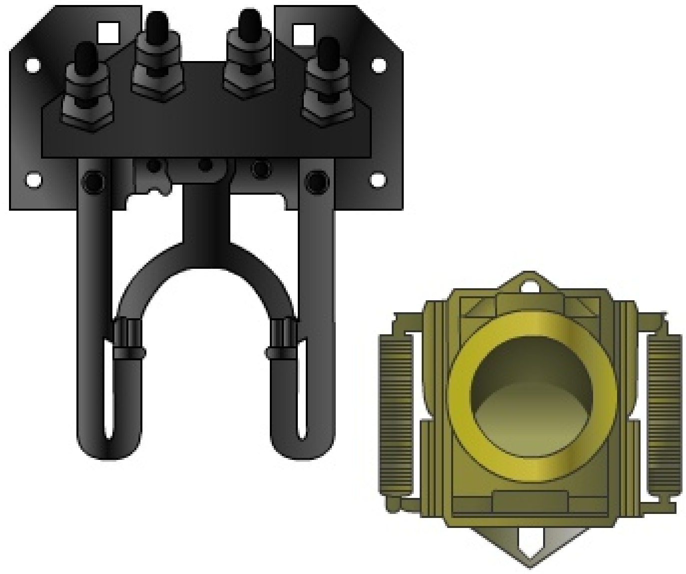

Figure 10-14 — Two major parts of a centrifugal switch.

The direction of rotation of a split-phase motor may be reversed by reversing the connections leading to the starting winding. This action can usually be done on the terminal block in the motor. *Figure 10-15* shows a diagram of the connections of a split-phase motor.

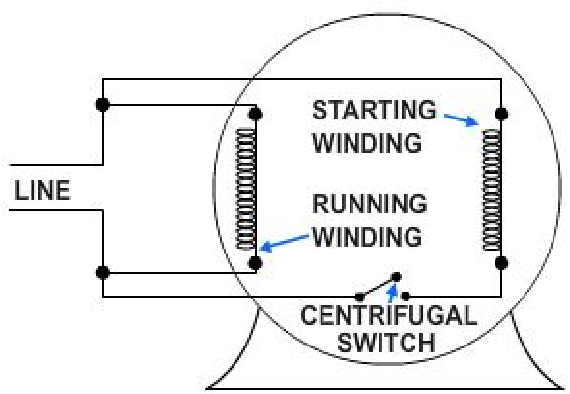

Figure 10-15 — Diagram of the connections of a split phase motor.

7.1.1 Troubleshooting and Repair

Motors require occasional repairs, but many of these can be eliminated by following a preventive maintenance schedule. Preventive maintenance, in simple terms, means taking care of the trouble before it happens. For example, oiling, greasing, cleaning, keeping the area around the equipment clean, and seeing that the equipment has the proper protective fuses and overload protection are preventive maintenance steps that eliminate costly repairs.

To analyze motor troubles in a split-phase motor, first check for proper voltage at the terminal block. If you have the proper voltage, check the end bells for cracks and alignment. The bolts or screws may be loose and the ends may be out of line. Next, check for a ground. With the motor disconnected, check the connections from the terminal block to the frame with an ohmmeter or megger. If you find a ground in this test, remove the end bell with the terminal block and centrifugal switch and separate the starting winding and running winding and make another ground check on each of these windings. In many cases you will find the ground in the loops where the wires are carried from one slot to the next. This situation can sometimes be repaired without removing the winding. In some cases, the ground may be in the centrifugal switch due to grease that has accumulated from over greasing.

If the first test does not show a ground in the motor, check to see that the rotor revolves freely. If the rotor turns freely, connect the motor to the source of power and again check to see that the rotor turns freely when energized. If the rotor turns freely with no voltage applied, but locks when it is applied, you will know that the bearings are worn enough to allow the iron in the rotor to make contact with the iron in the pole pieces.

If the trouble is a short, either the fuse will blow or the winding will smoke when you connect the motor to the line. In either event you will have to disassemble the motor. A burned winding is easily recognizable by its smell and burned appearance. The only remedy is to replace the winding. If the starting winding is burned, it can usually be replaced without disturbing the running winding, but check closely to be sure that the running winding is not damaged. In making a check for a shorted coil, the proper procedure is to use an ohmmeter to check the resistance in the coil that you suspect to be bad. Then check this reading against a reading from a coil you know to be good.

An open circuit can be caused by a break in a wire in the winding or by the centrifugal switch not closing properly when the motor is at a standstill. Too much end play in the rotor shaft may cause the rotating part of the centrifugal switch to stop at a point where it allows the contacts on the stationary part of the switch to stand open. Should the rotor have more than 1/64-inch end play, place fiber washers on the shaft to line the rotor up properly.

If the motor windings are severely damaged, send the motor to a motor shop for repairs. The repairs will usually be done in a shop operated by Public Works or the motor may be sent outside the base to a civilian operated motor shop. For this reason only the basic principles of the winding procedure will be covered.

Repair of a split-phase motor with a damaged winding consists of several operations: taking the winding data, stripping the old windings, insulating the slots, winding the coils and placing them in the slots, connecting the windings, testing, and varnishing and baking the winding.

Before taking the motor apart, mark the end plates with a center punch so that they may be reassembled properly. Put one punch mark on the front end plate and a corresponding mark on the frame. Make two marks on the opposite end plate and also on the frame at that point.

Taking the winding data is one of the most important parts of the operation. This action consists of obtaining and recording information concerning the old winding, namely, the number of poles, the pitch of the coil (the number of slots that each coil spans), (*Figure 10-16*), the number of turns in each coil, the size of the wire in each

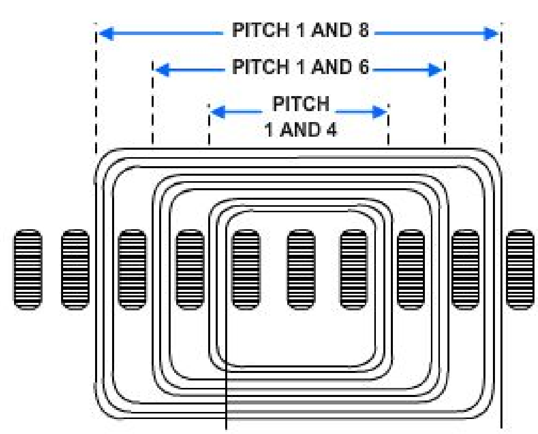

Figure 10-16 — The pitch of a coil.

winding, the type of connection (series or parallel), the type of winding, and slot insulation. See *Table 10-4*.

Take this data while removing the old winding from the motor frame. Cut one coil at a place where the number of turns may be counted. Then enter on the data sheet the size of the wire and other data.

Table 10-4 — Split phase motor data sheet.

MAKE					
HP	RPM	VOLTS	AMPS		
CYCLE	TYPE	FRAME	STYLE		
TEMP	MODEL	SERIAL NO	PHASE		
NO OF POLES	END ROOM	NO OF SLOTS			
LEAD PITCH	COMMUTATOR PITCH				
WIRE INSULATION	WINDING (HAND, FORM, AND SKEEN)				
SLOT INSULATION	TYPE	SIZE	THICKNESS		
TYPE CONNECTIONS	SWITCH	LINE			
WINDING	TYPE	SIZE AND KIND WIRE	NO OF CIRCUITS	COIL PITCH	TURNS
RUNNING					
STARTING					

SLOT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
RUN																	
START																	

SLOT	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
RUN																	
START																	

ROTATION	CLOCKWISE	COUNTER CLOCKWISE

Clean the old insulation and varnish from the slots before installing the new slot insulators. This cleaning is usually done with a torch. The slot insulators are formed from one of several types of material available for this purpose. The best procedure is to reinsulate the slots with the same type and size insulation that was used in the original winding.

Then wind the coils according to the data sheet and replaced in the slots in the same position as the windings you removed. ALWAYS place the starting windings 90 electrical degrees out of phase with the running windings.

When you have completed and tested all the connections between the poles of the windings and attached the leads, place the stator in a baking oven at a temperature of about 250°F and bake it for three hours to remove any trace of moisture. Heating the windings also helps the varnish to penetrate the coils.

Then dip the stator in a good grade of insulating varnish, allow it to drip for about an hour and then place it in the oven and bake it for several hours.

When you remove the stator from the oven, scrape the inner surface of the core of the stator to remove the varnish so that the rotor will have sufficient space to rotate freely.

7.1.2 Control for a Split Phase Motor

The control switch for a split-phase motor is usually a simple OFF and ON switch if the motor is equipped with an overload device. If the motor does not have this overload device, the switch will be of a type illustrated in *Figure 10-17*. This type of switch has two push buttons, one to start and one to stop the motor. It uses interchangeable thermal overload relay heaters for protection of various size motors. In some cases, a 30-ampere safety switch with the proper size fuse may be used.

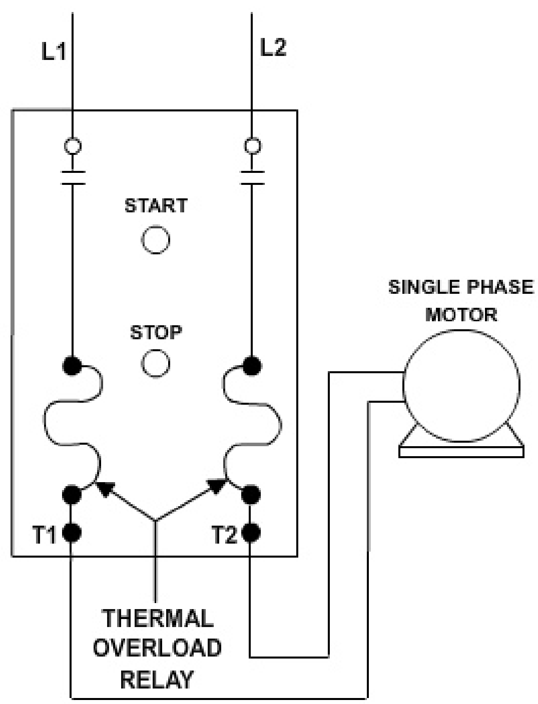

Figure 10-17 — Starting switch for a single phase motor.

7.2.0 Capacitor Motors

The capacitor motor is similar to the split-phase motor, but an additional unit, called a capacitor, is connected in series with the starting winding. These motors may be of capacitor-start or the capacitor-run type.

The capacitor is usually installed on top of the motor; but it may be mounted on the end of the motor frame, or inside the motor housing, or remote from the motor. A capacitor acts essentially as a storage unit. All capacitors have this quality and all are electrically the same. The only difference is in the construction. The type of capacitor usually used in fractional-horsepower motors is the paper capacitor. This type has strips of metal foil separated by an insulator, usually waxed paper. The strips are rolled or folded into a compact unit which is placed in a metal container either rectangular or cylindrical in shape. Two terminals are provided for connections.

The capacitor-start motor, like the split-phase motor, has a centrifugal switch which opens the starting winding when the rotor has reached the predetermined speed, while the capacitor-run motor does not have the centrifugal switch, and the starting winding stays in the circuit at all times. *Figure 10-18* shows a capacitor-start motor winding circuit. The capacitor motor provides a higher starting torque with a lower starting current than the split-phase motor.

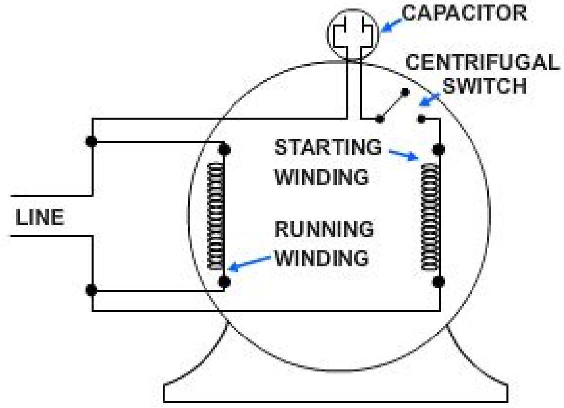

Figure 10-18 — Capacitor start motor winding circuit.

7.3.0 Troubleshooting and Repair

The procedure for troubleshooting and repair for the capacitor motor is the same as for the split-phase motor except for the capacitor. Capacitors are rated in microfarads and are made in various ratings, according to the size and type. A capacitor may be defective due to moisture, overheating or other conditions. In such a case, you must replace it with another one of the same value of capacity. To test a capacitor, remove the motor leads from the capacitor and connect the capacitor in series with a 10-amp fuse across a 110- volt line. If the fuse burns out, the capacitor is short-circuited and must be replaced. If the fuse does not burn out, leave the capacitor connected to the line for a few seconds to build up a charge. Do not touch the terminals after the charging process, as serious injury may result from the stored charge.

Short the terminals with an insulated handle screwdriver. A strong spark should show if the capacitor is good. If no spark or a weak spark results, replace the capacitor.

The procedure for rewinding a capacitor motor is the same as for the split-phase motor except for the capacitor.

7.4.0 Universal Motors

A universal motor is one that operates on either single-phase AC or DC power. These motors are normally made in sizes ranging from 1/200 to 1/3 horsepower. You can get them in larger sizes for special conditions. The fractional horsepower sizes are used on vacuum cleaners, sewing machines, food mixers, and power hand tools.

The salient-pole type is the most common type of universal motor. It consists of a stator with two concentrated field windings, a wound rotor, a commutator, and brushes. The stator and rotor windings in this motor are connected in series with the power

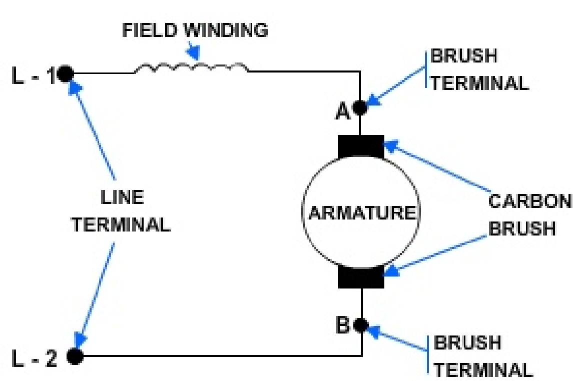

Figure 10-19 — Universal motor schematic.

source. There are two carbon brushes that remain on the commutator at all times. They are used to connect the rotor windings in series with the field windings and the power source (*Figure 10-19*). The universal motor does not operate at a constant speed. It runs as fast as the load permits, i.e., low speed with a heavy load and high speed with a light load. Universal motors have the highest horsepower-to-weight ratio of all the types of electric motors.

The operation of a universal motor is much like a series DC motor. Since the field winding and armature are connected in series, both the field winding and armature winding are energized when voltage is applied to the motor. Both windings produce magnetic fields which react to each other and cause the armature to rotate. The reaction between magnetic fields is caused by either AC or DC power.

7.5.0 Shaded Pole Motors

The shaded-pole motor is a single-phase induction motor that uses its own method to produce starting torque. Instead of a separate winding like the split-phase and capacitor motors, the shaded-pole motor's start winding consists of a copper band across one tip of each stator pole (*Figure 10-20*). This copper band delays the magnetic field through that portion of the pole. When AC power is applied, the main pole reaches its polarity before the shaded portion of the pole. This action causes the shaded poles to be out of phase with the main poles, producing a weak rotating magnetic field. Because of the low-starting torque, it isn't feasible to build motors of this type larger than 1/20 horsepower. They are used with small fans, timers, and various light load control devices.

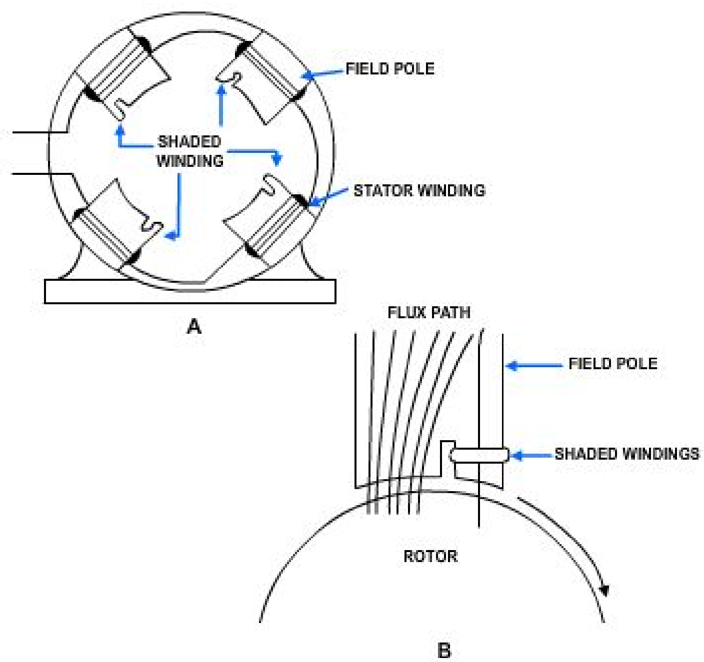

Figure 10-20 — Shaded pole stator.

Remember, all single-phase induction motors have some auxiliary means to provide the motor with starting torque. The method used for this starting torque depends on the application of the motor.

7.6.0 Fan Motors

A wide variety of motors are used for fans and blowers. Here we will discuss the different methods of varying the speed of common fan motors.

Different manufacturers use different methods for varying the speed. On some motors only the running winding voltage is varied while the voltage in the starting winding is constant. On others the running winding consists of two sections connected in series across 230 volts for high speed. If low speed is required, the two sections are connected to 155 volts through an auto-transformer. Usually, these motors are connected for three speeds.

7.7.0 Speed Control of Shaded Pole Motors

Many fans have a shaded-pole type motor. The speed of these motors is varied by inserting a choke coil in series with the main winding. Taps on the choke coil provide the different speeds.

7.8.0 Speed Control of Split Phase and Capacitor Motors

Split-phase and capacitor motors are commonly used in floor and wall fans. Two-speed split-phase motors are normally made with two run windings and either one or two start windings, depending on the manufacturer. In a three-speed split-phase motor, the speeds are obtained with only three windings: one running, one auxiliary, and one starting winding. For high speed, the running winding is connected across the line, and the starting winding is connected in series with the auxiliary winding across the line. For medium speed, the running winding is connected in series with half the auxiliary winding, and the starting winding is connected in series with the other half of the auxiliary winding. For low speed, the running and auxiliary windings are in series across the line, and the starting winding is connected across the line. Actually, a tap at the inside point of the auxiliary is brought out for medium speed. A centrifugal switch is connected in series with the starting winding.

The capacitor motor used for two-speed floor fans is a permanent-split capacitor motor. This motor does not use a centrifugal switch. For three speeds, the auxiliary winding is tapped at the center point, and a lead is brought out for medium speed. This motor is similar to the three-speed split-phase motor, except that the centrifugal switch is removed and a capacitor substituted. This motor is used extensively for blowers in air-conditioning systems.

Split-phase motors used on wall fans are wound like the ordinary split-phase motor, but many do not have a centrifugal switch. A special type of autotransformer, located in the base of the fan, is used to change the speed and also to produce an out-of-phase current in the starting winding. The primary of the transformer is tapped for different speeds and is connected in series with the main winding. The starting winding is connected across the transformer secondary.

A capacitor motor for a wall fan (*Figure 10-21*) contains a capacitor of approximately 1 microfarad (µf) in the starting-winding circuit. To increase the effective capacity and consequently the starting torque of this motor, connect the capacitor across an autotransformer. The taps on the transformer permit a choice of various speeds.

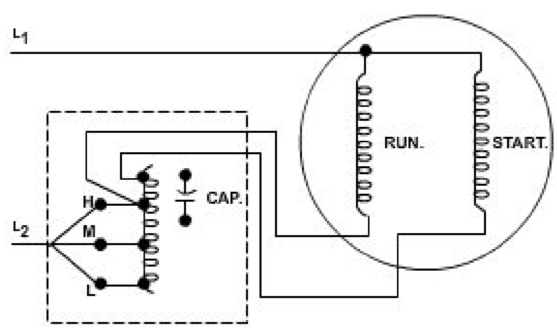

Figure 10-21 — Capacitor motor used for a wall fan.

7.9.0 Speed Control of Universal Fan Motors

The universal fan motor has a resistance unit in the base to vary the speed. A lever that extends outside the base is used to insert the resistance in the circuit.

8.0.0 CONSTRUCTION of THREE PHASE MOTORS

Construction of a three-phase motor consists of three main parts: stator, rotor, and end bells. Its construction is similar to a split-phase motor, but the three-phase motor has no centrifugal switch (*Figure 10-22*).

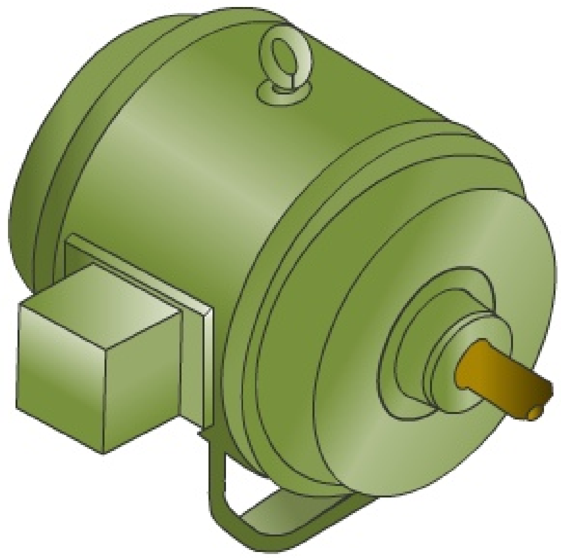

Figure 10-22 — Three phase motor.

8.1.0 Stator

The ***stator***, as shown in *Figure 10-23*, consists of a frame and a laminated steel core, like that used in split phase and repulsion motors, and a winding formed of individual coils placed in slots.

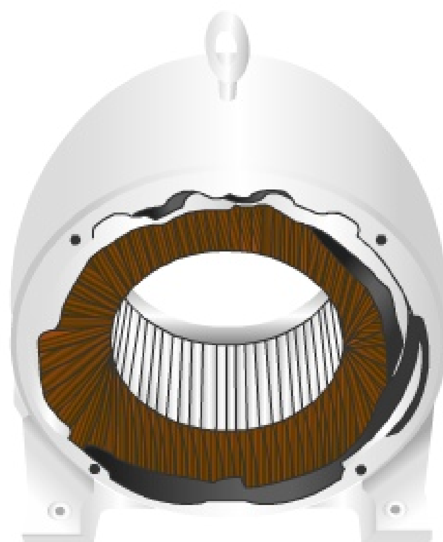

Figure 10-23 — Three phase stator.

8.2.0 Rotor

The ***rotor*** may be a die-cast aluminum squirrel-cage type or a wound type. Both types contain a laminated core pressed onto a shaft. The squirrel-cage rotor (*Figure 10-24*) is like the rotor of a split-phase motor. The wound rotor (*Figure 10-25*) has a winding on the core that is connected to three slip rings mounted on the shaft.

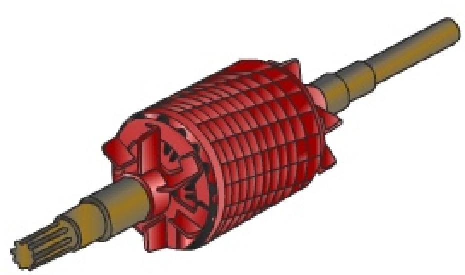

Figure 10-24 — Squirrel cage rotor.

8.3.0 End Bells

The end bells, or brackets, are bolted to each end of the stator frame and contain the bearings in which the shaft revolves. Either ball bearings or sleeve bearings are used for this purpose.

9.0.0 CONNECTING THREE PHASE MOTORS

Connecting a three-phase motor is a simple operation. All three-phase motors are wound with a number of coils, with a 2-to-1 ratio of slots to coils. These coils are connected to produce three separate windings called phases, and each must have the same number of coils. The number of coils in each phase must be one-third the total number of coils in the stator. Therefore, if a three-phase motor has 36 coils, each phase will have 12 coils. These phases are usually called Phase A, Phase B, and Phase C. All three-phase motors have their phases arranged in either a wye connection or a delta connection.

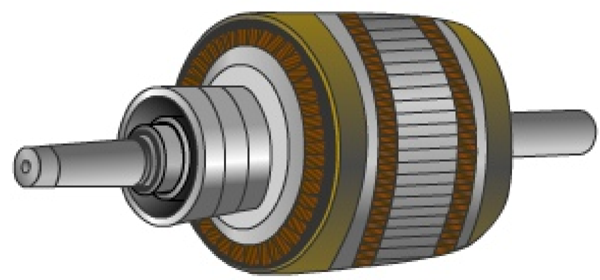

Figure 10-25 — Three phase wound motor.

9.1.0 Wye Connection

A wye-connected three-phase motor is one in which the ends of each phase are joined together paralleling the windings. The beginning of each phase is connected to the line. *Figure 10-26* shows the wye connection.

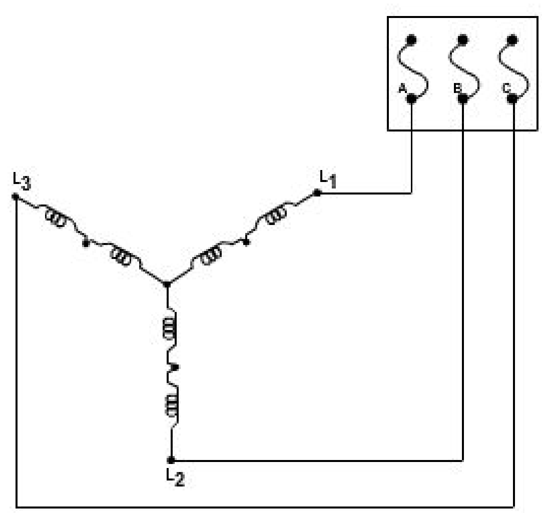

Figure10-26 — Star or wye connection.

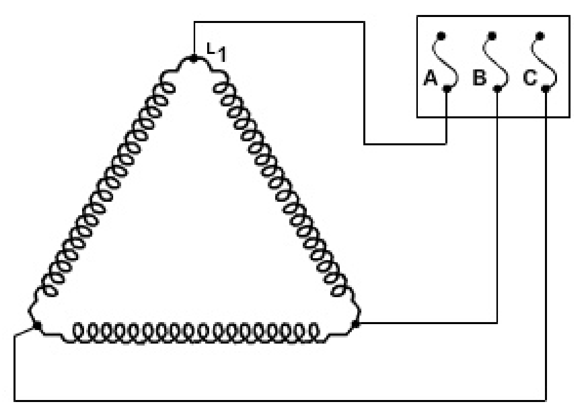

Figure 10-27 — Delta connection.

9.2.0 Delta Connection

A delta connection is one in which the end of each phase is connected in series with the next phase. Figure *10-27* shows the end of Phase A connected to the beginning of

Phase B. The end of Phase B is connected to the beginning of Phase C, and the end of Phase C is connected to the beginning of Phase A. At each connection, a wire is brought out to the line.

9.3.0 Voltages

Most small- and medium-sized three-phase motors are made so that they can be connected for two voltages. The purpose in making dual-voltage motors is to enable the same motor to be used in facilities with different service voltages. *Figure 10-27* shows four coils which, if connected in series, may be used on a 460-volt AC power supply. Each coil receives 115 volts. If the four coils were connected in two parallel sets of coils to a 230-volt line, as shown in *Figure 10-28*, each coil would still receive 115 volts. So, regardless of the line voltage, the coil voltage is the same. This is the principle used in all dual-voltage machines. Therefore, if four leads are brought out of a single-phase motor designed for 460/230 or 230/115-volt operation, the motor can be readily connected for either voltage.

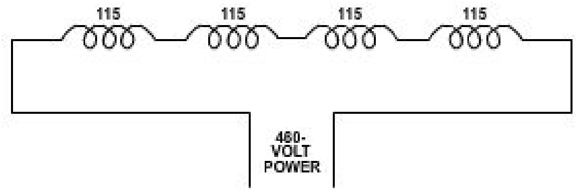

Figure 10-28 — Four 115 volt coil connected in series to produce 460 volts.

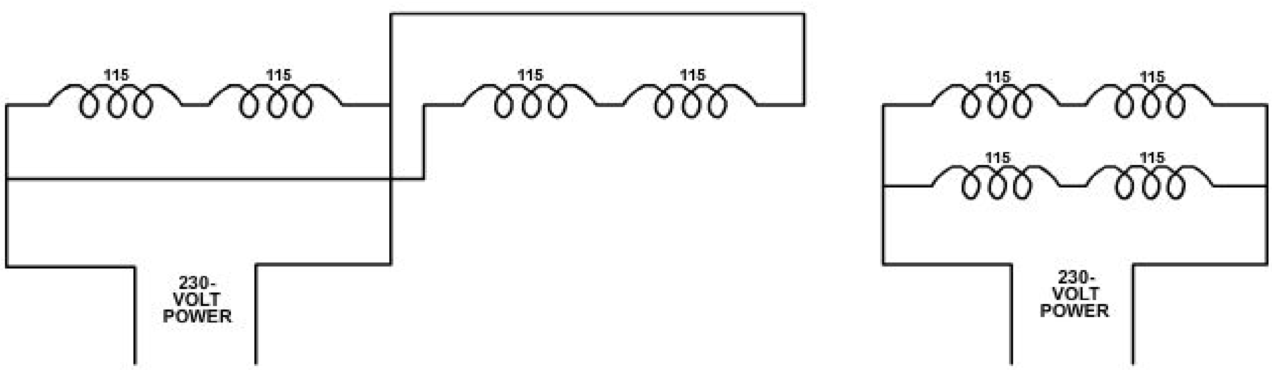

Figure 10-29 — Four 115 volt coils connected in parallel for 230 volts; each coil still receives only 115 volts.

9.3.1 Dual Voltage Wye Motor

When you are connecting a dual-voltage wye motor, remember practically all three-phase dual-voltage motors have nine leads brought out of the motor from the winding. These are marked T1 through T9, so that they may be connected externally for either of the two voltages. These are standard terminal markings and are shown in *Figure 10-30* for wye-connected motors.

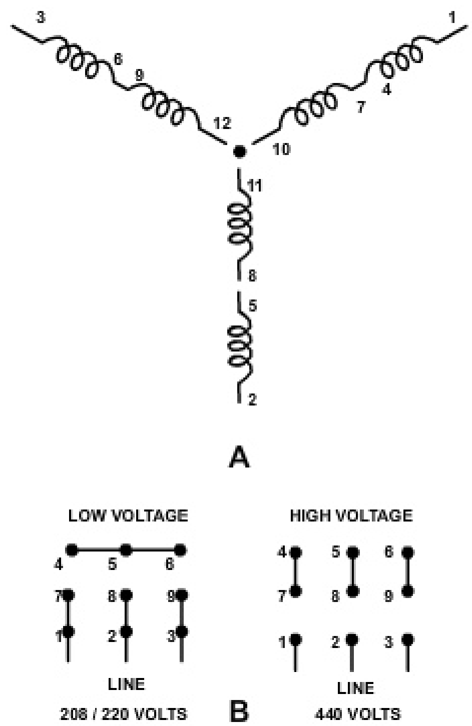

Figure 10-30 — Terminal markings and connections for a wye connected dual voltage motor.

9.3.1.1 High Voltage

To connect for high voltage, connect groups in series, as shown in *Figure 10-31*. Use the following procedure:

1. Connect T6 and T9; twist and wire nut.
2. Connect leads T4 and T7; twist and wire nut.
3. Connect T5 and T8; twist and wire nut.
4. Connect leads T1, T2, and T3 to the three phase line.

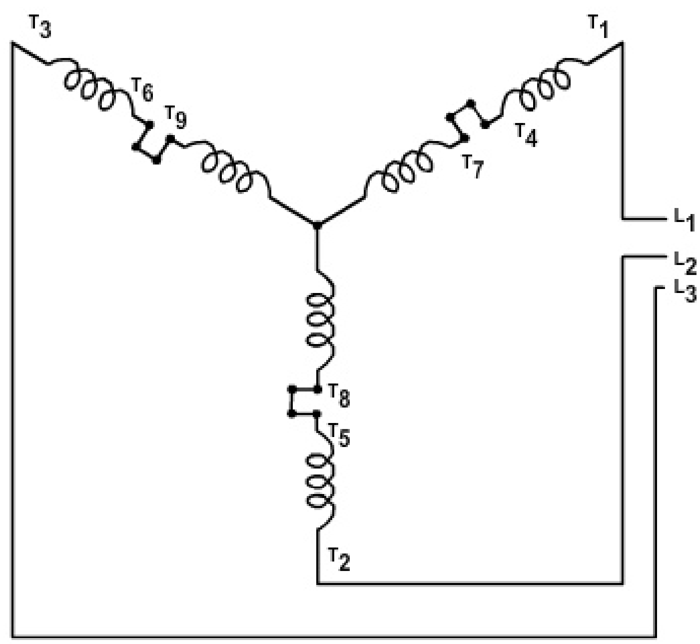

Figure 10-31 — Two voltage wye motor windings connected in series for high voltage operations.

9.3.1.2 Low Voltage

This same motor can be connected for low voltage. Use the following procedure:

1. Connect lead T7 to T1 and to line lead L1.
2. Connect lead T8 to T2 and to line Lead L2.
3. Connect lead T3 to T9 and line lead L3.

4. Connect T4, T5, and T6 together.

9.3.2 Dual Voltage Delta Motor

For connecting a dual-voltage delta motor, refer to *Figure 10-32* for the standard terminal markings of a dual-voltage, delta-connected motor.

9.3.2.1 High Voltage

For high-voltage operation, connect lead T4 to T7; connect lead T5 to T8; connect lead T6 to T9; connect T1, T2, and T3 to LI, L2, and L3, respectively.

9.3.2.2 Low Voltage

For low-voltage operation, connect leads Tl, T7, and T6 to the line lead LI. Connect leads T2, T4, and T8 to line lead L2. Connect leads T3, T5, and T9 to line lead L3.

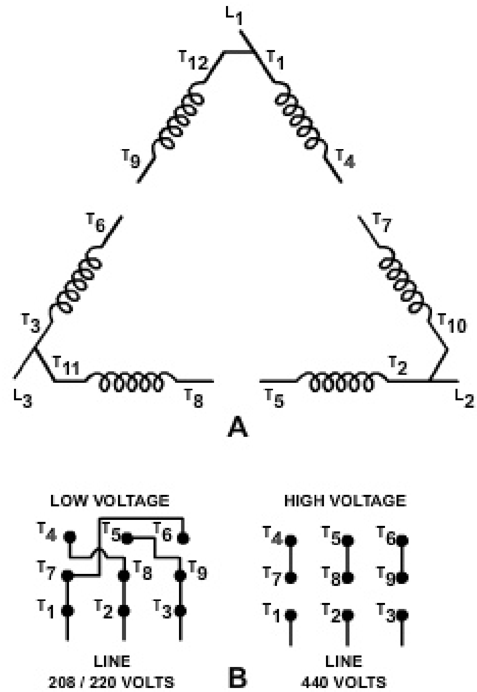

Figure 10-32 — Standard markings and connections for a delta connected dual voltage motor.

9.3.3 Reversing Three Phase Motors

For reversing three-phase motors, Figure 10-33 shows the three leads of a three-phase motor connected to a three-phase power line for clockwise rotation. To reverse any three-phase motor, interchange any two of the power leads.

Test your Knowledge

3. How many connections are associated with the dual voltage wye motor?

   A. 3
   B. 5
   C. 7
   D. 9

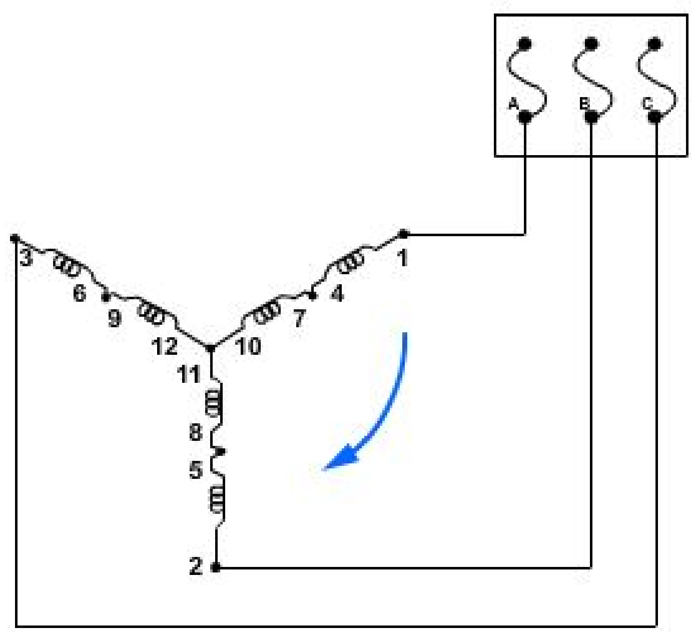

Figure 10-33 — Wye connected motor to three phase power for clockwise rotation.

10.0.0 AC MOTOR CONTROLLERS

This section covers common electric controllers. The term controller includes any switch or device normally used to start or stop a motor.

Controllers are classified as either manual or magnetic. The manual controller uses a toggle mechanism, moved by hand, to open or close the circuit. It may be a switch, a disconnect, or even an attachment plug. Magnetic controllers use a magnetic coil to move the mechanism which opens or closes the circuit. Magnetic controllers are operated manually by pressure on a button or automatically by a pressure switch or a similar device. The controller must be within sight of the motor, unless the disconnect device or the controller can be locked in the open position, or the branch circuit can serve as a controller. A distance of more than 50 feet is considered equivalent to "out of sight."

10.1.0 Controller Capabilities

Each controller must be capable of starting and stopping the motor it controls and, for an AC motor, it must be capable of interrupting the stalled-rotor current of the motor.

10.1.1 Horsepower Ratings

The controller must have a horsepower rating not lower than the horsepower rating of the motor. Exceptions are indicated below.

- For a stationary motor rated at 1/8 horsepower or less, normally left running and so constructed that it cannot be damaged by overload or failure to start (such as clock motors), the branch circuit overcurrent device may serve as the controller.
- For a stationary motor rated at 2 horsepower or less and 300 volts or less, the controller may be a general use switch with an ampere rating of at least twice the full load current rating of the motor.
- For a portable motor rated at 1/3 horsepower or less, the controller may be an attachment plug connector and receptacle.
- A branch circuit circuit breaker, rated in amperes only, may be used as a controller. Branch circuit conductors must have an amperage capacity (ampacity) not less than 125 percent of the motor full load current rating.

10.1.2 Single Controller Serving a Group of Motors

Each motor must have an individual controller, except for motors of 600 volts or less; a single controller can serve a group of motors under any of the following conditions:

- A number of motors drive several parts of a single machine or piece of apparatus, such as a metal and woodworking machine, crane, hoist, and similar apparatus.
- A group of motors is under the protection of one overcurrent device.
- A group of motors is located in a single room within sight of the controller location.

Conductors supplying two or more motors must have an ampacity equal to the sum of the full-load current rating of all motors plus 25 percent of the highest rated motor in the group.

10.2.0 Controller Markings

Controllers are marked with the maker's name or identification, the voltage, the current or horsepower rating, and other data as may be needed to properly indicate the motors for which it is suitable. A controller that includes motor running overcurrent protection or is suitable for group motor application is marked with the motor running overcurrent protection and the maximum branch-circuit overcurrent protection for such applications. Be extremely careful about installing unmarked controllers into any circuit. Controllers should be properly marked.

10.3.0 Controller Circuitry

Before you condemn a motor, make sure that the fault does not lie within the controller. The only way to be sure the fault is not in the controller is to understand the circuitry of the controller. As previously mentioned, there are two general types of motor controllers: manual and magnetic.

10.3.1 Manual Controllers

Manual controllers (motor starters) are available up to 7 1/2 horsepower at 600 volts (three-phase) and to 3 horsepower at 220 volts (single-phase).

10.3.1.1 Toggle Switches or Circuit Breakers

A toggle switch or circuit breaker can serve as a controller, provided its ampere rating is at least twice the full-load current rating of the motor and the motor rating is 2 horsepower or less. It must be connected in a branch circuit with an overcurrent device that opens all ungrounded conductors to the switch or circuit breaker. These switches or circuit breakers may be air-brake devices operable directly by applying the hand to a lever or handle. An oil switch can be used on a circuit with a rating which does not exceed 600 volts or 100 amperes, or on a circuit exceeding this capacity, under expert supervision and by permission. A single phase motor requires a one-element overload device, while a polyphase motor requires a two-element overload device (*Figure 10-34*).

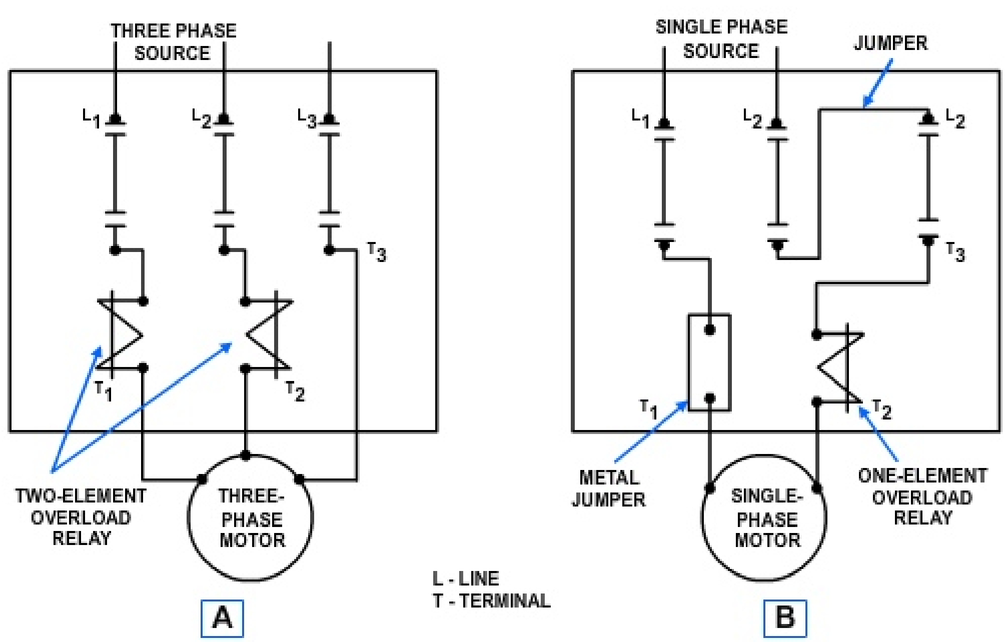

Figure 10-34 — Across the line manual controller.

10.3.1.2 Disconnects

Disconnects may be used as controllers on motors rated up to 3 horsepower at 220 volts. They must be located within sight of the motor or be able to lock in the open position. A distance of more than 50 feet is considered "out of sight." Double-throw disconnects may be used for reversing three-phase motors if they conform to these requirements.

10.3.1.3 Drum Control

The drum control is a lever-operated, three-position switch. The center position is usually the OFF position with the right and left positions FORWARD and REVERSES, respectively. Normally, it is used to direct the rotation of a three phase motor. Oil-immersed drum switches are used wherever the air can become charged with corrosive gases or highly flammable dust or lint.

10.3.2 Magnetic Full Voltage Starters

Magnetic starters are made to handle motors from 2 to 50 horsepower. They can be controlled by a start-stop station located locally or remotely. The starter has two different circuits: the control circuit and the load circuit.

10.3.2.1 Control Circuit

The control circuit receives its power from the incoming leads to the starter. It is a series circuit (*Figure 10-35*) going through the start/stop station, the magnetic coil, the overload contacts, and returning to another phase. However, it may return to the ground, depending on the voltage rating of the coil.

10.3.2.2 Load Circuit

The current flowing through the coil activates a mechanical lever and closes the main line contacts. This closing develops the load circuit and applies power to the motor. The fourth set of contacts provides a shunt around the start button, known as the holding circuit.

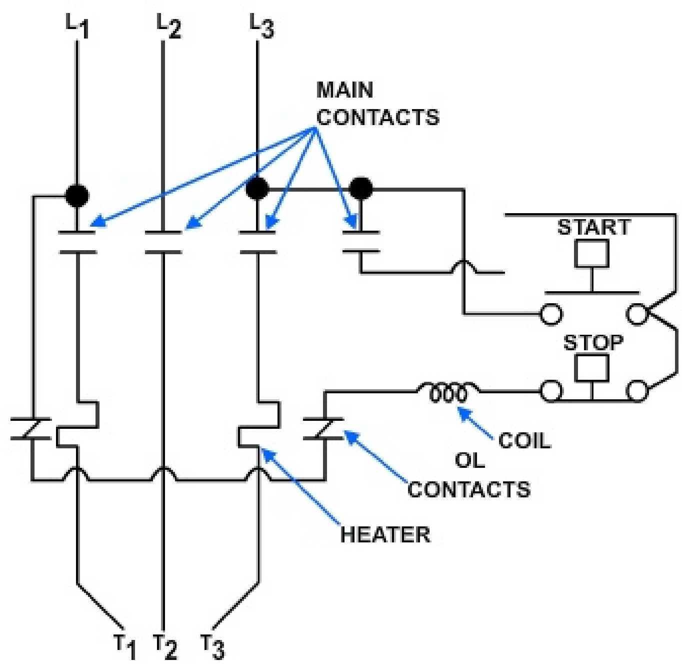

Figure 10-35 — Magnetic starter circuit.

10.3.2.3 Starter Coil

The coil of the starter may be de-energized in three ways. The stop button is pressed, one of the overload contacts opens, or the line voltage drops low enough to allow the coil to release. If one of these things happens, the main contacts are separated by spring pressure, removing power to the motor.

The overload contacts are opened by excess current flowing through the heater, located in the power circuit (*Figure 10-35*). The size of the heaters to be installed is determined by the full-load current draw to the motor. Magnetic starters are manufactured by many different companies. Information for the proper size of heater is given on the cover of the starter.

10.3.2.4 Heaters and Horsepower

Table 10-5 is a typical horsepower and heater table for motors of different sizes and voltage. To determine the heater number, you must know the horsepower and voltage and if the motor is single or three-phase. Once you have that information, look at *Table 10-5, View A*, and find the full-load motor amperage. Using the chart from *Table 10-5, View B*, you can find the heater number for this motor. For example, you want to know the number of a heater for a 5-horsepower, 230-volt AC, single-phase motor. Checking *Table 10-5, View A*, you find that the motor draws 28 amps. Referring to *Table 10-5, View B*, you find heater number 42227 has an amperage range from 26.0 to 28.3. This is the heater you should use. Also in the table you will find the maximum fuse size and the amperage at which the heater will open the control circuit. Remember that each manufacturer has its own heater table to be used with it’s across-the line starters.

Table 10-5 — Horsepower rating and heater table.

DC Motors			Single Phase AC Motors		Three Phase AC Motors		
HP	120V	240V	115V	230V	115V	230V	460V
1/4	2.9	1.5	5.8	2.9			
1/3	3.6	1.8	7.2	3.6			
1/2	5.2	2.6	9.8	4.9	4	2	1
3/4	7.4	3.7	13.8	6.9	5.6	2.8	1.4
1	9.4	4.7	16	8	7.2	3.6	1.8
1 1/2	13.2	6.6	20	10	10.4	5.2	2.6
2	17	8.5	24	12	13.6	6.8	3.4
3	25	12.2	34	17		9.6	4.8
5	40	20	56	28		15.2	7.6
7 1/2	58	29	80	40		22	11
10	76	38	100	50		28	14

A

Heat Cat No	Trip Amps	Full Load Motor Amps Min-Max.	Max Fuse Size	Heater Cat No	Trip Amps	Full Load Motor Amps Min Max.	Max Fuse Size
42013	7.2	5.76-6.53	20	42022	22.4	17.9-19.4	80
42014	8.4	6.72-7.59	25	42225	25	20-21.8	100
42015	9.6	7.7-8.4	35	42226	28	22.4-24.4	100
42016	10.9	8.7-9.5	35	42227	32.6	26-28.3	125
42017	12.6	10.1-11	40	42228	36.3	29-31.6	125
42018	13.7	11-11.5	45	42229	42	33.5-36.5	150
42019	14.5	11.6-12.6	50	42230	48	38.4-41.5	150
42020	15.8	12.6-13.7	50	42231	52	41.6-45.2	172
42021	18.3	14.6-15.9	60	42232	57	45.5-49	200
42224	20	16-17.6	70	42233	60.5	49-52.5	200
B							

10.3.2.5 Heater Troubleshooting

A heater must be manually reset at the motor starter. If the magnetic starter fails to energize, the trouble is within the control circuit. However, if the coil should energize but the motor fails to run, the trouble must be within the load circuit or motor. Check the load circuit at terminals TI, T2, and T3. If the proper voltage requirements are there, the trouble is most likely in the motor.

10.3.3 Push Button Stations

An example of a push-button station with overload protection is shown in *Figure 10-36*. In this case, the controller is connected to a 208-volt single-phase motor. This controller is a single-phase, double-contact device which connects or disconnects both undergrounded conductors to the motor. It has a start and stop button that mechanically opens or closes the contacts. Pressing the start button closes both contacts, and pressing the stop button opens both contacts. The control has two overload devices connected in series with the contacts. If an overload condition occurs, either overload device will open both sets of contacts. A typical application of this type control would be to control small machine tools.

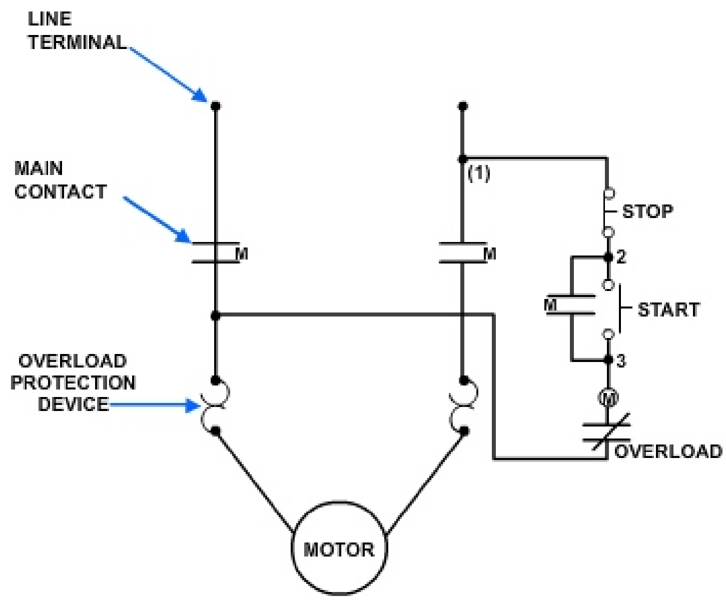

Figure 10-36 — Schematic for a single phase manual controller with overload protection.

10.3.4 Full Voltage Reversing Starters

Reversing magnetic controllers use two magnetic across-the-line starters whose power leads are electrically interconnected to reverse two of the three phases. The two motor starters are generally contained in one box and are mechanically interlocked so that one cannot close without the other opening. They are sometimes also electrically interlocked to help prevent closing both starters at the same time.

10.3.5 Reduced Voltage Starters

Reduced-voltage starters are generally used for motors rated above 50 horsepower. Reduced-voltage starters are designed to reduce the current draw of the motor during the starting period only. They use either an autotransformer or resistor, both using the same basic principles.

Figure 10-37 is a schematic drawing of an autotransformer reduced-voltage starter. The autotransformer starter provides greater starting torque per ampere of starting current drawn from the line than any other reduced-voltage motor starter. But this type of starter is not always desirable, because, with the changing of the S and R relays, the motor is without power for a short time. Therefore, a resistance-reduced voltage starter may be used. Resistance starters are sometimes applied where the circuit should not be opened during the transition from reduced to full voltage. They are particularly desirable when sudden mechanical shock to the driven load must be avoided.

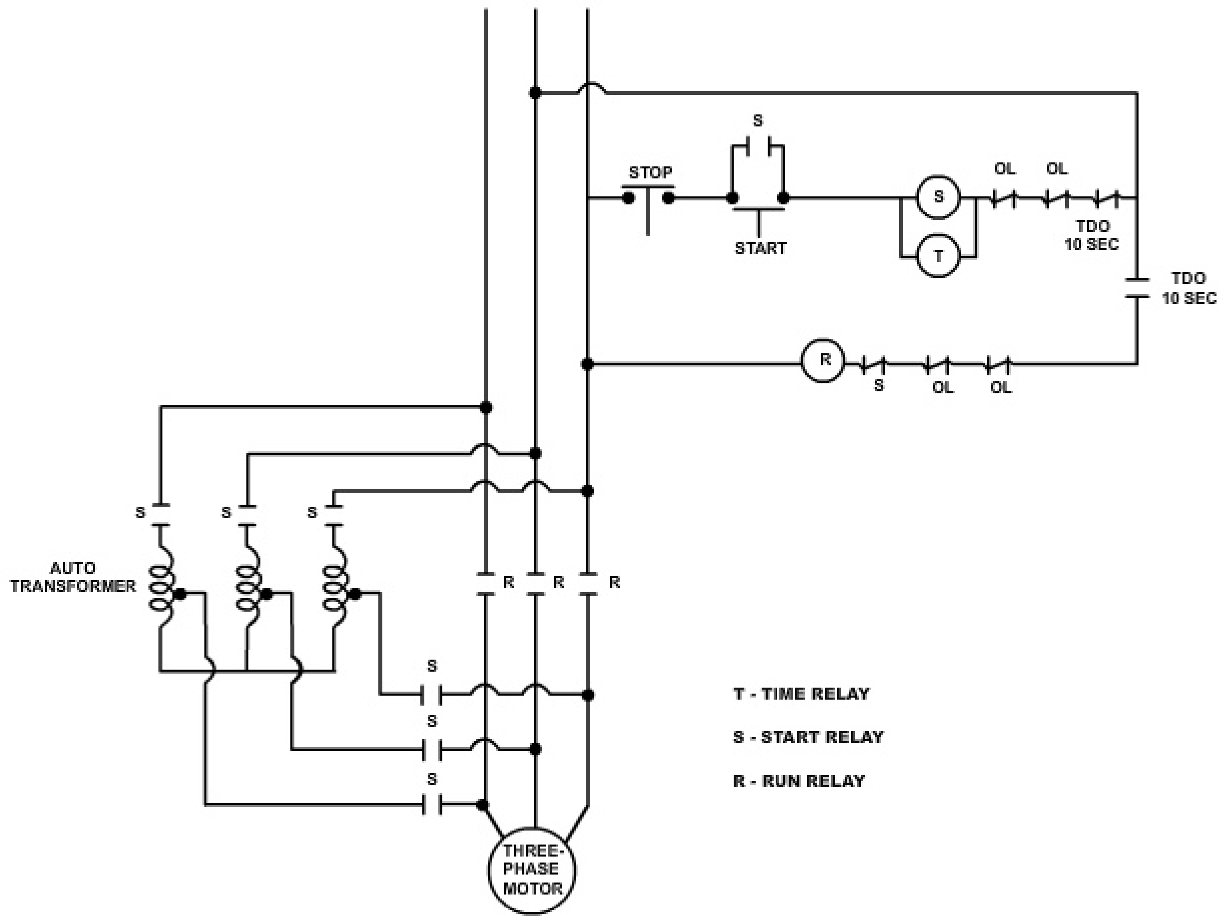

Figure 10-37 — Autotransformer reduced voltage starter.

Figure 10-38 shows a typical resistance-reduced voltage starter. Pressing the start button energizes the S relay. The S contacts close, connecting power through the resistors to the motor. Voltage is dropped across the resistors, lowering the voltage to the motor. After a period of time, the T contact closes, energizing the R relay. The R relay contacts close, shunting around the resistors, to apply full voltage to the motor. The contact device may be a time delay relay or even a centrifugal switch, operated from the speed of the motor. Protective devices used in reduced-voltage starters are determined in the way previously described.

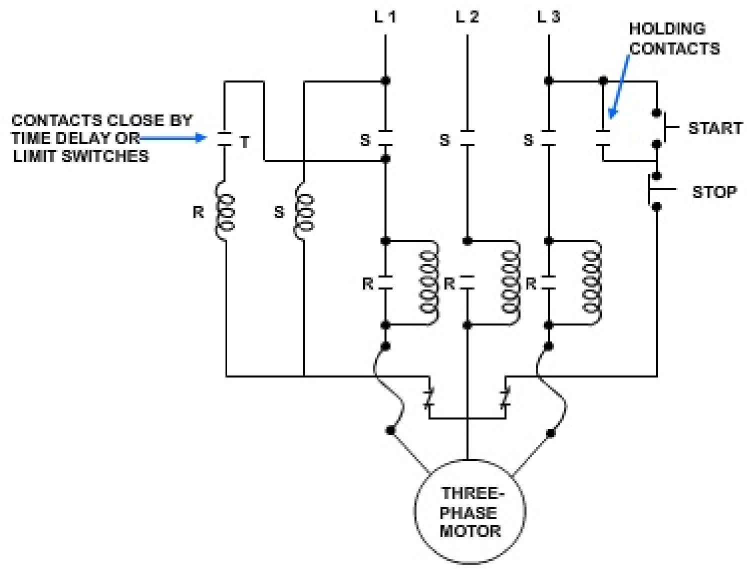

Figure 10-38 — Resistance reduced voltage starter.

10.3.6 Part Winding Starters

Part-winding starters use two magnetic starters and operate like a resistance start controller. *Figure 10-39* is a schematic drawing of a wye-connected, three-phase motor. The control circuits for the S and R relays are the same as for a resistance reduced-voltage starter, and so they are not shown. The S relay is energized first, connecting voltage to only part of the winding. The motor starts to run but develops little torque. At a predetermined time, the R relay closes. This action parallels the windings in the motor, reducing their resistance and causing increased current flow and more torque.

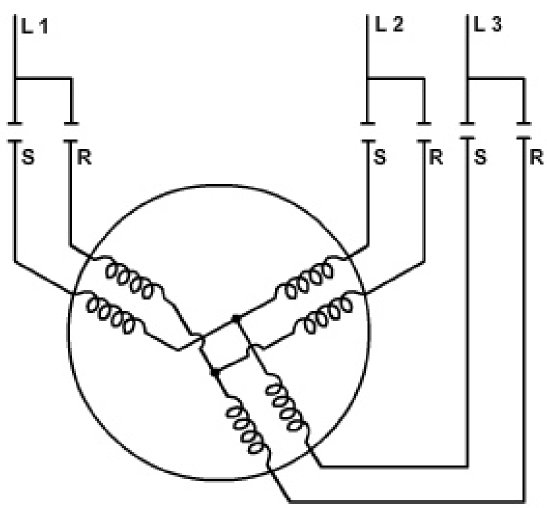

Figure 10-39 — Part winding starter.

10.4.0 Motor Maintenance, Testing, and Repair

An electric motor must be checked, maintained, and repaired just like any other piece of mechanical equipment. With proper servicing, a motor will last longer and give more efficient service. Included in maintenance services are cleaning, lubrication, ventilation, and testing.

10.4.1 Cleaning

Inspect motors internally and externally for foreign materials, such as dust, dirt, corrosion, and paint. Open frame motors may be blown out with compressed air. You should not apply too many coats of paint to motors. A thick coat of paint will interfere with heat dissipation.

CAUTION

Air pressure used for cleaning should not exceed 25 psi nozzle pressure. Excessive pressure can damage the insulation on the windings.

Wipe all excess dirt, grease, and oil from the surfaces of a motor with a cloth moistened with an approved solvent.

WARNING

Do not use flammable or toxic solvents when cleaning motors. Solvents may cause injury to personnel or damage to equipment.

10.4.2 Lubrication

Lubrication should be done according to the manufacturer’s instructions. Improper lubrication causes motor bearings to overheat and eventually causes bearing failure. Check a motor for signs of grease and oil-seal failure. If an inside seal fails, the lubricant can get into the motor windings and deteriorate the insulation. This condition also allows dust to adhere to the windings and restricts air circulation, then the motor windings heat and burn out. Inadequate lubrication causes the bearings to wear excessively and, eventually, to seize. When lubricating a motor, refer to the manufacturer's manual to determine the correct type of lubricant to use. Some motors have bearings lubricated with oil, while others require grease. Many motor bearings are lubricated and sealed at the factory and usually last the life of the bearing.

10.4.3 Ventilation

Check the running temperature of all motors. If the motor temperature is hotter than specified on the nameplate, you must find the problem. The normal procedure for diagnosing motor overheats is to check the motor for restricted ventilation. Inspect the area around the motor for any obstructions which could hamper free air circulation. If air circulation is not hampered in any way and the motor continues to run hot, reduce the load on the motor or use a motor with more power capability.

10.4.4 Testing

The proper testing of a motor has a logical sequence. Proper testing can prevent unnecessary labor and parts. Testing motors is generally classed under two major methods: visual tests and operational tests.

10.4.4.1 Visual Tests

A visual test can discover a great deal about the condition of a motor and the possible causes of trouble. Read the nameplate data and be sure that the motor connections are correct for the supplied voltage.

Look at the windings to see if the insulation has overheated (or has been overheating). You can tell when the insulation is burned by the odor within the motor. If you aren’t sure of the condition of the windings, test them with a megger to determine if they have been damaged beyond use. Connect the leads of the megger to each set of windings.

CAUTION

Disconnect the motor leads from each other to ensure reading only one winding at a time.

If the winding is good, you will get a reading of continuity. If the winding indicates a large amount of resistance, it is damaged and must be replaced.

Now connect one lead from the megger to the frame of the motor. Connect the *other* lead of the megger to each lead of the motor, one at a time. A low-resistance reading means insulation breakdown or a short to the motor frame, and replacement of the winding is necessary.

Inspect the commutator for solder thrown from the risers, and for loose, burned, high, and flat bars. Also test for high mica. Notice the surface film on both the commutators and slip rings and the general condition of the brushes. Check the air gap on large motors for any indication of bearing wear or misalignment. For large motors, take an air gap measurement at one reference point on the rotor or armature; then rotate the rotor or armature and measure four points on the stator or field frame to the same reference point. The air gap measurement should be within plus or minus 5 percent at any of these points.

Check the condition and operation of the starting rheostat in DC motors and the starting and control equipment used with AC motors. Also check the terminal connections on all of the control equipment to ensure they are correct and secure. Make sure the proper voltage is at the terminal lead of the motor.

If the visual tests have not revealed the trouble, perform some operational tests on the motor.

10.4.4.2 Operational Tests

Perform a heat run test, observing the manufacturer's recommendations for that particular motor.

CAUTION

Do not attempt to operate a series DC motor without a load.

If the temperature of the motor in normal operation does not exceed the maximum recommended by the manufacturer, the motor is operating satisfactorily. Always refer to the manufacturer's manual for definite specifications for the motor you are inspecting.

WARNING

Be sure the master switch is in the off position before connecting or disconnecting any motor lead connections.

Because of their effect on insulating materials, high temperatures shorten the operating life of electric motors. When the windings or the bearings of a motor not specifically designed for high temperature service get hotter than 90 degrees centigrade, investigate the operating conditions and relieve the temperature conditions by cooling or relocating the motor. Gradually rising temperature in a motor warrants a shutdown and thorough examination of the unit. The nameplate on the motor usually specifies its normal running temperature in degrees centigrade. Check the current draw of the motor against the data on the nameplate. Excess current causes heating and, in time, will destroy the windings.

Check the motor for proper speed. A speed above or below that indicated on the nameplate signifies a malfunction in the unit. When a motor's operation is sluggish, check the line voltage to the motor. If you find the voltage low, apply the proper value and continue checking to determine if the motor is overloaded. If it is, reduce the load or replace the motor with one of a larger horsepower. There are other conditions which could make motor operation sluggish. You may find that the brushes have shifted off NEUTRAL, and you must reset them. You may also find that the armature or rotor is dragging on the stator or field poles. To correct this situation, you may need new bearings. A field pole may be loose, causing it to drag on the armature or rotor.

Other conditions which could cause a motor to be sluggish are shorted field-winding circuits, shorted armature windings, and surface leaks across the commutator segments. After finding the fault in the motor, you may have to replace it. When you replace it, be sure to install a motor of the same size.

CAUTION

Be sure to de-energize the motor circuit before disconnecting the unit.

While the motor is running, look for any sparking at the brushes. Many faulty conditions contribute to sparking brushes at the commutator. The two major causes are a faulty armature and malfunctioning brushes. Some of the faults that could develop in an armature include rough commutators, bent armature shafts, and short circuits in the armature windings. Brushes may malfunction because they are off NEUTRAL, they bind in the brush holders, they are wound beyond recommended limits, or they intermittently fail to contact the commutator because of insufficient brush spring tension. Whenever a motor is arcing at the brushes, disassemble it, locate the problem, and make the necessary repairs,

There are many causes of motor noise. Listen and feel for any unusual noises. First, check the motor-mounting bolts for looseness and the alignment of the motor with the driven equipment. If the motor is secure and properly aligned, continue your inspection. Check the motor's balance. Also inspect the motor for loose rotor bars or a bent shaft. If any of these conditions exist, replace the rotor or armature. Sometimes the centrifugal switch rattles or rubs the interior of the motor housing. Align the switch and tighten the mounting bolts. If the switch has excessive wear, replace it. Check all motor accessories for looseness and tighten as needed. Check the drive pulley and the condition of the belts. Loose pulleys rattle and will damage belts. You will hear a distinct slap when the belt has been damaged.

10.4.5 Motor Repair

After you have performed visual and operational tests on a motor and isolated the problem, you may have to disassemble the motor to make the repairs. You should know the procedures and precautions for motor repair.

10.4.5.1 Disassembly

The careless disassembly of a motor can cause serious damage to the delicate components within it. Remove and handle all parts with care and always use the proper tools. It is just as important to tag all parts, take down accurate data, and store the parts in an orderly arrangement in a safe place. Before disassembling a motor, consider the following:

- The area for disassembly must be clean and free of dirt, dust, and moisture.
- Tag all leads and the point of connection from where the leads have been removed.
- Wipe all excess dirt, grease, and oil from the exterior surface with a clean cloth moistened with an approved solvent.
- Inspect all leads for burned, cracked, or deteriorated insulation at the point of their entry into the motor.
- Turn the motor shaft by hand to determine whether the armature turns freely. If not, inspect the motor for a bent shaft, misalignment of the end bells, loose or frozen bearings, a loose pole piece, or foreign objects inside the motor.

WARNING

Use gloves or a cloth to protect your hands from the sharp edges of the keyway when turning the shaft.

10.4.5.1.1 End Bell Removal

When you are removing the end bells, remember that on some motors the bearings must be removed before the end bells. To remove the end bells, use the following procedure:

1. Punch mark the frame and end bells for reassembly purposes (*Figure 10-40*).
2. Remove the end bell fastening screws or bolts.
3. Remove the bearing first, if necessary.
4. Part the end bells from the frame, as shown in *Figure 10-41.*
5. Record and disconnect the leads from the internal mechanism and components.
6. Clean the end bells and frame.
7. Inspect the disassembled parts and replace as needed.

Figure 10-40 — Punch marking motor frame and end bells.

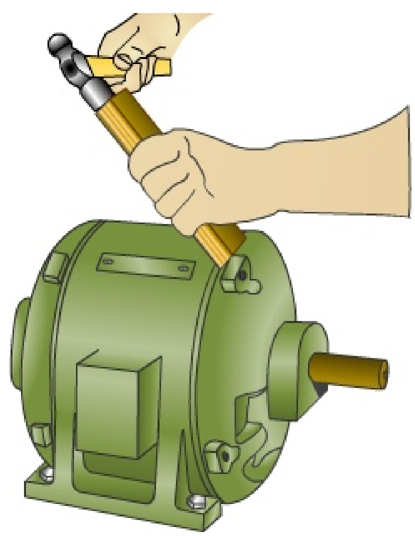

Figure 10-41 — Separating motor frame from end bells.

10.4.5.1.2 Bearing Removal

Sometimes you can remove the bearings before removing the end bells. In other cases, the bearings slip off the shafts with the end bells. Frequently, the bearings are press fitted to the shafts and end bells, making their removal difficult. Since bearing removal varies with the different types of motors, only some of the most important procedures and precautions are listed.

- Never remove bearings in good condition from the shafts or end bells unless it is absolutely necessary.
- Remove all bearing attachment screws or bolts before attempting to remove the bearings.
- Remove ball bearings that are to be reused with arbor plates and an arbor press to prevent distortion.
- Remove ball bearings to be discarded with a hook type puller.
- Remove sleeve bearings with arbor plates and an arbor press. When an arbor press isn't available, you may remove sleeve bearings with a well fitted arbor and hammer.
- Sometimes you may be required to remove sleeve bearings by drilling them out with a drill press.
- Handle bearings with clean, dry hands or clean canvas gloves. Handling a bearing with hands that are perspiring can cause corrosion. Fingerprint patterns are sometimes found rusted into bearing surfaces.
- Keep bearings in their packages or in oil proof paper until they are installed.

10.4.5.1.3 Brush Removal

Brush removal is necessary when you are replacing brushes or you need access to parts of the unit otherwise inaccessible. If the brushes are not to be removed, place them in the raised position. Use the following procedure for removing brushes and brush rigging:

1. Record the placement and angle of brush rigging and brushes.
2. Check the brush spring pressure.
3. Remove the screws holding the brush pigtails and rigging.
4. Clean, inspect, and store the brushes and brush rigging.

10.4.5.1.4 Centrifugal Switch Removal

Internal switches of the centrifugal type are usually attached to the inside of end bells. When you are removing the end bells, be careful not to break the switch springs. For removing a centrifugal switch, follow these steps:

1. Note and record the lead connections to the switch.
2. Disconnect the leads.
3. Remove the mounting screws of the stationary part of the switch which is secured to the end bell.
4. Clean and inspect the switch and replace the damaged parts.
5. Tag and store the unit.

10.4.5.1.5 Armature and Rotor Removal

The removal of armatures and rotors from within the frame of the unit requires considerable care to avoid damage to the parts. For removing an armature or rotor, follow these suggestions:

1. Support the armature or rotor only by its shaft when possible.
2. Slide a thin piece of cardboard between the underside of the rotor and stator to protect the laminations and windings during rotor removal.
3. In a shop, use a hoist to remove the rotors of large motors.

10.4.5.2 Testing Components

After a motor is disassembled, you perform certain tests to determine which components are faulty.

10.4.5.2.1 Field Winding

To locate a grounded field winding, disconnect and separate the internal connections between the windings. With this done, position one lamp prod of a series test lamp to the housing. With the other test lamp prod, touch each winding lead individually. If the test lamp lights, that particular winding is grounded. Test all the windings. You may also perform this test with an ohmmeter. A reading of continuity indicates a short; no reading indicates that the field winding is not grounded.

The test for an open circuit in the field windings of a motor may also be done with a series test lamp. Touch one test lead to one coil terminal and the other lead to the opposite coil terminal. If the test lamp doesn't light, the winding is open. If it does light, an open circuit doesn't exist, and the winding is serviceable.

To test for shorts in the field winding of a motor, compare the relative voltage drop in each field winding section with a voltmeter. You should get the same reading for each section. A decrease in voltage drop in a section indicates a short circuit.

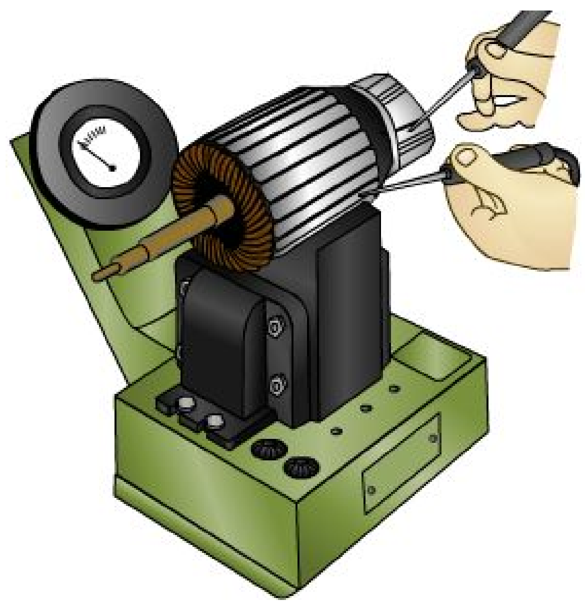

Figure 10-42 — Testing for grounds in armature windings.

10.4.5.2.2 Armature Winding

The first test on an armature winding should be to locate grounded circuits. This test is also performed with a series test lamp. Touch one test prod to the armature core or shaft, as shown in *Figure 10-42*. Using the other test prod, touch each commutator segment. If the armature winding is grounded, the test lamp will light when you apply the lamp prod to the grounded armature winding or commutator segment. Replace the grounded armature when all attempts to remove the ground have failed.

When checking for a shorted armature, place the armature in an armature test set (growler). Lay the test blade lengthwise with the flat side loosely in contact with the armature core, as shown in *Figure 10-43*. Turn the test stand to the ON position and slowly rotate the armature while holding the test blade stationary. If there is a short in the armature windings, the test blade will be attracted to the armature (magnetized) and will vibrate.

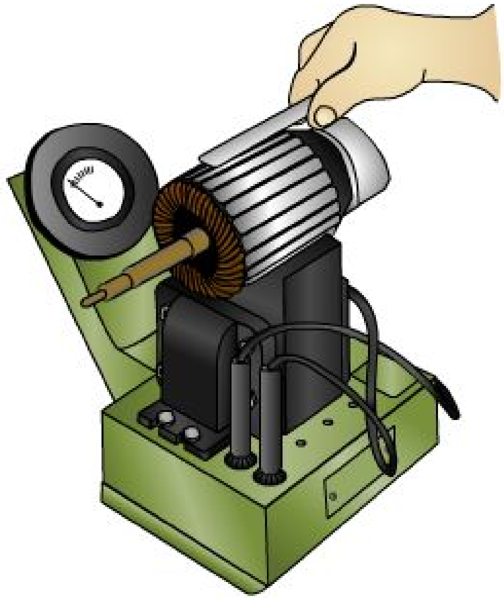

Figure 10-43 — Testing for shorts in armature windings.

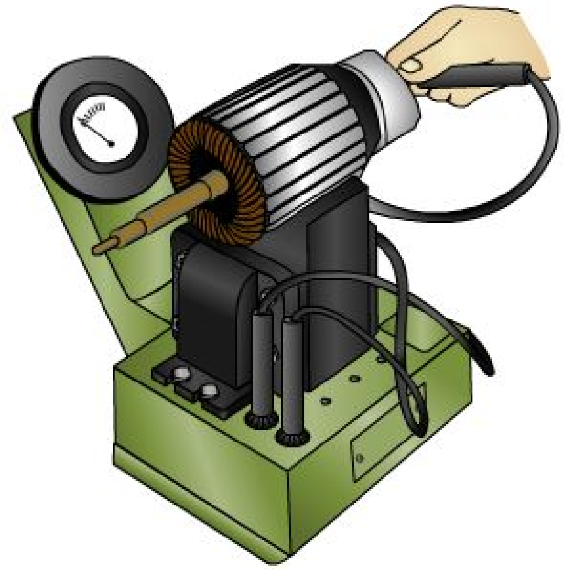

Figure 10-44 — Testing for open in a commutator.

CAUTION

Place the test set switch in the off position before removing the armature, and never leave the test set turned on unless there is an armature placed in the core.

When you are testing an armature for an open circuit, place the armature in an armature test set and turn the test set ON. Place the armatures double prods on two adjoining commutator segments and note the reading on the ammeter, as shown in *Figure 10-44*. Rotate the armature until you have read each pair of adjoining commutator segments. All the segments should read the same. No reading indicates an open circuit, and a high reading indicates a short circuit.

CAUTION

Place the test set switch in the off position before removing the armature from the test stand.

Check the commutator for broken leads. Repair and resolder any you find. If you find an open winding, check the commutator for burned spots. They reveal the commutator segment to which the open winding is connected. Open circuits in the windings generally occur at the commutator and can be found by a visual inspection. If there is excessive sparking at the brushes with the motor reassembled, disassemble it and replace the armature.

Figure 10-45 — Fabricated cleaning pad.

In testing for a grounded brush holder or rigging, touch one test lamp prod of the armature test set to the motor housing. With the other test prod, touch each brush holder individually. If the lamp lights, there is a ground in the brush holder.

CAUTION

Remove all leads to the brush holders and brushes before you attempt this test.

The color of the commutator and slip rings will indicate the type of trouble. An even chocolate-brown color indicates a normal condition and a black color indicates brush arcing. You can remove slight burns on the commutator segments by polishing the commutator as the armature rotates. Use a canvas pad, as shown in *Figure 10-45*. To remove the deeper burns, use fine sandpaper instead of the canvas pad. When a commutator is deeply scored, it must be reconditioned in a lathe or with a special tool.

CAUTION

Never use emery cloth to polish commutators because the emery particles can lodge between the segments and cause the commutator circuits to short.

Slip rings used on rotors are usually made of bronze or other nonferrous metals. Under normal conditions, the wearing surface should be bright and smooth. When the rings are pitted, they should be polished. When excessively worn and eccentric, they should be trued with a special tool.

10.4.5.3 Reassembly

After you have inspected all parts and repaired or replaced the faulty ones, you are ready for reassembly. To assemble motors, follow in reverse order the procedures of their disassembly. Be sure to check any available literature you may find. Be sure to oil or grease the bearings as required. Remove the relief plug in the bottom of the housing while you apply grease.

10.5.0 Motor Controller Maintenance and Repair

The most important rule to remember when you are making repairs or inspecting motor controllers is as follows:

CAUTION

Be sure the controller is disconnected from the power source before touching any of the operating parts.

Inspect and service control equipment on the same maintenance schedule as motors. Motor starters can normally be repaired on the job site at the time of inspection. After securing the power, the first thing you should do to keep controllers operating at maximum efficiency is keep them free of dirt, dust, grease, and oil, both inside and out. Clean the operating mechanism and contacts with a clean, dry, lintless cloth or a vacuum cleaner. Clean small and delicate mechanical parts with a small, stiff bristle brush and a Navy-approved solvent.

Check the contacts to ensure proper electrical connections. When contacts open and close the rolling and rubbing action keeps the contacts bright and clean. Infrequently operated contacts or contacts under heavy loads can overheat, which creates oxidation on the contacts.

10.5.1 Copper Contacts

Copper contacts are used for most heavy-duty power circuits, and, in many cases, in relay and interlock circuits. They should be inspected regularly. If projections extend beyond the contact surfaces or if the contacts are pitted or coated with copper oxide, sand them down with fine sandpaper.

Welding of contacts sometimes occurs in spite of all precautions. Low voltage is the most common cause. Welding may also result from overloads, low-contact pressure resulting from wear or weak springs, loose connections, or excessive vibrations. If welding occurs, it is an indication of trouble in the electrical system. The contacts must be replaced, but it is useless to replace them without finding and correcting the cause of the welding.

10.5.2 Carbon Contacts

Carbon contacts are used when a contactor is frequently opened and closed. It is essential that the contactor be open when it is de-energized. Since carbon contacts will not weld together when closed, they are better than metal contacts for ensuring that a deenergized contact is open. However, carbon contacts are used only when necessary. Because the current capacity of carbon per square inch of contact surface is very low, contacts made of carbon must be relatively large.

10.5.3 Silver Contacts

Silver contacts are used extensively in pilot and control circuits, on relays, interlocks, master switches, and so on. They are used also on smaller controllers and on heavy-duty equipment where the contactors remain closed for long periods of time with infrequent operation. Silver contacts are used because they ensure better contact than other, less expensive, material.

Do not replace pure silver contacts and silver-cadmium-oxide contacts until they become too worn to give good service. Their appearance will indicate when they are worn to such an extent that they are no longer serviceable (*Figure 10-46*).

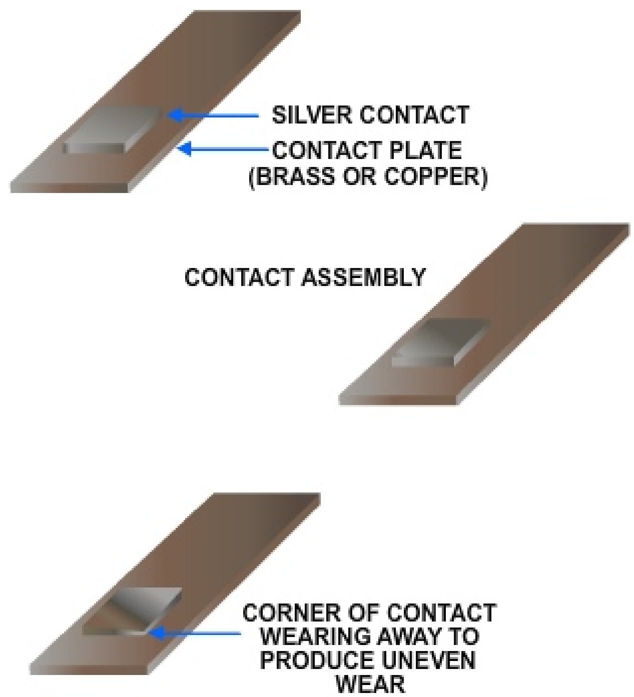

Figure 10-46 — Silver contacts.

10.5.3.1 Electrical and Mechanical Wear

Normally, contacts are subjected to electrical and mechanical wear as they establish and interrupt electric currents. Electrical wear is usually greater than mechanical wear. If a movable contact assembly has no appreciable sliding action on its associated stationary contact assemblies, mechanical wear will be insignificant.

Electrical wear or erosion is caused by arcing when the contacts are establishing and interrupting currents. During arcing, a small part of each contact is melted, vaporized, and blown away from the contact. As a pure silver contact erodes, its arcing surface changes in color, contour, and smoothness. *Figure 10-46* shows typical changes in contour and smoothness.

Normally, a new contact has a uniform silver color, a regular contour, and a smooth arcing surface. As the contact wears, discolorations usually give it a mottled appearance, showing silver, blue, brown, and black. The black color comes from the silver oxide formed during arcing. Silver oxide is beneficial to the operation of the contact.

Electrical erosion may cause uneven wear of the contacts and consequent contour irregularity. Uneven contact wear doesn't necessarily indicate that the contact should be replaced Manufacturers usually provide a total thickness of silver equal to twice the wear allowance associated with the contact to allow for uneven contact wear.

Melting and vaporization of contacts cause pitting of the arcing surface. The pitted surface has high spots which are quite small in area. Tests indicate that such a surface is better than a surface which has not been subjected to arcing because its circuit-making reliability is improved.

A silver-cadmium-oxide contact shows the same wear characteristics as a pure silver contact, except that small black ***granules*** may be evident on the arcing surface. These granules are cadmium oxide, a black material which is scattered throughout the mixture that has formed on the contacts. Silver oxide is formed during arcing, just as with a pure silver contact. The addition of cadmium oxide greatly improves contact operation because it minimizes the tendency of the contacts to weld together, retards heavy transfer of material from one contact to the other, and inhibits erosion.

10.5.3.2 Wear Allowance

A contact is in service as long as its wear allowance, and its associated contacts, exceeds the minimum value specified by the manufacturer. (Usually the minimum value is 0.015 to 0.030 inch). The "wear allowance" of contacts is defined as the total thickness of contact material which may be worn away before the contact of two associated surfaces becomes inadequate to carry rated current.

In an electric-motor contactor, the wear allowance of the power pole contacts is usually related to the closed position of the magnetic operator. The wear allowance of the power pole contacts of a magnetic contactor is the amount of silver that can be worn away without resulting in failure of the contacts to touch when the magnetic operator is at its closed position.

10.5.4 Blowout Coils

Blowout coils seldom wear out or give trouble when used within their rating. However, if they are required to carry excessive currents, the insulation becomes charred and fails, causing flashovers and failure of the device.

Arc shields are constantly subjected to the intense heat of arcing and may eventually burn away, allowing the arc to short-circuit to the metal blowout pole pieces. Therefore, arc shields should be inspected regularly and renewed before they burn through.

Arc barriers provide insulation between electrical circuits and must be replaced if broken or burned to a degree where short circuits are likely to occur. The importance of having clean, tight electrical connections must be emphasized. Where practical, it is a good idea and common practice to solder electrical connections.

Excessive slamming on closing, particularly on AC magnetic-operated devices, will eventually damage the laminated face of the magnetic armature and may damage the shading coil.

Keep magnetic coils dry. Always dry out wet coils before using by baking them in a well-vented oven at not more than 194°F to prevent water from boiling in the insulation. The length of time in the oven depends on the size of the coil. If an oven isn't available, place the unit under a canvas cover roomy enough for hot air to be circulated within. Another alternative is to direct infrared lamps on the windings.

The closed pressure of contacts is an important factor in their ability to carry current. A small contact with proper contact pressure carries more current than a large one with little pressure. Contact springs must be kept in condition. Replace them when they have been damaged or have lost temper by exposure to high temperatures.

Connections should always be clean and tight. Loose connections result in overheated parts that eventually need replacing. Periodic inspections are necessary because temperature changes, vibration, and carelessness may loosen the connections.

Inspect the movable core of a controller for cleanliness. Accumulated dirt causes sluggish mechanical action, which impairs the opening and closing of the contact.

Noise results if the movable and stationary pole pieces don't fit together well when the contactor is closed or when dirt or rust prevents proper closure. The most prominent noise produced in a controller comes from a broken shaded pole, which is a single turn of wire or strap, imbedded in part of the laminated magnetic structure.

Check the cabinet which houses the controller for cleanliness. Make sure the cover fits properly to keep moisture, dirt, and dust from entering. Check for corrosion of all metal parts. *Table 10-6* is a guide for troubleshooting AC controllers.

Table 10-6 — Troubleshooting chart for AC controllers.

Trouble	Probable Cause	Remedy
Failure to close	No power	Check power source. Replace faulty fuses.
	Low voltage	Check power supply voltage.
		Apply correct voltage.
		Check for low power factor.
	Inadequate lead wires	Install lead wires for proper size.
	Loose connections	Tighten all connections.
	Open connections and broken wiring	Locate opens and repair or replace wiring.
		Remove dirt form controller contacts.
	Contacts affected by long idleness or high operating temperature	Clean and adjust.
	Contacts affected by chemical fumes or salty atmosphere	Replace with oil immersed contacts.
	Inadequate contact pressure	Replace contacts and adjust spring tension.
	Open circuit breaker	Check circuit wiring for possible fault.
	Defective coil	Replace with new coil.
	Overload relay contact latched open	Operate hand or electric reset.
Failure to open	Interlock does not open circuit	Check control circuit wiring for possible fault.
		Test and repair.
	Holding circuit grounded	Test and repair or replace grounded parts.
	Misalignment of parts; contacts apparently held together by residual magnetism	Realign and test for free movement by hand.
		Magnetic sticking rarely occurs unless caused by excessive mechanical friction or misalignment of moving parts. Wipe off pole faces to remove accumulation of oil.
	Contacts welded together	See contacts welded together section.

Sluggish Operation	Spring tension too strong	Adjust for proper spring tension.
	Low voltage	Check power supply voltage.
		Apply correct voltage.
	Operating in wrong position	Remount in correct operating position.
	Excessive friction	Realign and test for free movement by hand.
		Clean pivots.
	Rusty parts due to long periods of idleness	Clean or renew rusty parts.
	Sticky moving parts	Wipe off accumulations of oil and dirt. Bearings do not need lubrication.
	Misalignment of parts	Check for proper alignment. Realign to reduce friction and test by hand for free movement.
Erratic Operation (Unwanted openings and closures and failure of overload protection)	Short circuits	Test and repair or replace defective parts.
	Grounds	Test and repair or replace defective parts.
	Sneak currents	These are usually caused by intermittent grounds or short circuits in the machines or wiring circuit. Test and replace faulty parts or wiring.
	Loose connections	Tighten all connections. Eliminate any vibrations or rapid temperature changes that may occur in close proximity to the controller.
Overheating of coils	Shorted coil	Replace coil.
	High ambient temperature or poor ventilation	Relocate controller, use forced ventilation, or replace with suitable type controller.
	High voltage	Check for shorted control resistor.
		Check power supply voltage.
		Apply correct voltage.
	High current	Check current rating of controller.
		Make check for high voltage as above. If necessary, replace with suitable type

		controller.
	Loose connections	Tighten all connections.
		Check for undue vibrations in vicinity.
	Excessive collection of dirt and grime	Clean but do not re-oil parts. If DC covers do not fit tightly, realign and adjust fasteners.
	High humidity, extremely dirty atmosphere, excessive condensation, and rapid temperature changes	Use oil immersed controller or dust-tight enclosures.
	Operating on wrong frequency	Replace with coil of proper frequency rating.
	DC instead of AC coil	Replace with AC coil.
	Too frequent operation	Adjust to apply larger control.
	Open armature gap	Adjust spring tension. Eliminate excessive friction or remove any blocking in gap.
Contacts welded together	Improper application	Check load conditions and replace with a more suitable type controller.
	Excessive temperature	Smooth out contact surface to remove concentrated hot spots.
	Excessive binding of contact tip upon closing	Adjust spring pressure.
	Contacts close without enough spring pressure	Replace worn contacts. Adjust or replace weak springs. Check armature overtravel.
	Sluggish operation	See sluggish operation section.
	Rapid, momentary, touching of contacts without enough pressure	Smooth contacts. Adjust weak springs.
		Where controller has JOG or INCH control button, operate this less rapidly.
Overheating of contacts	Inadequate spring pressure	Replace worn contacts. Adjust or replace weak springs.
	Contacts overloaded	Check load data with controller rating.
		Replace with correct size contactor.
	Dirty contacts	Clean and smooth contacts.
	High humidity, extremely dirty atmosphere, excessive	See overheating of coils

	condensation, and rapid temperature changes	section.
	High ambient temperature or poor ventilation	See overheating of coils section.
	Chronic arcing	Adjust or replace arc chutes. If arcing persists, replace with a more suitable controller.
	Rough contact surfaces	Clean and smooth contacts.
		Check alignment.
	Continuous vibration when contacts are closed	Change or improve mounting of controller.
	Oxidation of contacts	Keep clean, reduce excessive temperature, or use oil immersed contacts.
Arcing at contacts	Arc not confined to proper path	Adjust or renew arc chutes. If arcing persists, replace with more suitable controller.
	Inadequate spring pressure	Replace worn contacts. Adjust or replace weak springs.
	Slow in opening	Remove excessive friction. Adjust spring tension. Renew weak springs. See sluggish operation section.
	Faulty blowout coil or connection	Check and replace coil.
		Tighten connection.
	Excessive inductance in load circuit	Adjust load or replace with more suitable controller.
Pitting or Corroding of contacts	Too little surface contact	Clean contacts and adjust springs.
	Service too severe	Check load conditions and replace with more suitable controller.
	Corrosive atmosphere	Use airtight enclosure. In extreme cases, use oil immersed contacts.
	Continuous vibration when contacts are closed	Change or improve mounting of controller.
	Oxidation of contacts	Keep clean, reduce excessive temperature, or use oil immersed contacts.
Noisy operation (Hum or Chatter)	Poor fit at pole face	Realign and adjust pole faces.
	Broken or defective shading coil	Replace coil.
	Loose coil	Check coil. If correct size,

		shim coil until tight.
	Worn parts	Replace with new parts.
Vibration after repairs	Misalignment of parts	Realign parts and test by hand for free movement.
	Loose mounting	Tighten mounting bolts.
	Incorrect coil	Replace with proper coil.
	Too much play in moving parts	Shim parts for proper tightness, and clearance.

Test your Knowledge (Select the Correct Response)

4. What temperature can not be exceeded when drying magnetic coils in an oven?

   A. 155°F
   B. 194°F
   C. 216°F
   D. 267°F

11.0.0 MOTOR BRANCH CIRCUITS

A motor-branch circuit is a wiring system extending beyond the final automatic overload protective device. Thermal cutouts or motor overload devices are not branch-circuit protection. These are supplementary overcurrent protection. The branch circuit represents the last step in the transfer of power from the service or source of energy to utilization devices.

11.1.0 Motor Branch Circuit Short Circuit and Ground Fault Protection (NEC® 430, PART IV)

The code requires that branch-circuit protection for motor circuits protect the circuit conductors, the control apparatus, and the motor itself against overcurrent caused by short circuits or grounds (sections 430.51 through 430.58). Fuses or circuit breakers are the most common protectors used as branch-circuit protective devices. These protective devices must be able to carry the starting current of the motor. To carry this current, they may be rated 300 or 400 percent of the running current of the motor, depending on the size and type of motor.

Motor controllers provide motor protection against all ordinary overloads but are not intended to open during short circuits.

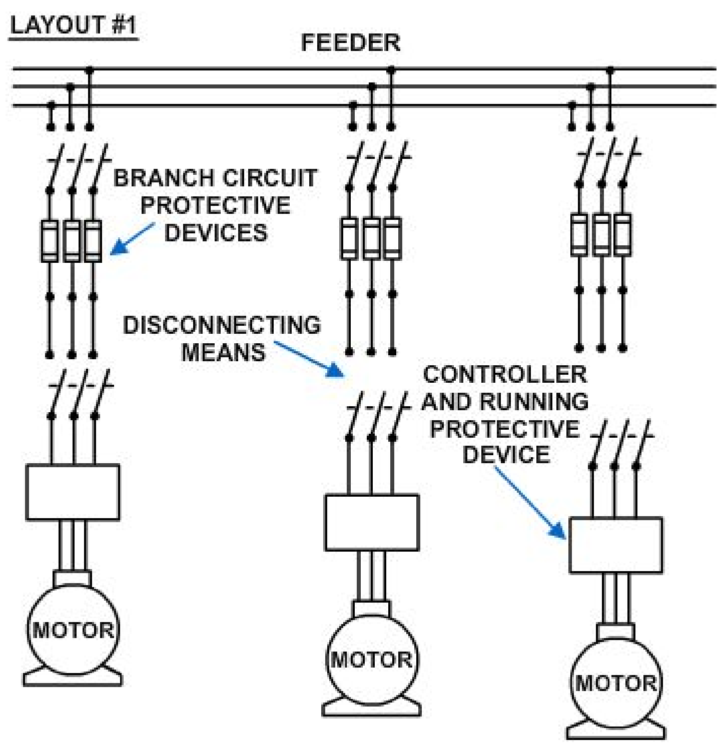

Figure 10-47 — Branch circuit layout #1.

Motor-branch circuits are commonly laid out in a number of ways. *Figures 10-47 through 10-49* show three motor-branch circuits and how the circuit protection is used in various types of layouts.

As mentioned before, the motor-branch-circuit short-circuit and ground-fault protective device must be capable of carrying the starting current of the motor. For motor circuits of 600 volts or less, a protective device is permitted that has a rating or setting that does not exceed the values given in Table 430.52 of the code. Refer to *Table 10-7*. An instantaneous-trip circuit breaker (without time delay) may be used ONLY if it is adjustable and is part of a listed combination controller, having motor overload and also short-circuit and ground-fault protection in each conductor.

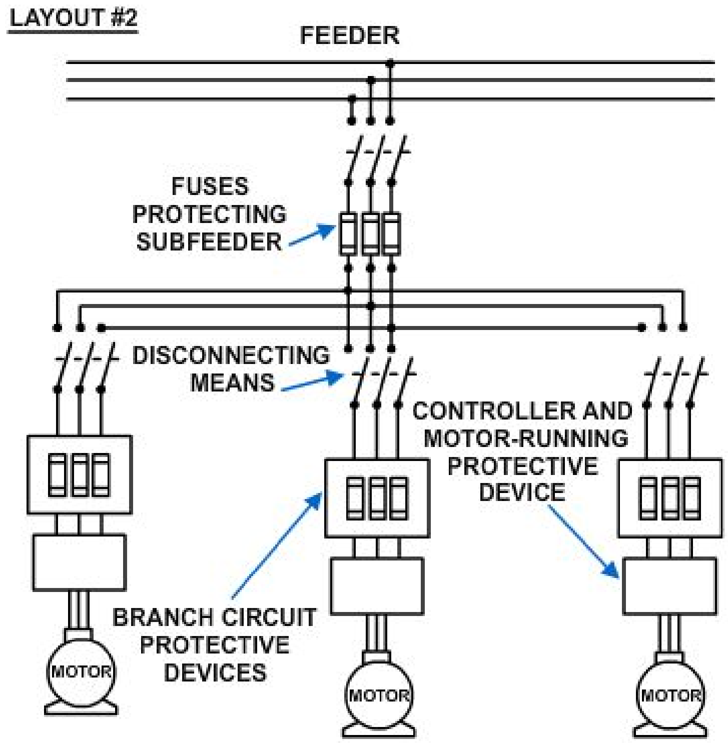

Figure 10-48 — Branch circuit layout #2.

When values for branch-circuit protective devices, as shown in the NEC®, Table 430.52 and *10-7*, do not correspond to the standard sizes or ratings of fuses, nonadjustable circuit breakers, or thermal protective devices, you may use the next higher size, rating, or setting.

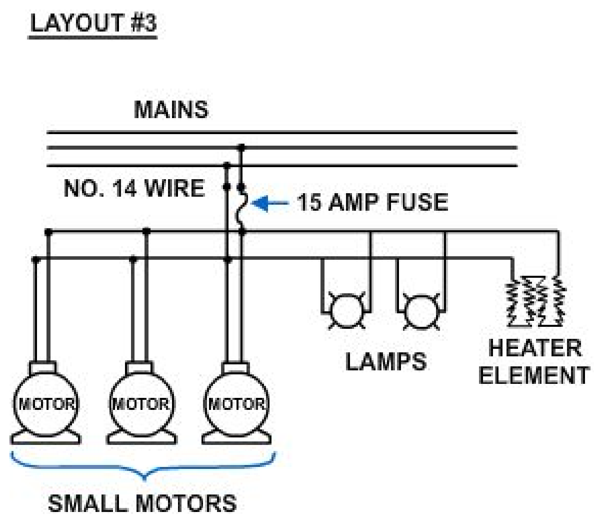

Figure 10-49 — Branch circuit layout #3.

The National Electrical Manufacturer's Association (NEMA) has adopted a standard of identifying code letters that may be marked by the manufacturers on motor nameplates to indicate the motor kilovoltampere input with a locked rotor. These code letters, with their classification, are given in the NEC®, Table 430.7(B) and *Table 10-7*. In determining the starting current to use for circuit calculations, use values from Table 430.7(B) or *Table 10-7*. Exceptions to the above are given in Table 430.52.

When maximum branch-circuit protective device ratings are shown in the manufacturer's overload-relay table for use with a motor controller or are marked on equipment, you may not exceed them even if higher values are indicated in Table 430.52 of the NEC®; however, you may use branch-circuit protective devices of smaller sizes. If you use a branch-circuit device that is smaller, you need to be sure that it has sufficient time delay to permit the motor-starting current to flow without opening the circuit.

Table 10-7 — Maximum rating or setting of motor branch circuit short – circuit and ground fault protective devices.

Percentage of Full Load Current				
Type of Motor	**Nontime Delay Fuse** [1]	**Dual Element (Time Delay) Fuse** [1]	**Instantaneous Trip Breaker**	**Inverse Time Breaker** [2]
Single phase motors	300	175	800	250
AC polyphase motors other than wound rotor Squirrel cage – other than Design B energy efficient	300	175	800	250
Design B – energy efficient	300	175	1100	250
Synchronous [3]	300	175	800	250
Wound rotor	150	150	800	150
DC (constant voltage)	150	150	250	150

Note: For certain exceptions to the values specified, see 430.54.

1: The values in the Nontime Delay Fuse column apply to Time Delay Class CC fuses.

2: The values given in the last column also cover the ratings of nonadjustable inverse time types of circuit breakers that may be modified as in 430.52(C), Exception No. 1 and No. 2.

3: Synchronous motors of the low torque, low speed type (usually 450 rpm or lower), such as are used to drive reciprocating compressors, pumps, and so forth, that start unloaded, do not require a fuse rating or circuit breaker setting in excess of 200 percent of full load current.

Often it is not convenient or practicable to locate the branch-circuit short-circuit and ground-fault protective device directly at the point where the branch-circuit wires are connected to the mains. In such cases, the size of the branch-circuit wires between the feeder and the protective device must be the same as the mains unless the length of these wires is 25 feet (7.6 meters) or less. When the length of the branch circuit wires is not greater than 25 feet, the NEC® rules allow the size of these wires to be such that they have an ampacity not less than one third of the ampacity of the mains if they are protected against physical damage.

Figure 10-50 gives you an example of branch-circuit conductor sizing, using the figures found in the NEC® Tables 430.52 and 430.7(B) or *Table 10-8*.

Table 10-8 — Locked rotor indicating code letters.

Code Letter	Kilovolt – Amperes per Horsepower with Locked Rotor
A	0 – 3.14
B	3.15 – 3.54
C	3.55 – 3.99
D	4.0 – 4.49
E	4.5 – 4.99
F	5.0 – 5.59
G	5.6 – 6.29
H	6.3 – 7.09
J	7.1 – 7.99
K	8.0 – 8.99
L	9.0 – 9.99
M	10.0 – 11.19
N	11.2 – 12.49
P	12.5 – 13.99
R	14.0 – 15.99
S	16.0 – 17.99
T	18.0 – 19.99
U	20.0 – 22.39
V	22.4 and up

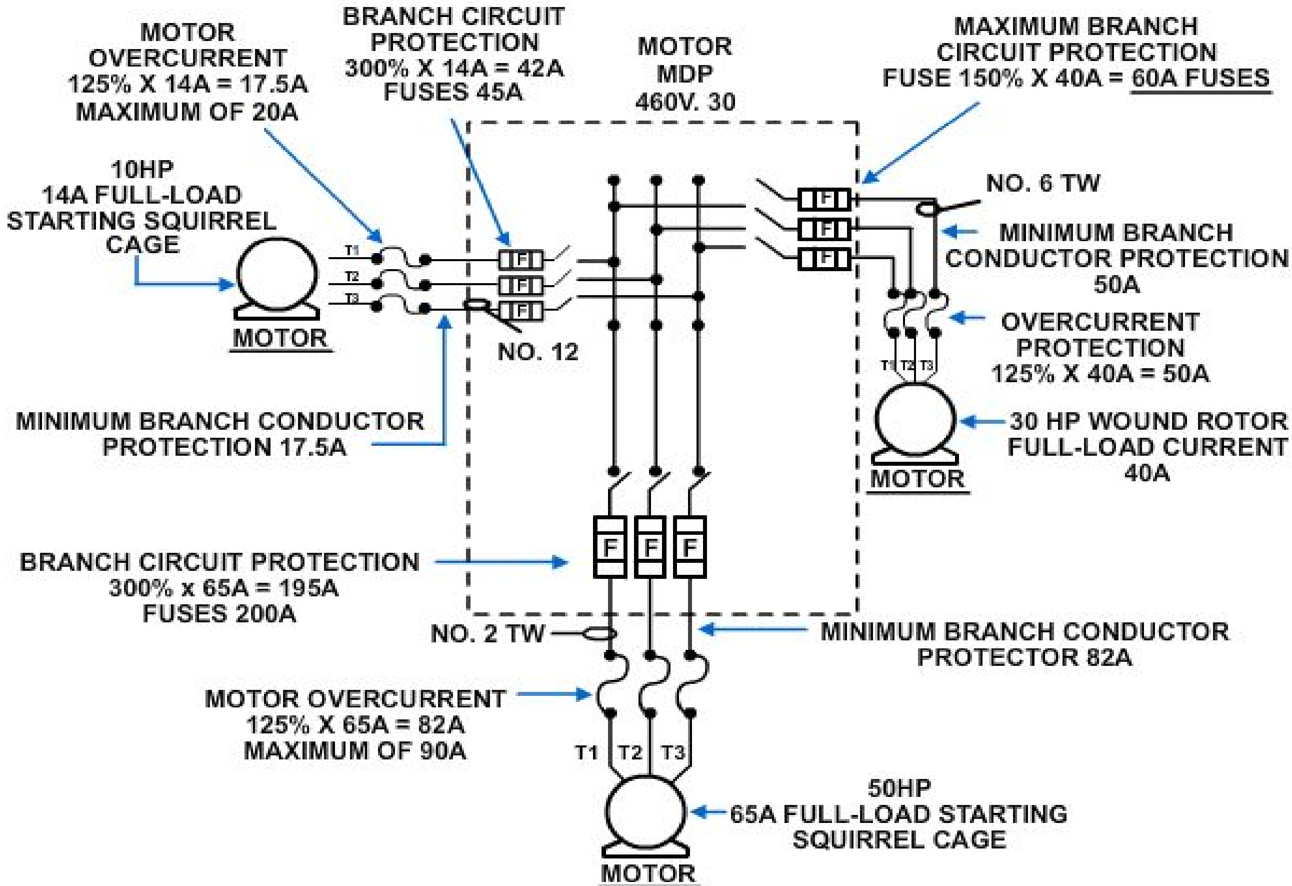

Figure 10-50 — Branch circuit conductor sizing.

11.2.0 Several Motors or Loads on One Branch Circuit

You may use a single-branch circuit to supply two or more motors or one or more motors and other loads according to section 430.52 of the code. Some examples are as follows:

1. Several motors, each not exceeding 1 horsepower, are permitted on a branch circuit protected at not more than 20 amperes at 120 volts or less, or at 600 volts or less protected at not over 15 amperes if all of the following conditions can be met:
   - The rating of the branch circuit short circuit and ground fault protective device marked on the controllers is not exceeded.
   - The full load rating of each motor does not exceed 6 amperes.
   - Individual overload protection conforms with section 430.32 of NEC®.
2. You may connect two or more motors of any rating to a branch circuit that is protected by a short circuit and ground fault protective device selected according to the maximum rating or setting of the smallest motor.
3. You may connect two or more motors of any rating and other loads to one branch circuit if the overload devices and controllers are approved for group installation and if the branch circuit fuses or circuit breaker rating is according to section 430.52 of the NEC®.

11.3.0 Motor Feeder short Circuit and Ground Fault Protection (NEC® 430, Part V)

Overcurrent protection for a feeder to several motors must have a rating or setting not greater than the largest rating or setting of the branch-circuit protective device for any motor of the group plus the sum of the full-load currents of the other motors supplied by the feeder.

Protection for a feeder to both motor loads and a lighting and/or appliance load must be rated on the basis of both of these loads. The rating or setting of the overcurrent device must be sufficient to carry the lighting and/or appliance load plus the rating or setting of the motor branch-circuit protective device.

11.4.0 Motor Controllers(NEC® 430, Part VII)

A controller is a device that starts and stops a motor by making and breaking the power current flow to the motor windings. A push-button station, a limit switch, or any other pilot-control device is not considered a controller. Each motor is required to have a suitable controller that can start and stop the motor and perform any other control functions required. A controller must be capable of interrupting the current of the motor under locked-rotor conditions (NEC® 430.82.B) and must have a horsepower rating not lower than the rating of the motor, except as permitted (NEC® 430.83.A.1).

Branch-circuit fuses or circuit breakers are considered to be acceptable controller devices under the following conditions:

- For a stationary motor rated at one eighth horsepower or less that is normally left running and is constructed so that it cannot be damaged by overload or failure to start.
- For a portable motor rated at one third horsepower or less, the controller may be an attachment plug and receptacle.

The controller may be a general-use switch having an ampere rating at least twice the full-load current rating of a stationary motor rated at 2 horsepower or less and 300 volts or less.

A branch-circuit breaker, rated in amperes only, may be used as a controller. When this circuit breaker is also used for short-circuit and ground-fault and/or overload protection,

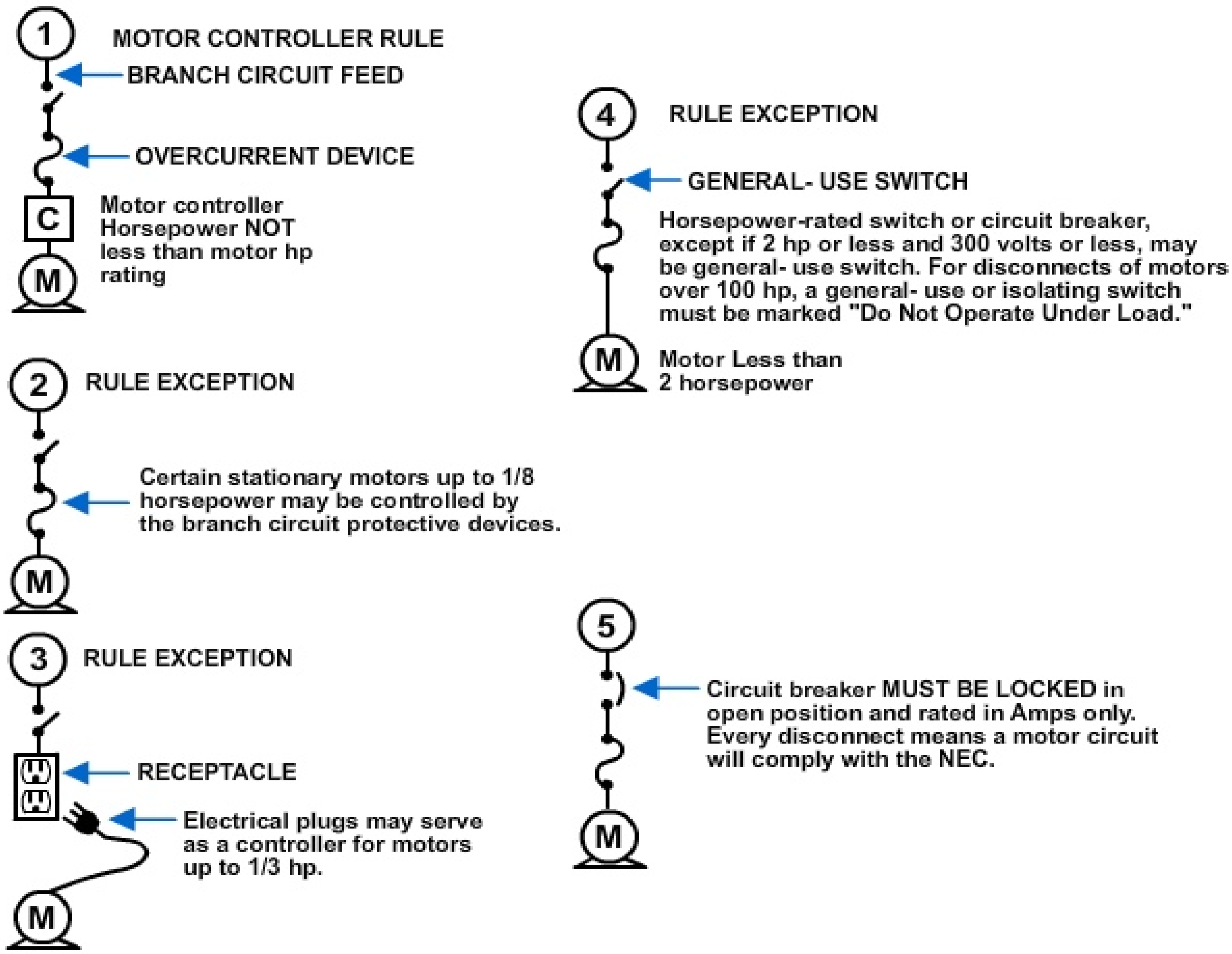

Figure 10-51 — Motor controllers basic rules and exceptions.

it will conform to the appropriate provisions of the NEC® governing the type of protection afforded. *Figure 10-51* will help you to understand controller definitions.

- Where a number of motors drive several parts of a single machine or a piece of apparatus, such as metal working and woodworking machines, cranes, hoists, and similar apparatus
- Where a group of motors is under the protection of one overcurrent device, as permitted in NEC® section 430.53(A)
- Where a group of motors is located in a single room within sight of the controller location. A distance of more than 50 feet (15.3 meters) is considered equivalent to being out of sight

11.5.0 Disconnecting Means, Motors, and Controllers (NEC® 430, Part VIII)

Each motor, along with its controller or magnetic starter, must have some form of approved manual disconnecting means, rated in horsepower, or a circuit breaker. This disconnecting means, when in the OPEN position, must disconnect both the controller and the motor from all ungrounded supply conductors. It must plainly indicate whether it is in the OPEN or the CLOSED position and may be in the same housing as the controller.

For motor circuits of 600 volts or less, the controller manual disconnecting means must be within sight and not more than 50 feet away from the location of the motor controller. There are two exceptions in the code rule requiring a disconnect switch to be in sight from the controller:

1. For motor circuits over 600 volts, the controller disconnecting means is permitted to be out of sight from the controller, provided the controller is marked with a warning label giving the location and identification of the disconnecting means, and the disconnecting means can be locked in the OPEN position.
2. On complex machinery using a number of motors, a single common disconnect for a number of controllers may be used. This disconnect may be out of sight from one or all of the controllers if it is adjacent to them.

The code also stipulates that a manual disconnecting means must be within sight and not more than 50 feet from the motor location and the driven machinery. The exception to this rule is that the disconnecting means may be out of sight if it can be locked in the OPEN position. See *Figure 10-51* for other exceptions and basic rules.

The NEC® rules allow a single switch to be the disconnecting means of a group of motors under 600 volts. Also, manual switches or circuit breakers rated in horsepower can be used as a disconnecting means and the controller for many motor circuits.

11.6.0 Motor and Branch Circuit Overload Protection (NEC® 430, Part III)

Each continuous-duty motor must be protected against excessive overloads under running conditions by some approved protective device. This protective device, except for motors rated at more than 600 volts, may consist of fuses, circuit breakers, or specific overload devices. Overload protection will protect the branch circuit, the motor, and the motor control apparatus against excessive heating caused by motor overloads. Overload protection does not include faults caused by shorts or grounds.

Each continuous-duty motor rated at more than 1 horsepower must be protected against overload by one of the following means:

1. A separate overload device that is responsive to motor current. This device is required to be rated or selected to trip at no more than the following percentage of the motor nameplate full-load current rating (See *Table 10-9*):

Table 10-9 — Percentage of motor full load current rating.

MOTOR	PERCENT
Motors with a marked service factor not less than 1.15	125
Motor with a marked temperature rise not over 40°C.	125
All other motors.	115

For a multispeed motor, each winding connection must be considered separately. Modification of these values is permitted. See section 430.34.

2. A thermal, protector, integral with the motor, is approved for use with the motor that it protects on the basis that it will prevent dangerous overheating of the motor caused by overload and failure to start. The percentages of motor full-load trip current are given in section 430.32 (A.2).
3. A protective device, integral with the motor that will protect the motor against damage caused by failure to start is permitted if the motor is part of an approved assembly that does not normally subject the motor to overloads.

Non-portable, automatically started motors of 1 horsepower or less must be protected against running overload current in the same manner as motors of over 1 horsepower, as noted in section 430.32 (C).

Motors of 1 horsepower or less that are manually started, within sight of the controller location, and not permanently installed are considered protected by the branch-circuit protective device.

11.7.0 Fuses for Motor Overload Protection (NEC® 430, Part III)

If regular fuses are used for the overload protection of a motor, they must be shunted during the starting period since the starting current would blow a regular fuse having a rating of 125 percent of the motor full-load current. Many DC-motor and some wound-rotor-induction-motor installations are exceptions to this rule. Aside from these exceptions, it is not common practice to use regular fuses for the overload protection of motors. Time-delay fuses sometimes can be used satisfactorily for overload protection since the starting current will not blow those rated at 125 percent of the motor full-load current. In fact, the manufacturers of these fuses recommend fuses of a smaller rating than 125 percent of the motor full-load current for ordinary service.

Even time-delay fuses may not be satisfactory unless they are shunted during the starting period because the 125 percent value cannot be exceeded

11.8.0 Overload Devices Other Than Fuses (NEC® 430, Part III)

The NEC® (Table 430.37) or *Table 10-10* indicate the number and location of overload protective devices, such as trip coils, relays, or thermal cutouts. These overload devices are usually part of a magnetic motor controller. Typical devices include thermal bimetallic heaters, resistance or induction heaters, and magnetic relays with adjustable interrupting and/or time-delay settings. Overload devices can have a manual or automatic reset.

Table 10-10 — Overload Units.

Kind of Motor	Supply System	Number and Location of Overload Units, Such as Trip Coils or Relays
1 –phase AC or DC	2 – wire, 1 – phase AC or DC ungrounded	1 in either conductor
1 –phase AC or DC	2 – wire, 1 – phase AC or DC, one conductor grounded	1 in ungrounded conductor
1 –phase AC or DC	3 – wire, 1 – phase AC or DC, grounded neutral	1 in either ungrounded conductor
1 –phase AC	Any 3 – phase	1 in ungrounded conductor
2 –phase AC	3 – wire, 2 – phase AC, ungrounded	2, one in each phase
2 –phase AC	3 – wire, 2 – phase AC, one conductor grounded	2 in ungrounded conductors
2 –phase AC	4 – wire, 2 – phase AC, grounded or ungrounded	2, one per phase in ungrounded conductors
2 –phase AC	Grounded neutral or 5 – wire, 2 – phase AC, ungrounded	2, one per phase in any ungrounded phase wire
3 –phase AC	Any 3 - phase	3, one in each phase*
* Exception: An overload unit in each phase shall not be required where overload protection is provided by other approved means.		

11.9.0 Thermally Protected Motors (NEC® 430, Part III)

Thermally protected motors are equipped with built-in overload protection mounted directly inside the motor housing or in the junction box on the side. These devices are thermally operated and protected against dangerous overheating caused by overload, failure to start, and high temperatures. The built-in protector usually consists of a bimetallic element connected in series with the motor windings. When heated over a certain temperature, the contacts will open, thereby opening the motor circuit. On some types, the contacts automatically close when cooled; on others a reset button must be operated manually to restart the motor.

11.10.0 Protection of Live Parts – All Voltages (NEC® 430, Part XII)

The NEC® requires that live parts be protected in a manner judged adequate to the hazard involved. The following rules apply:

1. Exposed live parts of motors and controllers operating at 50 volts or more between terminals must be guarded against accidental contact by enclosure or by location as follows:

    a. By installation in a room or enclosure accessible only to qualified persons

b. By installation on a suitable balcony, gallery. or platform so elevated and arranged as to exclude unqualified persons

c. By elevation 8 feet (2.5 meters) or more over the floor

2. Exception: Live parts of motors operating at more than 50 volts between terminals shall not require additional guarding for stationary motors that have commutators, collectors, and brush rigging located inside of motor – end brackets and not conductively connected to supply circuits operating at more than 150 volts to ground.

12.0.0 EQUIPMENT GROUNDING

An equipment ground refers to connecting the noncurrent-carrying metal parts of the wiring system or equipment to ground. Grounding is done so that the metal parts with which a person might come into contact are always at or near ground potential. With this condition, there is less danger that a person touching the equipment will receive a shock.

12.1.0 Equipment Fastened in Place or Connected by Permanent Wiring Methods (Fixed) (NEC 250, Part VII Section 250.134)

The word fixed, as applied to equipment requiring grounding, now applies to equipment fastened in place or connected by permanent wiring, as shown in *Figure 10-52*. That usage is consistently followed in other code sections also.

The code requires that all exposed non-current carrying metal parts, such as equipment enclosures, boxes, and cabinets, must be grounded. Equipment must be grounded where supplied by metallic wiring methods, in hazardous locations, where it comes into contact with metal building parts; in wet, non-isolated locations, within reach of a person who is in contact with a grounded surface, and where operated at over 150 volts.

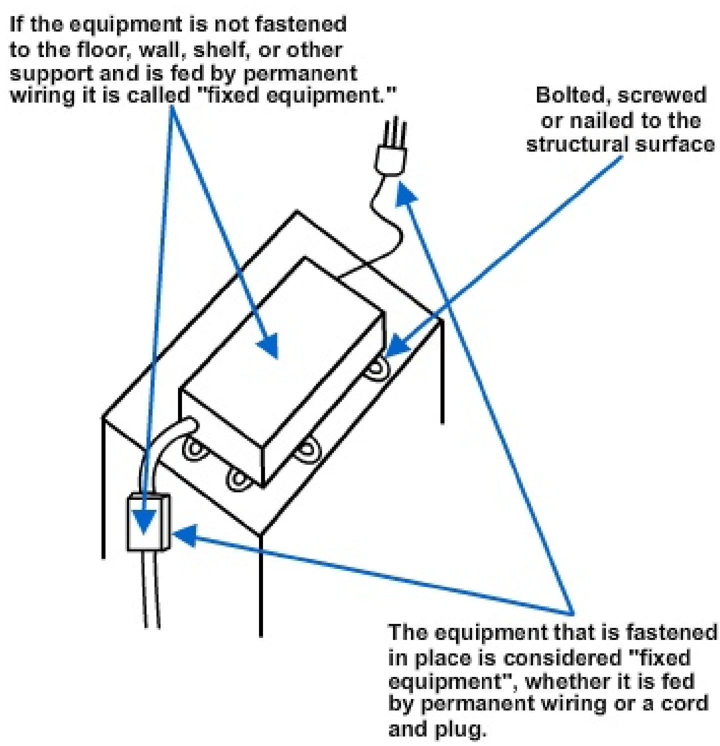

Figure 10-52 — Definition of fixed equipment.

12.2.0 Methods of Equipment Grounding (NEC® 250, Part VII)

Section 250.130 sets forth basic rules on the effectiveness of grounding. This rule defines the phrase effective grounding path and establishes mandatory requirements on the quality and quantity of conditions in any and every grounding circuit. The three required characteristics of grounding paths are very important for safety:

1. Every grounding path is permanent and continuous. The installer can ensure these conditions by proper mounting, coupling, and terminating of the conductor or raceway intended to serve as the grounding conductor. The installation must be made so that it can be inspected by an electrical inspector, the design engineer, or any other authority concerned. A continuity test with a meter, a light, or a bell will assure that the path is "continuous."
2. Every grounding conductor has the capacity to conduct safely any fault current likely to be imposed on it. Refer back to the section of the code that specifically establishes a minimum required size of grounding conductor.
3. The path to ground has sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit protective devices in the circuit.

12.3.0 Use of Grounded Circuit Conductor for Grounding Equipment (NEC® Section 250.142)

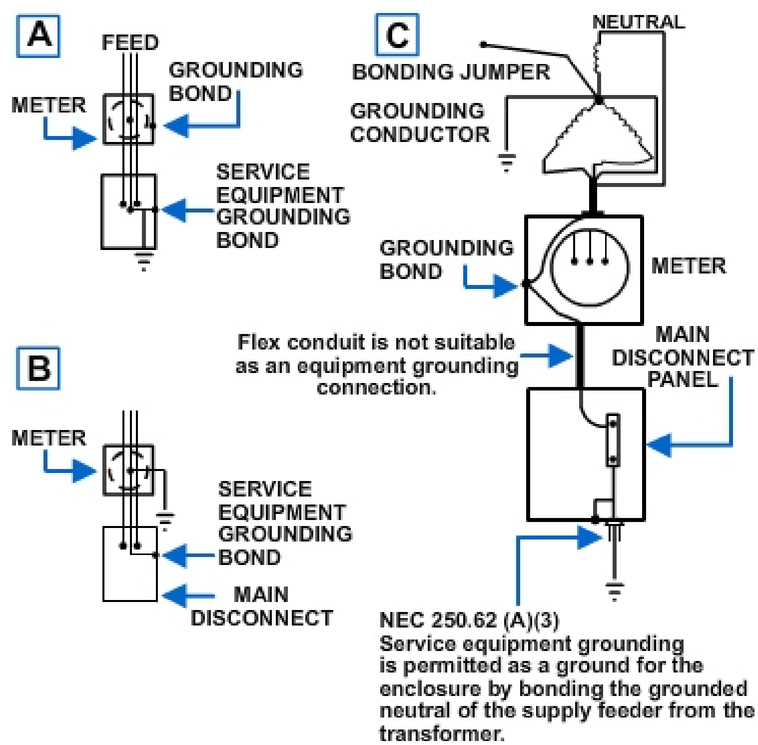

Figure 10-53 — Equipment housing ground connections (line side).

Part (A) of NEC®, section 250.142, permits the grounded conductor (usually the neutral) of a circuit to be used to ground metal equipment enclosures and raceways on the supply side of the service disconnect. *Figure 10-53* shows such applications. At (A), the grounded service neutral is bonded to the meter housing by means of the bonded neutral terminal lug in the socket. The housing is thereby grounded by this connection to the grounded neutral, which itself is grounded at the service equipment as well as at the utility transformer secondary supplying the service. At (B), the service equipment enclosure is grounded by connection (bonding) to the grounded neutral, which itself is grounded at the meter socket and at the supply transformer. These same types of grounding connections may be made for cabinets, auxiliary gutters, and other enclosures on the line side of the service entrance disconnect means, including the enclosure for the service disconnect. At (C), equipment is grounded to the neutral on the line (supply) side of the first disconnect fed from a step-down transformer (a separately derived system).

Aside from the permission given in the five exceptions to the rule of part (B) of section 250.142, the code prohibits connection between a grounded neutral and equipment enclosures on the load side of the service. So bonding between any system grounded conductor, neutral or phase leg, and equipment enclosures is prohibited on the load side of the service (*Figure 10-54*). The use of a neutral-to-ground panelboard or other equipment (other than specified in the exceptions) on the load side of service equipment would be extremely hazardous if the neutral became loosened or disconnected. In such cases, any line-to-neutral load would energize all metal components connected to the neutral, creating a dangerous potential for electrocution. Hence such a practice is prohibited. This prohibition is fully described in *Figure 10-55*.

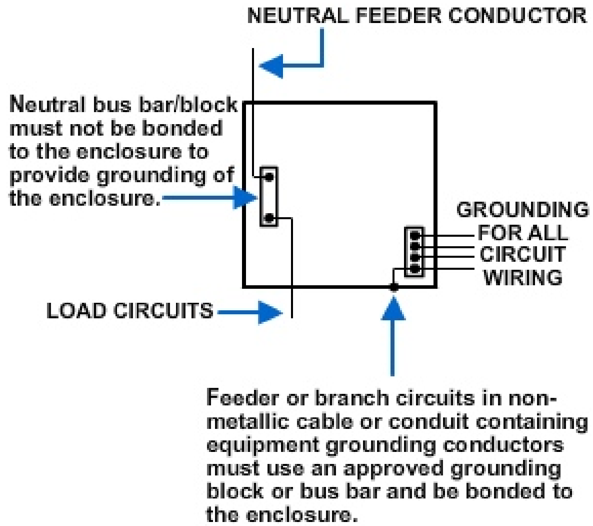

Figure 10-54 — Equipment housing ground connections (load side).

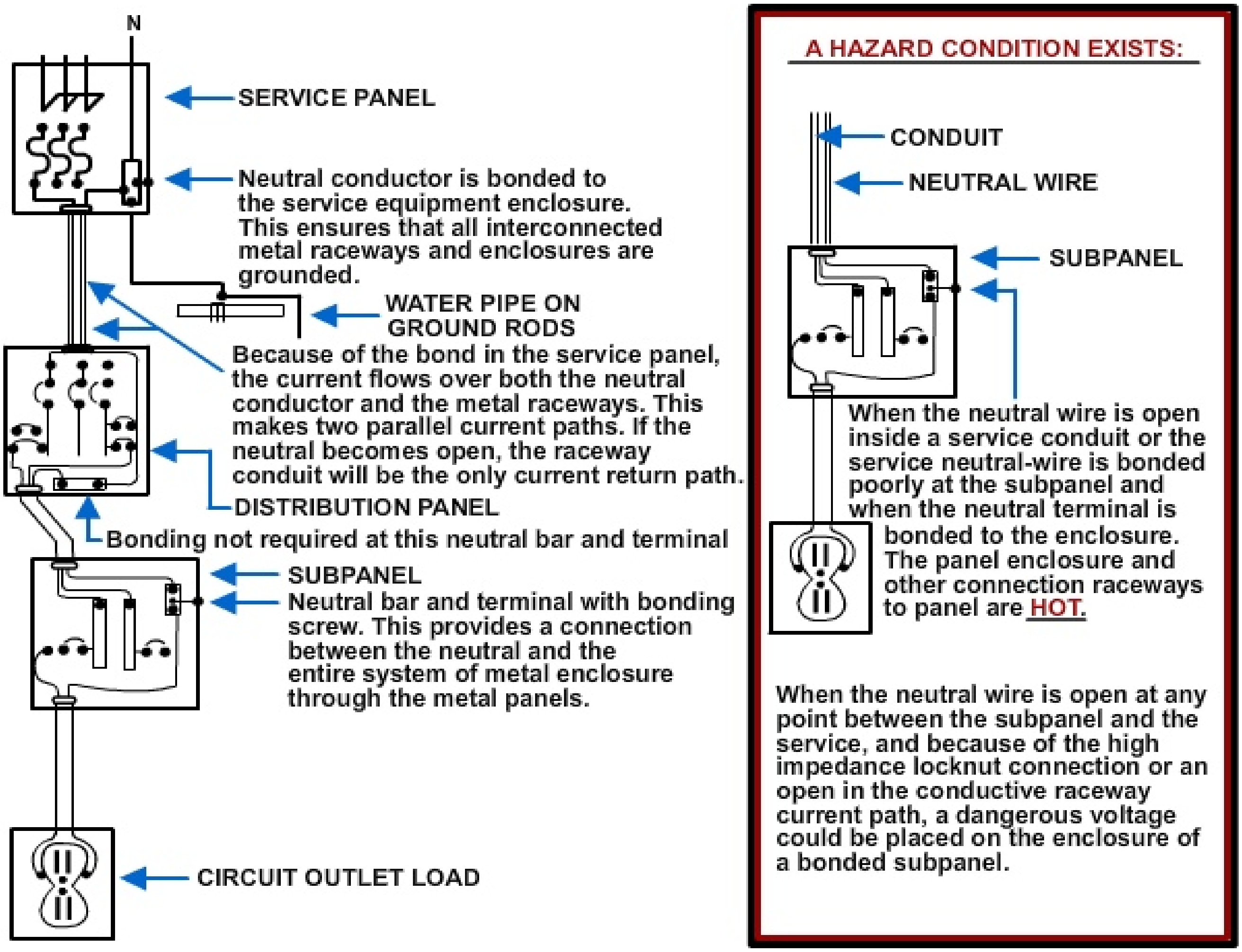

Figure 10-55 — Subpanel bonding hazards.

Although this rule of the code prohibits neutral bonding on the load side of the service, sections 250.50 (A) and 250.53 (B) clearly require such bonding at the service entrance.

The circuit conductors used for equipment grounding must be within the same raceway, cable, or cord or run with the circuit conductors. The conductors may be bare or insulated. Insulated conductors must have a continuous outer finish of green or green with one or more yellow stripes.

When the equipment grounding is to be accomplished by the protective device of the circuit conductors, it must be rigid metal conduit, intermediate metal conduit, electrical metallic tubing, flexible metal conduit, type AC cable, or the combined metallic sheath and grounding conductors of type MC cable.

Flexible metal conduit is permitted as an equipment grounding conductor under the following conditions: the length of the flex does not exceed 6 feet, the circuit conductors within are rated at 20 amperes or less, and the connectors are fittings listed for grounding. If the 6 feet of flex is exceeded, a bonding jumper wire, run inside the flex, must be used.

13.0.0 CONTROL CIRCUITS

The subject of electric control circuits is quite broad. The following section will cover a few of the basic control circuit requirements and controls. For more information, refer to special books devoted to this important phase of motor circuitry. Two such books are *Electric Motor Control* by Walter N. Alerich and *Electric Motor Repair* by Robert Rosenberg and August Hand. These textbooks provide an excellent insight on how to understand, select, and design control circuits.

13.1.0 Control Circuits General (NEC® 430 Part VI and Article 725)

A control circuit is a circuit that exercises control over one or more other circuits. These other circuits controlled by the control circuit may themselves be control circuits, or they may be “load” circuits that carry utilization current to a lighting, heating, power, or signal device. *Figure 10-56* clarifies the distinction between control circuits and load circuits.

The elements of a control circuit include all the equipment and devices concerned with the function of the circuit: conductors, raceway and contactor-operating coil, source of energy supply to the circuit, overcurrent protective devices, and all switching devices that govern energization of the operating coil.

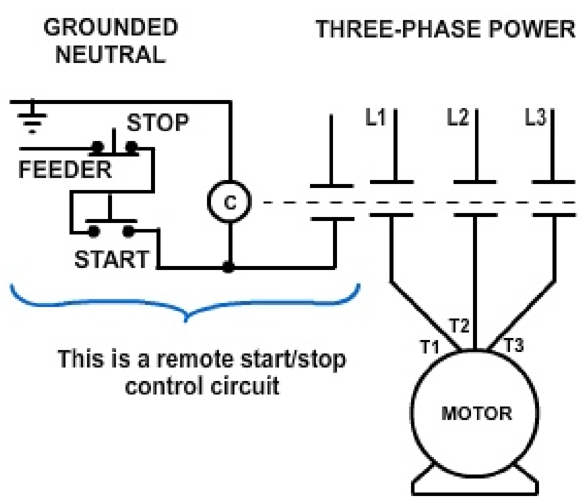

Figure 10-56 — Defining a control circuit.

Typical control circuits include the operating-coil circuit of magnetic motor starters, magnetic contactors, and relays. Control circuits include wiring between solid-state control devices as well as between magnetically actuated components. Low-voltage relay switching of lighting and power loads also are classified as remote-control wiring.

Control circuits are divided into three classes:

- Class 1 system may operate at any voltage that does not exceed 600 volts. They are, in many cases, merely extensions of light and power systems, and, with a few exceptions, are subject to all the installation rules for light and power systems.
- Class 2 and Class 3 systems are those in which the current is limited to certain specified low values. This limiting may be accomplished by fuses or circuit breakers, by transformers that deliver only very small currents, or by other voltages at which the system operates from 5 milliamps or less. All Class 2 and Class 3 circuits must have a power source with the power limiting characteristics described in NEC®, Table 11 (A) and 11 (B) or *Tables 10-11* and *10-12*. These requirements are in addition to the overcurrent device.

Table 10-11 — Class A and Class B AC power source limitations.

Power Source		Inherently Limited Power Source (Overcurrent Protection Not Required)				Not Inherently Limited Power Source (Overcurrent Protection Required)			
		Class 2			Class 3	Class 2		Class 3	
Source voltage V_{max} *(volts) (1)*		0 through 20*	Over 20 and through 30*	Over 30 and through 150	Over 30 and through 100	0 through 20*	Over 20 and through 30*	Over 30 and through 100	Over 100 and through 150
Power limitations VA_{max} *(volt-amperes) (1)*		-	-	-	-	250 (3)	250	250	N/A
Current limitations I_{max} *(amperes) (1)*		8.0	8.0	0.005	150/V_{max}	1000/V_{max}	1000/V_{max}	1000/V_{max}	1.0
Maximum overcurrent protection (amperes)		-	-	-	-	5.0	100/V_{max}	100/V_{max}	1.0
Power Source maximum nameplate rating	VA (volt-amperes)	5.0 x V_{max}	100	0.005 x V_{max}	100	5.0 x V_{max}	100	100	100
	Current (amperes)	5.0	100/V_{max}	0.005	100/V_{max}	5.0	100/V_{max}	100/V_{max}	100/V_{max}

* Voltage ranges shown are for sinusoidal AC in indoor locations or where wet contact is not likely to occur. For nonsinusoidal or wet contact conditions, see Note 2.

(1) V_{max} , I_{max} ,and VA_{max} are determined with the current limiting impedance in the circuit (not bypassed) as follows:

V_{max} : Maximum output voltage regardless of load with rated input applied.

I_{max} : Maximum output current under any noncapacitive load, including short circuit, and with overcurrent protection bypassed if used. Where a transformer limits the output current, I_{max} limits apply after 1 minute of operation. Where current limiting impedance, listed for the purpose, or as part of a listed product is used in combination with a non power limited transformer or a stored energy source, e.g., storage battery, to limit the output current, I_{max} limits apply after 5 seconds.

VA_{max} *:* Maximum volt-ampere output after 1 minute of operation regardless of load and overcurrent protection bypassed if used.

(2) For nonsinusoidal AC, VA_{max} shall not be greater than 42.4 volts peak. Where wet contact (immersion not included) is likely to occur, Class 3 wiring methods shall be used or VA_{max} shall not be greater than 15 volts for sinusoidal AC and 21.2 volts peak for nonsinusoidal AC.

(3) If the power source is a transformer, VA_{max} is 350 or less when VA_{max} is 15 or less.

Table 10-12 — Class A and Class 3 DC power source limitiations.

Power Source		Inherently Limited Power Source (Overcurrent Protection Not Required)					Not Inherently Limited Power Source (Overcurrent Protection Required)			
		Class 2				Class 3	Class 2		Class 3	
Source voltage V_{max} *(volts) (1)*		0 through 20*	Over 20 and through 30*	Over 30 and through 60*	Over 60 and through 150	Over 60 and through 100	0 through 20*	Over 20 and through 60*	Over 60 and through 100	Over 100 and through 150
Power limitations VA_{max} *(volt-amperes) (1)*		-	-	-	-	-	250 (3)	250	250	N/A
Current limitations I_{max} *(amperes) (1)*		8.0	8.0	150/V_{max}	0.005	150/V_{max}	1000/V_{max}	1000/V_{max}	1000/V_{max}	1.0
Maximum overcurrent protection (amperes)		-	-	-	-	-	5.0	100/V_{max}	100/V_{max}	1.0
Power Source max name plate rating	VA (volt-amperes)	5.0 x V_{max}	100	100	0.005 x V_{max}	100	5.0 x V_{max}	100	100	100
	Current (amperes)	5.0	100/V_{max}	100/V_{max}	0.005	100/V_{max}	5.0	100/V_{max}	100/V_{max}	100/V_{max}

* Voltage ranges shown are for sinusoidal AC in indoor locations or where wet contact is not likely to occur. For nonsinusoidal or wet contact conditions, see Note 4.

(1) V_{max}, I_{max}, and VA_{max} are determined with the current limiting impedance in the circuit (not bypassed) as follows:

V_{max} : Maximum output voltage regardless of load with rated input applied.

I_{max} : Maximum output current under any noncapacitive load, including short circuit, and with overcurrent protection bypassed if used. Where a transformer limits the output current, I_{max} limits apply after 1 minute of operation. Where current limiting impedance, listed for the purpose, or as part of a listed product is used in combination with a non power limited transformer or a stored energy source, e.g., storage battery, to limit the output current, I_{max} limits apply after 5 seconds.

VA_{max} : Maximum volt-ampere output after 1 minute of operation regardless of load and overcurrent protection bypassed if used.

(2) For nonsinusoidal AC, VA_{max} shall not be greater than 42.4 volts peak. Where wet contact (immersion not included) is likely to occur, Class 3 wiring methods shall be used or VA_{max} shall not be greater than 15 volts for sinusoidal AC and 21.2 volts peak for nonsinusoidal AC.

(3) If the power source is a transformer, VA_{max} is 350 or less when VA_{max} is 15 or less.

(4) For DC interrupted at a rate of 10 to 200 Hz, VA_{max} shall not be greater than 24.8 volts peak. Where wet contact (immersion not included) is likely to occur, Class 3 wiring methods shall be used or VA_{max} shall not be greater than 30 volts for continuous DC; 12.4 volts peak for DC that is interrupted at a rate of 10 to 200 Hz.

Conductors for any Class 1 control circuit must be protected against overcurrent. Number 14 and larger wires must generally be protected at their ampacities. Number 18 and Number 16 control wires must always be protected at 7 and 10 amperes, respectively.

Any number and type of Class 1 circuit conductors may be installed in the same conduit, raceway, box, or other enclosure if all conductors are insulated for the maximum voltage at which any of the conductors operates and the wires are functionally associated with each other.

Class 1 circuit wires may be run in raceways by themselves according to the NEC®. The number of conductors in a conduit must be determined from Tables 1 through 5 in Chapter 9 of the NEC®).

13.2.0 Control Symbols

In *Figures 10-57* and *10-58*, you see the electrical symbols that conform to the standards established by the National Electrical Manufacturer's Association (NEMA). Where NEMA standards do not exist, American Standards Association (ASA) standards are used; however, not all manufacturers use these established symbols. In spite of the lack of standardization, knowledge of the symbols presented in this section will give you a firm basis for interpreting variations found in the field.

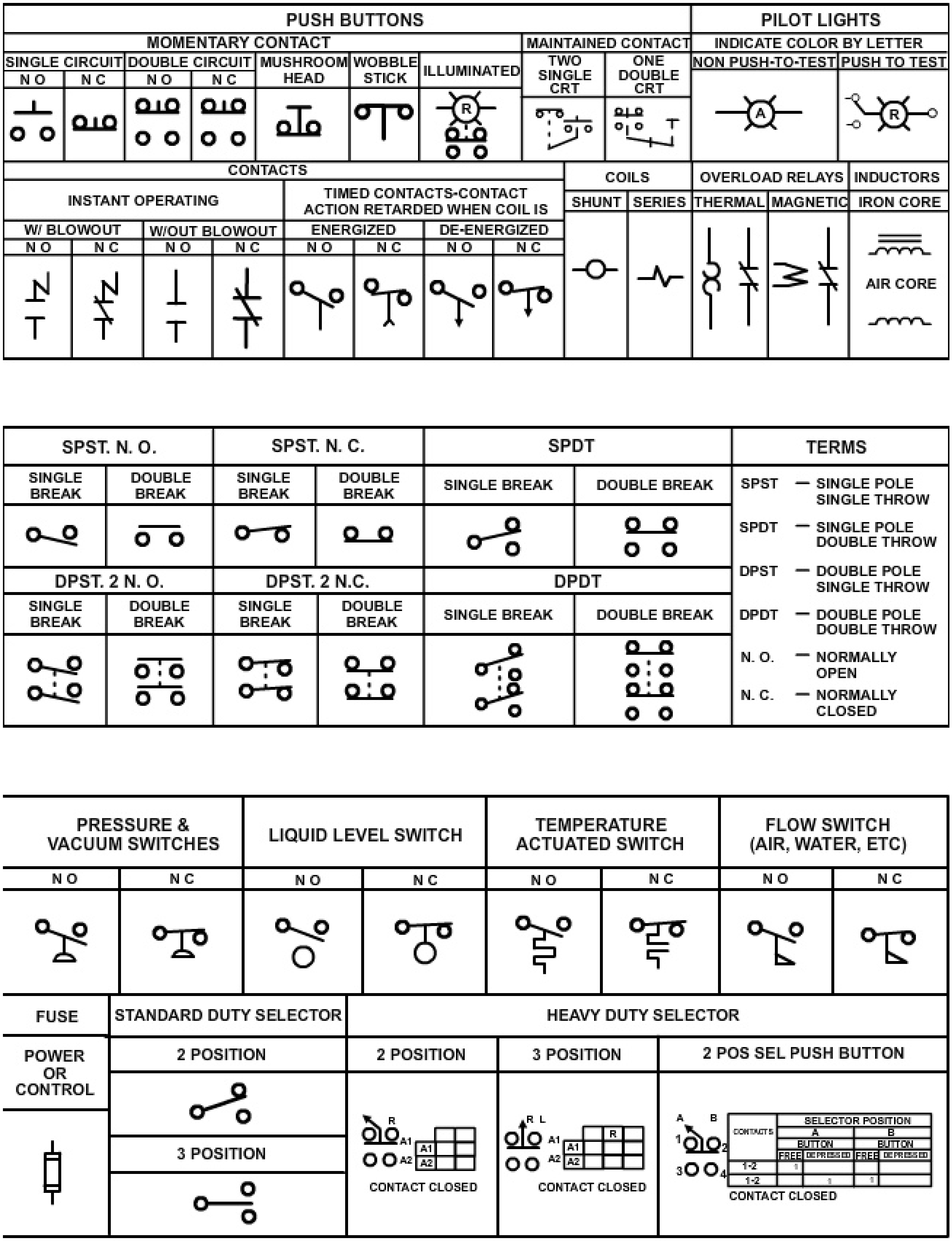

Figure 10-57 — Standard wiring diagram symbols.

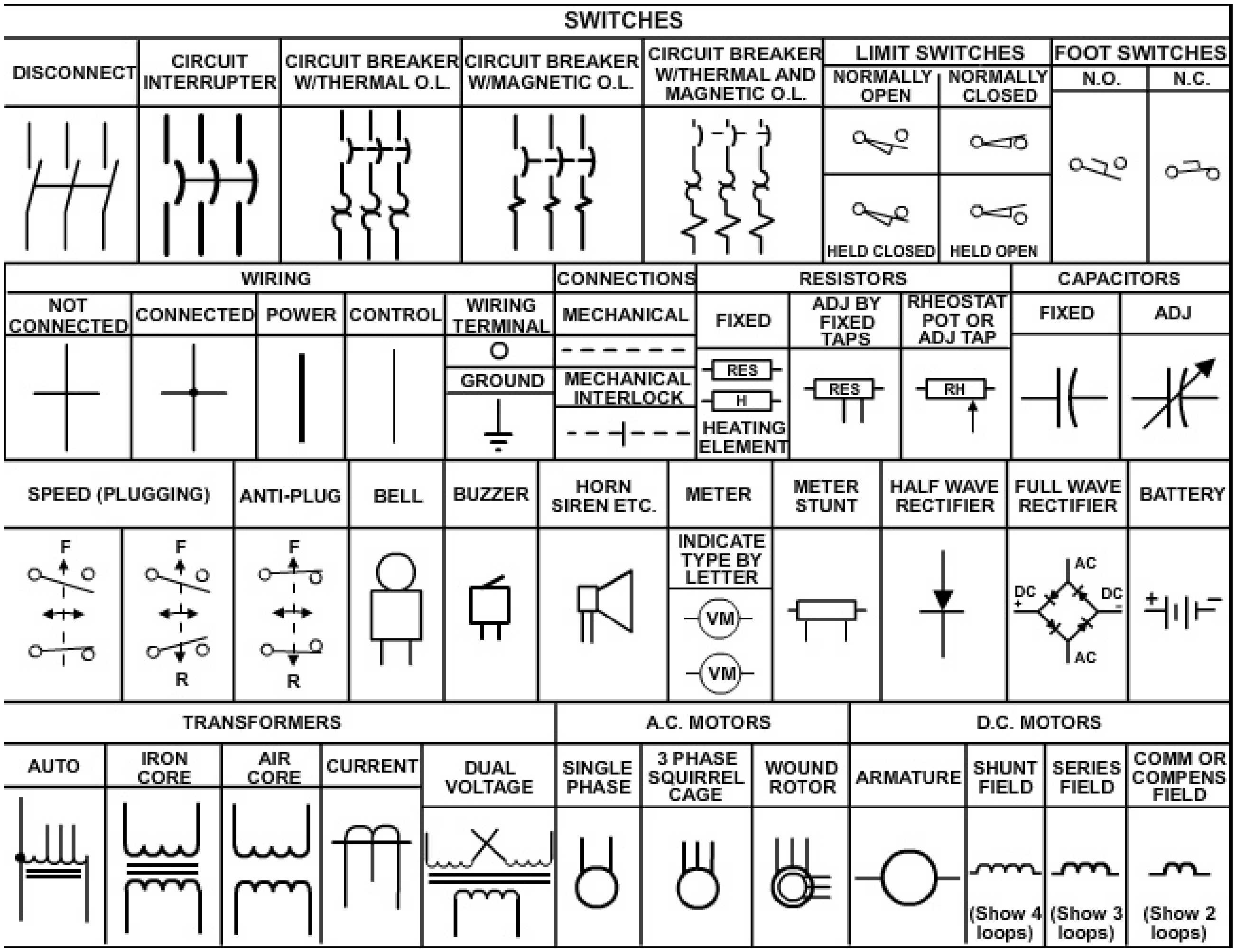

Figure 10-58 — Standard wiring diagram symbols.

The control-circuit line diagram in *Figure 10-59* shows the symbol of each device used in the circuit and indicates its function. The push-button station wiring diagram on the right of *Figure 10-59* represents the physical control station and shows the relative position of each device, the internal wiring, and the connections with the motor starter.

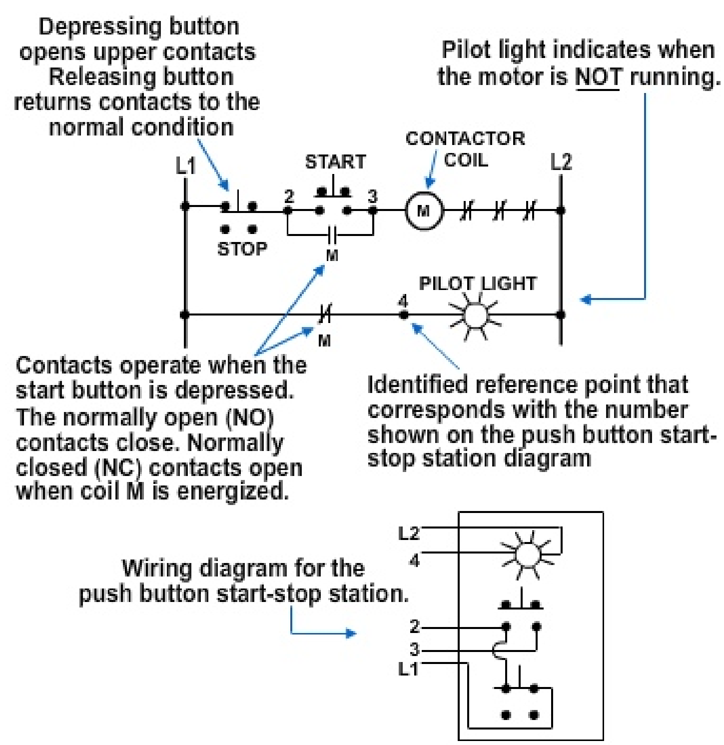

Figure 10-59 — Control circuit components.

13.2.1 Control and Power Connections

The correct connections and component locations for line and wiring diagrams are shown in *Table 10-8*. Compare the information given in the table with actual line diagrams to develop the ability to interpret the table quickly and use it correctly, for example, refer to *Figure 10-60* and the three-phase column of

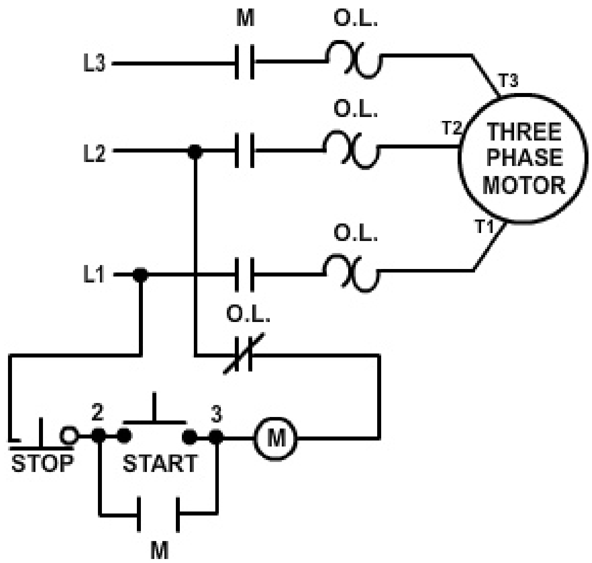

Figure 10-60 — Three phase motor controller diagram.

Table 10-13. Note that the control circuit switching is connected to line 1 (L1) and the contactor coil is connected to line 2 (L2).

Table 10-13 — Power and Control connection for across the line motor controllers/starters.

	DIRECT CURRENT	**SINGLE PHASE**	**THREE PHASE**
Line markings for	L1 & L2	L1 & L2	L1, L2, & L3
Overload relay heaters in	L1	L1	T1, T2, & T3
Contactor coil connected in	L2	L2	L2
Overload relay contacts in	L2	L2	L2
Control circuits connected to	L1 & L2	L1 & L2	L1 & L2
Control circuit switching connected to	L1	L1	L1
Reversing interchange lines	N/A	N/A	L1 & L3
Requiring grounding	L1 is **always** ungrounded	L1 is **always** ungrounded	L2

13.2.2 Control Wiring

Control wiring can be very confusing. A single operation of an electrical circuit is usually not complicated; however, a sequence of operations, one depending on the other, in a complex circuit can be difficult to understand. As you already know, most electrical circuits are represented as a wiring diagram or a line diagram. Work through the examples given throughout this section. This practice will improve your skills in reading and understanding electrical diagrams. If the diagrams are too complex, break them down to more elementary diagrams. These diagrams are your key to understanding how a machine operates and how to repair it when it breaks.

13.2.2.1 Two Wire Control

Two-wire control provides no-voltage release or low-voltage release. Two-wire control of a starter means that the starter drops out when there is a voltage failure and picks up as soon as the voltage returns. In *Figure 10-61*, the pilot device is unaffected by the loss of voltage. Its contact remains closed, ready to carry current as soon as line voltage returns to normal.

The phrases "no voltage release" and "two wire control" indicate that an automatic pilot device, such as a limit switch or a float switch, opens and closes the control circuit through a single contact.

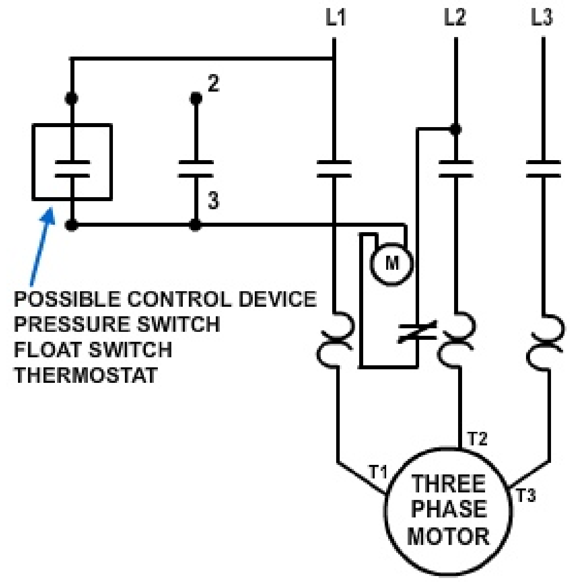

Figure 10-61 — Two wire control circuit.

13.2.2.2 Three Wire Control

The three-wire control involves a maintaining circuit. This method eliminates the need for the operator to press continuously on the push button to keep the coil energized. Refer to the elementary control circuit diagram in *Figure 10-62*. When the START button is pressed, coil M is energized across L1 and L2. This action closes contact M to place a shunt circuit around terminals 2, 3, and the START button. A parallel circuit is formed with one circuit through push-button terminals 2 and 3 and one circuit through contact M. As a result, current will flow through the M coil. If pressure is removed from the START button, terminals 2 and 3 open. The other circuit through contacts M remains closed, supplying current to coil M and maintaining a started-closed position. Such a circuit is called a maintaining circuit, a sealing circuit, or a holding circuit.

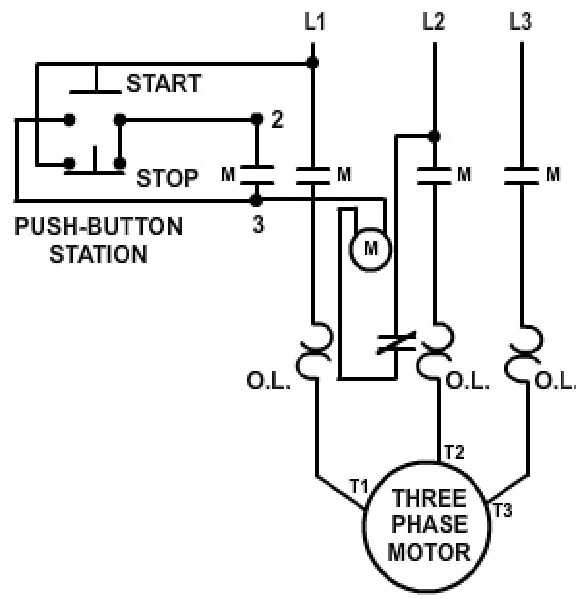

Figure 10-62 — Three wire control circuit.

The phrases "no-voltage protection" and "three-wire control" indicate to the electrician that the most common means of providing this type of control is a start-stop push-button station.

The main distinction between the two types of control is that in no-voltage release (two-wire control), the coil circuit is maintained through the pilot-switch contacts; in no-voltage protection (three-wire control), the circuit is maintained through a stop contact on the push-button station and an auxiliary (maintaining) contact on the starter.

13.2.2.3 Low Voltage Control

Sometimes it is desirable to operate push buttons or other control devices at some voltage lower than the motor voltage. In the control system for such a case, a separate source, such as an isolating transformer or an independent voltage supply, provides the power to the control circuit. This independent voltage is separate from the main power supply for the motor.

One form of separate control is shown in *Figure 10-63*. When the thermostat calls for cooling and the high-low pressure control is activated, the compressor motor starter coil M is energized through the step-down isolating transformer. When coil M is energized, power contacts in the 240-volt circuit close to start the refrigeration compressor motor. Since the control circuit is separated from the power circuit by the isolating control transformer, there is no electrical connection between the two circuits. For this reason, the wire jumper attached to L2 on a starter should be removed for different voltages; however, the overload relay control contact must be included in the separate control wiring.

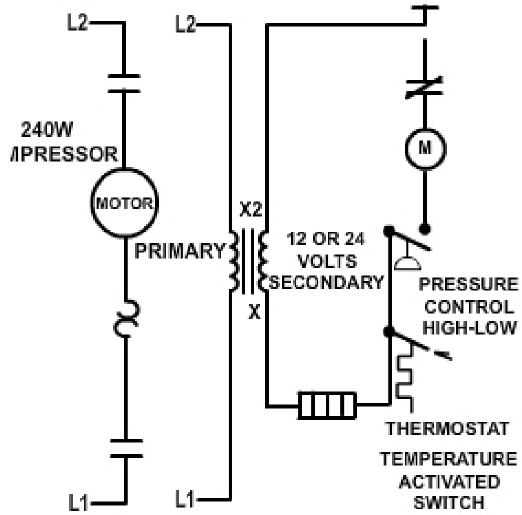

Figure 10-63 — Low voltage control circuit.

14.0.0 TROUBLESHOOTING and TESTING CONTROLLERS

In this section, assume that the motor and fuse are in good condition. To make certain that the motor is not at fault, connect a voltmeter at the motor terminals and determine whether voltage is available when the contacts of the controller are closed. If there is no voltage, the trouble probably lies in the controller.

14.1.0 Troubleshooting

By using a snap-around type of voltmeter/ohmmeter or individual instruments, you can conduct many of the tests needed to determine opens, shorts, grounds. and continuity in just a short time. You can test malfunctioning circuits for shorted coils, open coils, grounded coils, open resistances, shorted resistances, low voltages, high voltages, excessive amperes; broken, loose, or dirty connections; and many other problems with comparative ease. This testing is true of all motors as well as starters.

Follow a systematic procedure when troubleshooting controls.

WARNING

You must exercise extreme caution when testing live components. Always use the one-hand rule to avoid completing the circuit between the live component and a metal surface. Always have a second person standing by when working on energized equipment and ensure that person is qualified in CPR. When working on anything that should have the power off, always shut the power off yourself. Most disconnects allow a padlock to keep the power from being turned back on. This safety precaution is called "LOCKOUT." The NAVOSH Manual, OPNAVINST 5 100.23, provides guidance on the Lockout/Tag out program at shore activities according to OSHA regulations. It is extremely important to take this precaution. Controls with voltage over 240 volts should never be energized when you are troubleshooting.

Because there are so many different kinds and makes of controllers, we will outline a general procedure for locating the source of trouble.

1. If the motor does not start when the main contacts close, the trouble may be as follows:
    a. Open the overload heater coils or the poor or bad connections
    b. Main contacts not making contact - It is not unusual for one or more contacts to wear to the degree that they will not make when closed. This fault will also occur if the contacts become dirty, gritty, or burned.
    c. Broken, loose, or dirty terminal connections and loose or broken pigtail connections
    d. Open resistance units or open autotransformer readings from test equipment
    e. Obstruction of the magnet core, preventing the contacts from closing
    f. Mechanical trouble, such as mechanical interlocks, gummy pivots, and poor spring tension
2. If the contacts do not close when the START pushbutton is pressed, the trouble may be as follows:
    a. Open holding coil - This can be tested by connecting a voltmeter across the coil terminals when the START button is pressed. If there is voltage when the START button is pressed but the coil does not become energized, the coil is defective.
    b. Dirty START button contacts or poor contacts - Open or dirty STOP button contacts. If more than one station is connected to the same controller, each station should be checked. If FORWARD-REVERSE stations are used and they are interlocked, check all contacts.
    c. Loose or open terminal connections and open overload relay contacts
    d. Low voltage, shorted coil, or any mechanical failures encountered
3. If the contacts open when the START button is pressed, the trouble may be as follows:
    a. Contacts that do not close completely or are dirty, pitted, or loose
    b. Wrong connection of the station to the appropriate controller or controllers
4. If a fuse blows when the START button is pressed, the trouble may be as follows:
    a. Grounded circuits, open or shorted coils, or open or shorted contacts
5. If the magnet is noisy, chattering, or sticking in operation, the trouble may be as follows:
    a. Broken shaded pole causing chattering and/or Dirty or gummed up core face
6. If the magnet coil is burned or shorted, the trouble may be as follows:
    a. Overvoltage, excessive current due to large magnetic gap caused by dirt, grit, or mechanical trouble, or too frequent operation

14.2.0 Testing Component Circuits

The example used here is a control operated by a remote switch, such as a float switch. Assume that the device being controlled (a three-phrase motor) is in good working order but is not receiving power. *Figure 10-64* shows such a circuit.

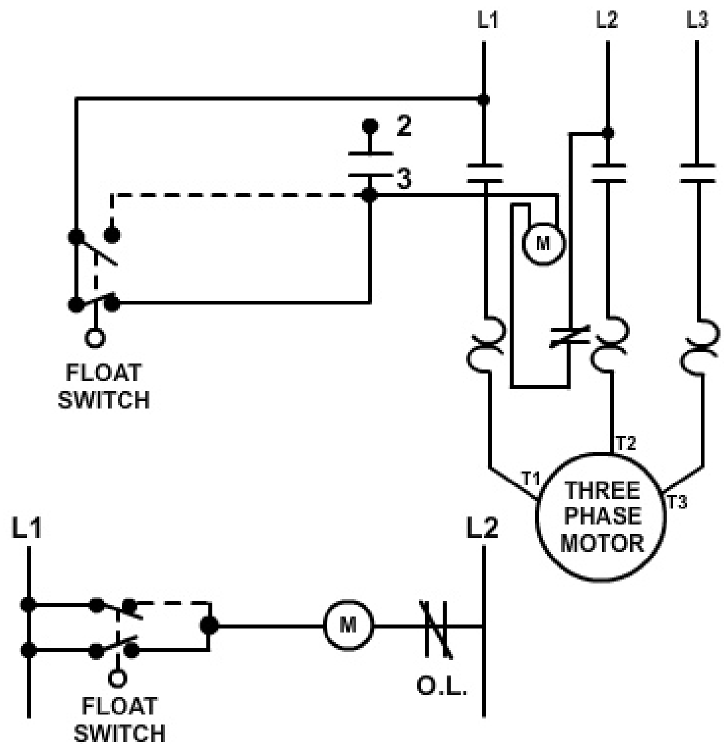

Figure 10-64 — Three phase starter controlled by a float switch.

The first thing you should check is the line voltage. To do this check, remove the cover of the control box and test each line with a voltmeter. You should take the volt readings between L1 and L2, L2 and L3, and then between L3 and L1. If you find full voltage, visually check the power circuit for loose connections. These terminals include L1, L2, L3, T1, T2, and T3. Look for signs of heating at these connections. When a connection becomes loose, the terminal becomes very hot, and the screw, wire, and terminal become discolored or charred. Check all terminals and tighten them if necessary. ONLY do this checking and tightening with the power OFF.

Next, check the control circuitry within the controller. Do this check by looking at the control circuit shown in *Figure 10-64*. The external controls, the magnetic holding coil, and the normally closed overload contacts are always located between line 1 and line 2. Unless the control has been altered, line 3 is not part of the control circuit. Check also that the externally located controlling switches, such as the push button, float, pressure, or limit switches, are connected between line 1 and the holding coil. The normally closed overload contacts are always located between the holding coil and line 2. A wiring diagram usually can be found in the cover of the controller. Now you have established that the motor and line voltage are in working order. This checking has narrowed the problem to the control circuit and the chance that some components are open.

You can locate opens in the control circuit with a voltmeter. Connect one lead of the voltmeter to line 1, and touch the other lead to first one terminal or the holding coil and then the other terminal. The voltage reading should be the same as between line 1 and line 2. If the control circuit voltage is supplied with a transformer, the voltage read should be that of the transformer output. If there is no voltage on either side of the holding coil, the overload contacts are open. Pushing the RESET button should close the overload contacts. If they do not close after they have had time to cool, they may be defective. In this case, replace them.

If there is a voltage on one terminal of the holding coil but not the other, the coil is open. You must then replace the coil. If there is a voltage on both terminals of the holding coil, assume the coil and the overload contacts are in working order. To double check these components, short out line 1 and the terminal marked 3 with a piece of wire. This action will bypass the external control, and then the holding coil should close the contacts. You can use a current limiting resistor in place of a wire. If the control functions, the problem is in the external controlling device.

Solid-state controllers have very complicated circuitry; thus, troubleshooting these units requires a good background in electronics and electric motors. These controllers have repair instructions with them as well as a list of parts that should be stocked for repair purposes. Repairs consist of replacing boards or modules that plug into the circuitry.

14.3.0 Combination Starters

A combination starter consists of a magnetic starter and a disconnect switch mounted in the same enclosure. These starters are supplied with either a fused disconnect switch or a circuit breaker. The fuses (or circuit breaker) provide short-circuit protection by disconnecting the line. A combination starter and circuit breaker will prevent single phasing by simultaneously opening all lines when a fault occurs in any one phase. This type of starter can be quickly reset after the fault has been cleared. *Figure 10-65* shows a fused combination starter. *Figure 10-66* shows a combination starter and a thermal-magnetic circuit breaker.

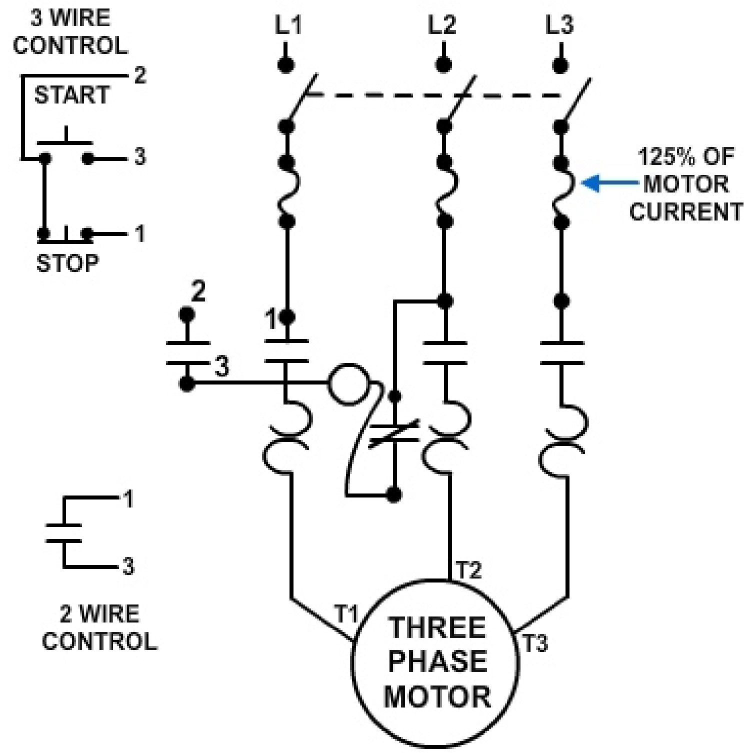

Figure 10-65 — Combination starter with a disconnect switch.

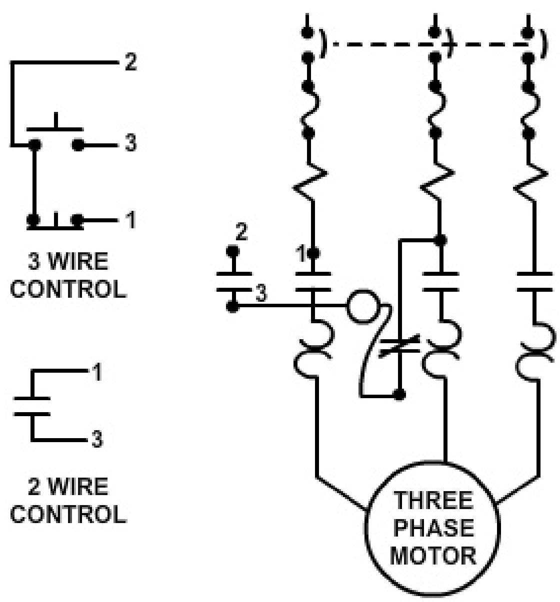

Figure 10-66 — Combination starter with a thermal magnetic circuit breaker.

14.4.0 Push Button Station Connections

We will now show you a number of control circuits with various combinations of push-button stations. All of these diagrams use one type of magnetic switch, but others can be used. *Figure 10-67* shows a magnetic switch that is operated from any of three stations. *Figure 10-68* shows a straight-line diagram of the control circuit of three start-stop stations. *Figure 10-69* shows the control circuit of two start-stop stations. In these diagrams, the START buttons are connected in parallel, and the STOP buttons are connected in series. These button connections must be made regardless of the number of stations. Note that the maintaining contact is always connected across the START button. All STOP buttons are connected in series with one another and in series with the holding coil, so the motor can be stopped from any position in case of emergency.

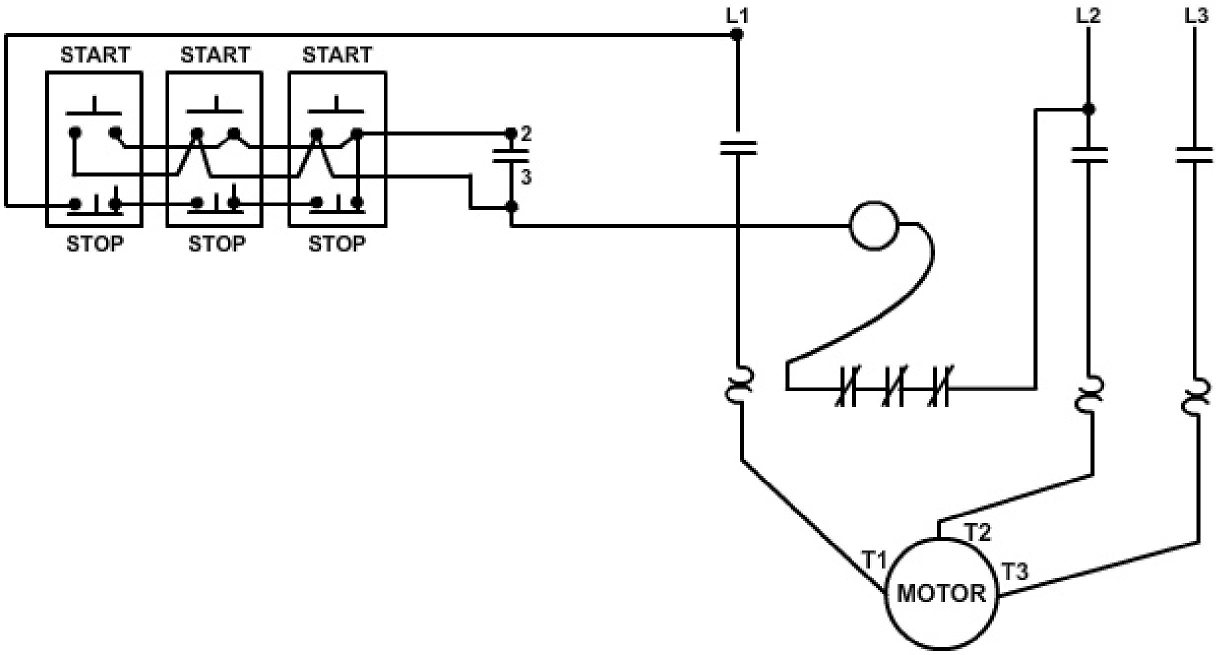

Figure 10-67 — Magnetic switch controlled by three start-stop stations.

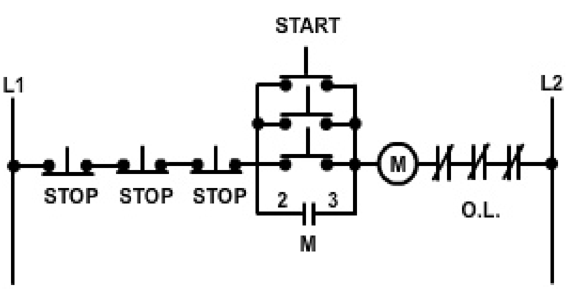

Figure 10-68 — Control circuit for three start-stop stations.

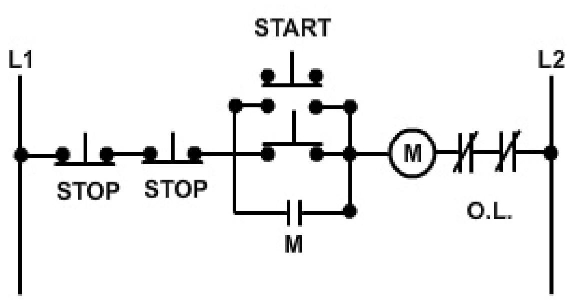

Figure 10-69 — Control circuit for two start-stop stations.

14.5.0 Start-Stop Station with a Pilot Light

Sometimes it is advisable to have a pilot light on the push-button station to indicate whether the motor is running. The lamp usually is mounted on the station and connected across the holding coil. Such a connection is shown in *Figures 10-70* and *10-71. Figure 10-72* shows a control circuit with the pilot light on when the motor is stopped. A normally closed contact is needed on this starter. When the motor is running, these contacts are open. Contacts are closed when the motor is stopped, and the pilot light goes on.

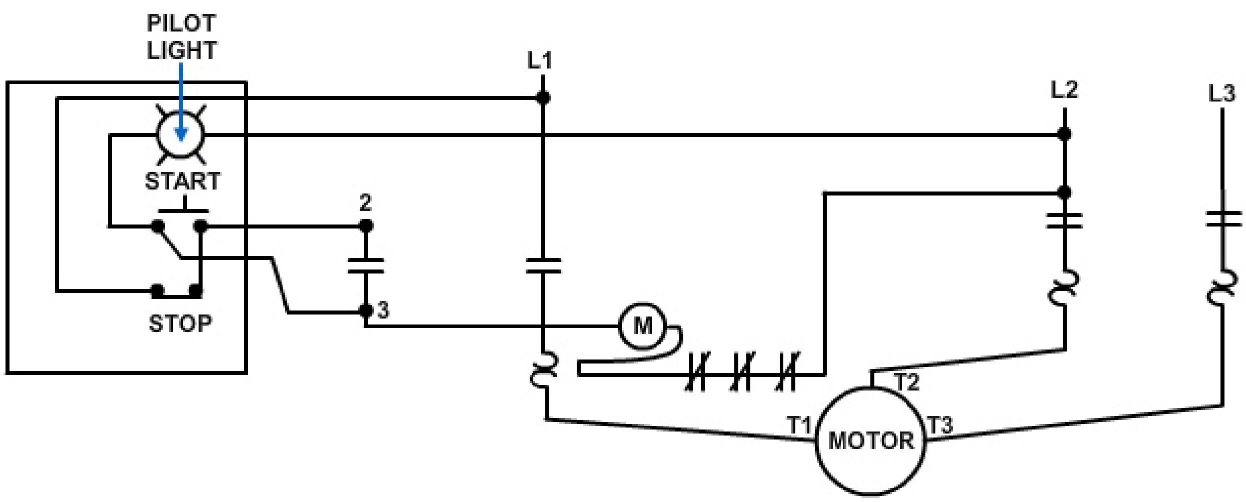

Figure 10-70 — Push button station with a pilot light.

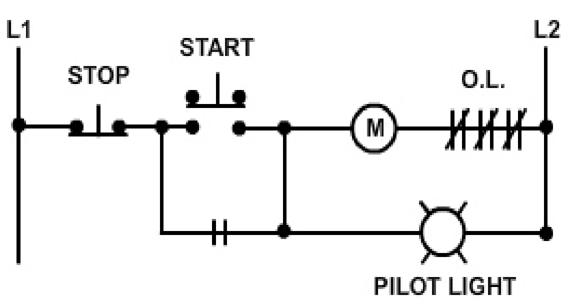

Figure 10-71 — Control circuit with a pilot light.

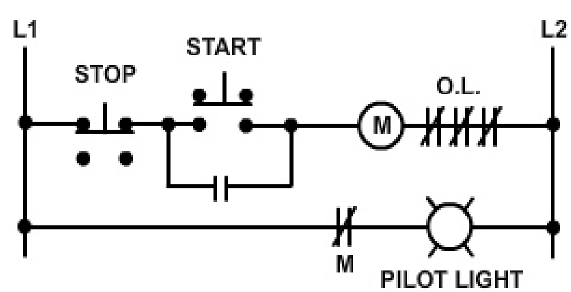

Figure 10-72 — Pilot light indicates when motor is not running.

15.0.0 MOTOR MAINTENANCE

Modern methods of design and construction have made the electric motor one of the least complicated and most dependable forms of machinery in existence and thereby made its maintenance comparatively simple. Do not, however, take this statement to mean that proper maintenance is not important; on the contrary, it must be given careful consideration if the best performance and longest life are to be expected from the motor. The two major features of maintenance, from the standpoint of their effect upon the general performance of the motor, are proper lubrication and care of insulation. Lubrication and insulation protect the most vital, and probably the most vulnerable, parts of the machine.

15.1.0 Lubrication

The designs of bearings and bearing housings of motors have been remarkably improved. However, this advance in design can cause problems. The bearings of modern motors, whether sleeve, ball, or roller, require infrequent attention. Older designs with housings less tight than those of modern machines require frequent oiling and greasing. The perpetuation of this habit causes the oiling and greasing of new motors to be overdone. The result is that oil or grease is copiously and frequently applied to the outside, as well as the inside, of bearing housings. Some excess lubricant is carried into the machine and lodges on the windings, where it catches dirt and hastens the ultimate failure of the insulation.

15.1.1 Greasing Ball Bearings

Only a high grade of grease with the following general characteristics should be used for ball-bearing lubrication:

1. Consistency, a little stiffer than that of petroleum jelly, maintained over the operating temperature range
2. Melting point preferably over 150°C and freedom from abrasive matter, acid, and alkali
3. Freedom from separation of oil and soap under operating and storage conditions

In greasing a motor, you must take care not to add too much grease. Over greasing will cause too high an operating temperature with resulting expansion and leaking of the grease, especially with large bearings operated at slow speeds.

⚠ CAUTION ⚠

Always review the Material Safety Data Sheet (MSDS) for greases, oils, lubricants, and other hazardous materials before use. Avoid prolonged skin contact with lubricants. Dispose of waste materials in an environmentally responsible manner.

15.1.2 Pressure Relief Systems

The following procedures are recommended for greasing ball-bearing motors equipped with a pressure-relief greasing system.

Before pumping grease into the grease fitting, wipe it clean to prevent the grease from carrying dirt into the fitting and bearing housing. Always remove the relief plug from the bottom of the bearing before using the grease gun. This action prevents applying excessive pressure, which could rupture the bearing seals inside the bearing housing.

With a clean screwdriver or similar tool, free the relief hole of any hardened grease so that any excess grease will run freely from the bearing. With the motor running, add grease with a hand-operated pressure gun until it begins to flow from the relief hole. This procedure tends to purge the housing of old grease.

After adding the grease, allow the motor to run long enough to permit the rotating parts of the bearing to expel all excess grease from the housing. This very important step prevents over greasing of the bearing. Stop the motor and tightly replace the relief plug with a wrench.

Motors that are not equipped with the pressure gun fitting and the relief plug on the bearing housing cannot be greased by the procedures described. Under average operating conditions, the factory packed grease in the bearing housings of these motors lasts approximately 1 year. When the first year of service has elapsed and once a year thereafter (or more often if conditions warrant), remove the old grease and lubricate the bearings with new grease. To do this, disassemble the bearing housings and clean the inside of the housings and housing plates or caps and the bearings with a suitable solvent. When you have thoroughly cleansed them of old grease, reassemble all parts except the outer plates or caps. Apply new grease, either by hand or from a tube, over and between the balls. The amount of grease you should use varies with the type and frame size of the particular motor. Consult the instruction sheet that accompanied the motor for this information.

Add enough grease to fill the bearing housing one-third to one-half full. Do not use more than the amount specified. After reassembling the motor, refill any V-grooves in the housing lip with grease (preferably a fibrous, high-temperature-sealing grease) that will act as an additional protective seal against the entrance of dirt or foreign particles.

15.1.3 Roller Bearings

The technique for greasing motors equipped with roller bearings is quite similar to that used for ball bearings. However, you should follow specific instructions for the individual design because more frequent greasing or slight changes in technique may sometimes be necessary.

15.1.4 Sleeve Bearings

With the motor stopped, periodically check the oil level in the sleeve-bearing housings. If the motor is equipped with an oil-filler gauge, the gauge should be approximately three-quarters full at all times.

If the oil is dirty, drain it off by removing the drain plug, which is usually located in the bottom or side of the bearing housing. Then flush the bearing with clean oil until the out coming oil is clean.

15.1.5 Fractional Horsepower Motors

Fractional-horsepower motors, may have no means of checking the oil level, as all the oil may be held in the waste packing. In such cases, a good general rule for normal motor service is to add 30 to 70 drops of oil at the end of the first year and to re-oil at the end of each subsequent 1,000 hours of motor operation.

Most fractional-horsepower motors built today require lubrication once a year. Small fan and agitator motors often require more frequent lubrication with 3-month intervals between oiling.

15.2.0 Motor Storage

Store motors in a dry, clean place until ready for installation. Heat should be supplied, especially for larger high-voltage machines, to protect them against alternate freezing and thawing. This advice is equally applicable to spare coils.

Motors that have been in transit in a moist atmosphere or have been idle for an extended period without heat to prevent the accumulation of moisture should be dried out thoroughly before being placed in service. Machines also may become wet by accident, or they may sweat as a result of a difference between their temperature and that of the surrounding air. This condition is harmful, particularly in the case of large or important motors. Prevent it by keeping them slightly warm at all times.

You can pass current at a low voltage through the windings, use electric heaters, or even use steam pipes for protective purposes. During extended idle periods, you can stretch tarpaulins over the motor and place a small heater inside to maintain the proper temperature.

If a motor should become wet from any cause, dry it out thoroughly before operating it again. The most effective method is to pass current through the windings, using a voltage low enough to be safe for the winding in its moist condition.

You can apply heat externally by placing heating units around or in the machine and covering the machine with canvas or some other covering, leaving a vent at the top to permit the escape of moisture. You can use small fans to help circulation. You should not allow the temperature of the windings to exceed 100°C for Class A insulated motors.

15.3.0 Periodic Inspection

A systematic and periodic inspection of motors is necessary to ensure best operation. Of course, some machines are installed where conditions are ideal and dust, dirt, and moisture are not present to an appreciable degree. Most motors, however, are located where some sort of dirt accumulates in the windings, lowering the insulation resistance and cutting down creepage distance. Dusts are highly abrasive and actually cut the insulation while being carried by ventilating air. Fine cast-iron dust quickly penetrates most insulating materials; hence, you can see why motors should be cleaned periodically. If conditions are extremely severe, open motors might require a certain amount of cleaning each day. For less severe conditions, weekly inspection and partial cleaning are desirable. Most machines require a complete overhauling and thorough cleaning out once a year.

15.4.0 Brush Inspection

Essential for satisfactory operation of brushes is free movement of the brushes in their holders. Uniform brush pressure is necessary to assure equal current distribution. Adjustment of brush holders should be set so that the face of the holder is approximately one eighth of an inch up from the commutator; any distance greater than this will cause brushes to wedge, resulting in chattering and excessive sparking.

Check the brushes to make sure that they will not wear down too far before the next inspection. Keep an extra set of brushes available so that replacements can be made when needed. Sand in new brushes, and run the motor without a load to seat the brushes.

Make sure that each brush surface in contact with the commutator has the polished finish that indicates good contact and that the polish covers all contact surfaces of the brush. Check the freedom of motion of each brush in the brush holder. When replacing a brush, be sure to put it in the same brush holder and in its original position. It will be easier for you to replace the brush properly if you scratch a mark on one side of the brush before removing it.

Check the springs that hold the brushes against the commutator. Improper spring pressure may lead to commutator wear and excessive sparking. Excessive heating may have annealed the springs, in which case you should replace them and correct the cause of overheating.

15.5.0 Commutator Inspection

Inspect the commutator for color and condition. The part where the brushes ride should be clean and smooth and should be a polished brown color. A bluish color indicates overheating of the commutator.

You should remove any roughness on the commutator by sandpapering or stoning. Never use an emery cloth or emery stone. For this operation, run the motor without load. If you use sandpaper, wrap it partly around a wooden block. The stone is essentially a piece of grindstone, known in the trade as a commutator stone. With the motor running without load, press the stone or sandpaper against the commutator with moderate pressure and move it back and forth across the commutator surface. If the armature is very rough, it should be taken out and the commutator turned down in a lathe.

WARNING

Use care not to come into contact with moving parts.

15.6.0 Records

The electrical shop should have a record card for every motor. At minimum, the information on the card should include inspections, repair work, age, and replacement stock number.

15.7.0 Cleaning

About once a year or more often if conditions warrant, clean motors thoroughly. Smaller motors, the windings of which are not easily accessible, should be taken apart.

First, remove the heavy dirt and grease with a heavy, stiff brush, wooden or fiber scrapers, and cloths. You can use rifle-cleaning bristle brushes in the air ducts. You can blow-dry dust and dirt off, using dry-compressed air at a moderate pressure, perhaps 25 to 50-psi pressure at the point of application, taking care to blow the dirt out and away from the windings. If the dirt and dust are metallic, conducting, or abrasive, using air pressure is not as satisfactory as using a suction system.

CAUTION

When cleaning motors with compressed air, wear safety goggles and hearing protection. Dispose of lubricants and contaminated materials in an environmentally responsible manner.

You can easily remove grease, oil, and sticky dirt by applying cleaning liquids specifically designed for the purpose. These liquids evaporate quickly and, if not applied too generously, will not soak or injure the insulation. If you do use one of these liquids, be sure to follow the manufacturer’s direction for use.

16.0.0 MOTOR START UP

After new motors and controls are installed, check them for operation under load for an initial period of at least 1 hour. During this time, the electrician can observe any unusual noise or hot spots that develop. The operating current must be checked against the nameplate ampere rating. This check requires skill in the proper connection, setting, and reading of a clamp-on ammeter. The nameplate ampere reading multiplied by the service factor (if any) sets the limits of the steady current. Do NOT exceed this value.

Check the power supply against the nameplate values; they should agree. Most motors will operate successfully with the line voltage within 10 percent (plus or minus) of the nameplate value or within 5 percent of the frequency (hertz). Most 220-volt motors can be used on 208-volt network systems but with slightly modified performance. Generally, 230-volt motors should not be used on 208-volt systems.

To reconnect a dual-voltage motor to a desired voltage, follow the instructions on the connection diagram on the nameplate.

Motor-starter-overload-relay heaters of the proper size must be installed. The motor will not run without them. Sizing information is found inside the control enclosure cover. The starting fuses should be checked in a similar manner. The selection of the correct fuse size must be according to the NEC® or local requirements.

If the motor has not been installed in a clean, well ventilated place, clean the area. Good housekeeping, as well as direct accident and fire-prevention techniques, must be emphasized.

Check the motor mounts to be sure that they are secure and on a firm foundation. If necessary, add grout to secure the mounts.

Rotate the end shields to place grease fittings, plugs, or any openings in the best, or most accessible, location. Oil or grease the bearings, if necessary.

Summary

Test equipment, motors, and controllers are an important factor in the accomplishment of your job as a Construction Electrician. As an electrician, there will be times when you will need to utilize the different pieces of test equipment to verify and troubleshoot electrical gear. Knowledge of safe operation and testing requirements are essential not only for your safety, but for the safety of your crewmembers. As a CE, you will be tasked to maintain and operate a wide range of motors and controllers. Your job is to be familiar with manufacturer's manuals, maintenance issues, and servicing requirements. Another factor to consider is the construction, maintenance, and troubleshooting knowledge needed to safely complete any mission assigned to your unit. Remember, safe distribution and maintenance of power is necessary.

The National Electrical Code handbook is the definitive reference publication utilized by the CE rating. Always remember that the NEC handbook is updated every three years. It is imperative that you as a CE refer to latest edition of the NEC handbook.

Review Questions (Select the Correct Response)

1. The transformer installed in the portable tool tester supplies approximately how much amperage through the tool cord equipment ground?

   A. 30
   B. 60
   C. 90
   D. 120

2. If the resistance of the ground on the equipment under test is approximately .2 to 1.5 ohms, which relay is activated?

   A. Open circuit sensing
   B. Faulty equipment ground sensing
   C. Overcurrent sensing
   D. Faulty ground sensing

3. What is the minimum range in length of a 16 gauge wire extension cord that can be tested by the portable tool tester?

   A. 100 feet
   B. 25 feet
   C. 6 feet

4. Which of the following does NOT cause the presence of a power ground indication?

   A. Carbon build up
   B. Moisture paths
   C. Insulation breakdown
   D. Sticky activation relays

5. For an ammeter to measure current in a circuit, it must be connected in what manner?

   A. Across the line
   B. In parallel with the circuit source and load
   C. In series with the circuit source and load
   D. In series-parallel with the load and line

6. What is the source of power to drive meter movement in the ammeter?

   A. Phase motor
   B. Core
   C. Coil winding
   D. Transformer secondary

7. When measuring current of unknown amperage with an ammeter that is capable of measuring several ranges, you should make the first measurement with the meter set at what range?

   A. A range slightly higher than the estimated current
   B. The highest range
   C. The range of the estimated current
   D. The lowest range

8. How are voltmeters connected to measure voltage?

   A. Across the circuit
   B. Parallel to the circuit
   C. Series-parallel to the circuit
   D. Vertical to the circuit

9. The presence of three internal resistors in a voltmeter schematic indicates that what voltmeter characteristic?

   A. The meter is more rugged than one with only one resistor.
   B. More protection is provided to this meter than to one with only one.
   C. The meter has three voltage ranges and scales.
   D. The meter may be used for three times its rated voltage.

10. Which of the following conditions indicate(s) you are measuring AC voltage with a line voltage indicator?

   A. Neon lamp indicator glowing
   B. Audible hum
   C. Vibration when testing indicator is hand-held
   D. Each of the above

11. **(True or False)** When you are measuring DC voltage with a line voltage indicator, both the positive and negative electrodes glow.

   A. True
   B. False

12. What must be accomplished before using the ohmmeter for a precise resistance measurement?

   A. Short leads together.
   B. Zero meter.
   C. Short leads together and zero meter.
   D. Select scale to be measured.

13. What action should you take after completing a test with an ohmmeter?

A. Select DC supply positive.
B. Select DC supply negative.
C. Turn the meter off.
D. Set the selector switch to R_1.

14. You are preparing to take a voltage reading with a multimeter. After you have determined the approximate voltage on the circuit you are about to test, what should be your next step?

A. Turn off power to the circuit.
B. Plug the test leads into the appropriate jacks.
C. Connect the test leads to the conductors.
D. Set the function switch.

15. What is the difference between a megger and a typical ohmmeter?

A. Megger uses AC voltage; ohmmeter uses DC voltage.
B. Megger can apply higher DC voltage to a circuit.
C. Megger has an indicator within the instrument enclosure.

16. When you are conducting an insulation resistance test using a megger, which of the following conditions can cause the needle to deflect to zero?

A. No resistance between the test leads
B. Test leads touching each other
C. Insulation broken near the test points
D. Each of the above

17. What is the purpose if any, of keeping records of insulation tests?

A. Technical publications require it.
B. It is necessary for scheduling future tests.
C. Trends may indicate future problems.
D. It serves no purpose.

18. With every increase in temperature of 50°F, you should reduce the resistance amount by which of the following time intervals?

A. Half
B. One quarter
C. One third
D. Three quarters

19. What is defined as the temperature at which the moisture vapor in air condenses as a liquid?

A. Wetness factor
B. Dew point
C. Humidity factor
D. Condensation point

20. Of the following conditions, which one(s) would cause a motor to have a low insulation resistance when tested?

A. Moisture
B. Dirt
C. Dust
D. Each of the above

21. When taking an insulation resistance test on a cable that is a performance natural, you get a reading of 6 megohms at a temperature of 104°F. What is the correct value of resistance?

A. 19.56 megohms
B. 23.10 megohms
C. 24.90 megohms
D. 30.48 megohms

22. When taking an insulation resistance test on an oil filled transformer, you get a reading of 2 megohms at a temperature of 131°F. What is the correct value of resistance?

A. 10 megohms
B. 22.4 megohms
C. 31 megohms
D. 31.7 megohms

23. When taking an insulation resistance test around a piece of high voltage equipment, you should take which of the following actions?

A. Ground the megger.
B. Disconnect the apparatus.
C. Work under direct supervision.
D. Perform each of the above.

24. When taking an insulation resistance test, when, if ever, should you discharge a cable of its capacitance?

A. Before making the test only
B. After making the test only
C. Before and after making the test
D. Never

25. What is the minimum time to leave leads connected to allow capacitance discharge to occur?

A. 15 seconds
B. 30 seconds
C. 45 seconds
D. 60 seconds

26. What type of material is used to provide shielding around a magnetic field?

A. Soft iron
B. Copper
C. Hard iron
D. Brass

27. What are the four main parts of a split phase electric motor?

A. Stator, rotor, end plates, and centrifugal switch
B. Poles, armature, core, and shaft
C. Starting windings, running windings, frame, and core
D. Coils, end bells, bearings, and commutator

28. The centrifugal switch disconnects a motor's starting windings at what percentage of the motor's full speed?

A. 50%
B. 75%
C. 80%
D. 100%

29. To reverse the direction of rotation of a split phase motor, you should interchange the connection of what leads of the motor?

A. Power
B. Running winding
C. Starting winding
D. Centrifugal switch

30. You are using an electric motor and the rotor suddenly locks. What is the possible cause of this malfunction?

A. Input voltage is too high
B. Motor bearings are worn out
C. Centrifugal switch did not open at the desired speed
D. Motor current is too high

31. Before you take an electric motor completely apart, which of the following actions should you take?

A. Take out the pulley connected to the motor shaft.
B. Mark the position of the shaft.
C. Put a center punch mark at the stator ends and their matching end plates.
D. Identify and mark the starting and running winding leads.

32. The starting winding of an electric motor is always placed what number of degrees out of phase with the running winding?

A. 30
B. 45
C. 90
D. 120

33. When all connections between the poles of the windings have been completed and tested and the leads attached, the stator should be placed in a baking oven and baked for how many hours?

A. 6
B. 1
C. 2
D. 3

34. Capacitor motors have what advantage over split phase motors?

A. Capacitor motors are less expensive.
B. Capacitor motors weigh less.
C. Capacitor motors have higher starting currents.
D. Capacitor motors have higher starting torque.

35. What type of electric motor can be operated with either AC or DC power??

A. Split phase
B. Salient pole
C. Capacitor start
D. Capacitor run

36. The stator and rotor windings in a salient pole universal motor are connected in what manner??

A. In series with the power source
B. In series with the centrifugal switch
C. In series with the capacitor
D. In parallel with the power source

37. How is the speed varied on a shaded pole motor?

A. Inserting a choke in parallel with the main winding
B. Inserting a choke in series with the main winding
C. Inserting a choke in parallel with the salient winding
D. Inserting a choke in series with the salient winding

38. Split phase and capacitor motors are typically used in what application(s)?

A. Floor fans
B. Wall fans
C. Floor and wall fans
D. Equipment fans

39. If a three phase motor has 36 coils associated with it, how many coils will each phase have?

A. 3
B. 6
C. 9
D. 12

40. The rotation of a three phase electric motor can be reversed by interchanging what leads?

A. All three of the motor's leads
B. Any two of the power leads
C. Starting winding leads
D. All three leads of the power source

41. At what distance is an AC motor controller considered "out of sight"?

A. 10 feet
B. 25 feet
C. 50 feet
D. 100 feet

42. Conductors supplying two or more motors must have an ampacity equal to the sum of the full load current rating of all motors plus what percentage of the highest rated motor in the group?

A. 100
B. 75
C. 50
D. 25

43. What are the horsepower and voltage limitations of manual motor controllers?

- A. 7.5 hp at 600 volts, three phase and 3.0 hp at 220 volts single phase
- B. 2.0 hp at 600 volts, three phase and 1.0 hp at 220 volts single phase
- C. 20.0 hp to 50.0 hp at 220 volts, three phase or single phase
- D. 2.0 hp or less at 300 volts or less, single phase only

44. Which of the following types of motors, if any, is allowed to be controlled by a toggle switch?

- A. All single phase motors
- B. 2.0 to 5.0 hp motors only
- C. Motors of 2.0 hp or less
- D. None

45. On a shaded pole motor, the starting windings are (a) constructed and (b) located in what manner?

- A. (a) Of small gauge magnet wire
  (b) Wound on top of the running windings
- B. (a) Of large gauge magnet wire
  (b) Wound on top of each stator pole
- C. (a) Of copper bands
  (b) Wrapped around one tip of each stator pole
- D. (a) Of copper bands
  (b) Wrapped around all of the stator poles

46. Shaded pole motors have which of the following characteristics?

- A. High torque
- B. Large horsepower
- C. Low torque
- D. High voltage

47. On a three speed, split phase fan motor, the windings are connected in what manner for low speed operation?

- A. Running winding is connected across the line and the starting winding is connected in series with auxiliary winding.
- B. Running winding is in series with half the auxiliary winding.
- C. Starting winding is in series with half the auxiliary winding.
- D. Running and auxiliary windings are in series across the line and the starting winding is connected across the line.

48. For a wye connected three phase electric motor, how many leads are brought out to the terminal box?

- A. 12
- B. 9
- C. 6
- D. 4

49. Disconnects may be used as controllers on motors rated up to how many horsepower at 220 volts?

A. 1
B. 2
C. 3
D. 4

50. Magnetic starters are made to handle motors rated to what maximum horsepower rating?

A. 6
B. 12
C. 25
D. 50

51. How many ways can the coil of the starter be deenergized?

A. 1
B. 2
C. 3
D. 4

52. Reduced voltage starters are generally used for motors rated above how many horsepower?

A. 50
B. 60
C. 75
D. 100

53. Part winding starters operate like a resistance start controller and use how many magnetic starters?

A. 1
B. 2
C. 3
D. 4

54. Air pressure used for cleaning open frame electric motors should not exceed what psi?

A. 10
B. 15
C. 25
D. 30

55. Testing motors is generally conducted by two major methods. One is called operational and other is known as what?

A. Routine
B. Corrective
C. Preventive
D. Visual

56. What is a major cause for sparking brushes at the commutator?

A. Worn coils
B. Burned windings
C. Faulty armature
D. Stator failure

57. What does the first test on the armature winding indicate?

A. Shorted armature
B. Grounded circuits
C. Stator vibrations
D. Open armature

58. While inspecting the slip rings, you notice a chocolate brown color around the rings. What does this indicate to the operator?

A. Normal condition
B. Ring slippage
C. Brush arcing
D. Commutator burrs

59. Motor contactors that remain closed for long periods of time with infrequent operation use what material for contacts?

A. Aluminum
B. Carbon
C. Copper
D. Silver

60. What is defined as the total thickness of contact material which may be worn away before the contact of two associated surfaces becomes inadequate to carry rated current?

A. Wear tolerance
B. Wear allowance
C. Burn tolerance
D. Burn allowance

61. What is the purpose of arc barriers?

A. Provide insulation between stator and rotor
B. Prevent arcing in the coils
C. Provide insulation between electrical circuits
D. Prevent arcing from commutator

62. In troubleshooting an AC controller, you notice the coils overheating. Which of the following is a probable cause for this condition?

A. Loose connections
B. Inadequate spring pressure
C. Misalignment of parts
D. Open armature gap

63. NEC® requirements for motor branch circuit and ground fault protection can be found in what part of Article 430?

A. I
B. II
C. III
D. IV

64. Motor branch circuit protection must protect which of the following circuit components?

A. Motor
B. Control apparatus
C. Conductors
D. All of the above

65. An instantaneous trip circuit breaker (without time delay) may be used only if it is part of a listed combination controller and is what type of device?

A. Fixed
B. Adjustable
C. Delaying
D. Fault protected

66. Which of the following devices can be considered a motor controller?

A. Pilot control device
B. Circuit breaker
C. Push button station
D. Limit switch

67. An approved disconnecting means for a motor circuit should have what kind of rating?

A. Ampere
B. Horsepower
C. Kilowatt
D. Voltage

68. The code permits a motor disconnecting means to be out of sight if what conditions can be met?

A. Can be locked in the ON position
B. Can be locked in the OPEN position
C. Cannot be locked in the ON position
D. Cannot be locked in the OPEN position

69. A motor overload protection should be capable of protecting the motor from which of the following circuit condition(s)?

A. Short circuit
B. Ground fault
C. Excessive circuit heat
D. All of the above

70. What must be done to a regular fuse used as an overload protection for a motor during the motor's starting period?

A. Must be grounded
B. Must be shunted
C. Should be outfitted with a time delaying device
D. None of the above

71. Which of the following non-current carrying metal parts of a motor circuit is/are required to be grounded?

A. Cabinets
B. Boxes
C. Equipment enclosures
D. All of the above

72. Flexible metal conduit can be used as an equipment grounding conductor provided its length does not exceed how many feet?

A. 6
B. 10
C. 15
D. 20

73. When flexible metal conduit used as grounding conductor exceeds its permitted length, you should install what component in the conduit?

A. Neutral wire
B. Additional hot wire
C. Bonding jumper wire
D. Connector listed for grounding

74. A flexible metal conduit used as equipment grounding conductor should have circuit conductors within it rated at what maximum amperes?

A. 10
B. 15
C. 20
D. 25

75. A control circuit is divided into how many classes?

A. Five
B. Two
C. Three
D. Four

76. In a Class 1 control circuit, a number 18 wire should be protected at how many amperes?

A. 7
B. 10
C. 16
D. 18

77. In a two wire control circuit, what component opens and closes the circuit?

A. Circuit breaker
B. Start-stop switch
C. Toggle switch
D. Automatic pilot device

78. In a three wire control circuit, what is the function of the maintaining circuit?

A. To maintain the voltage of the circuit
B. To eliminate the current of the circuit
C. To maintain power to the circuit
D. To eliminate the need for the operator to press start button constantly

79. Which of the following is another term for maintaining circuit?

A. Control circuit
B. Sealing circuit
C. Holding circuit
D. Both B and C above

80. Which of the following components is commonly used to open and close the circuit?

A. Limit switch
B. Circuit breaker
C. Push button station
D. Float switch

81. A low voltage control circuit uses a separate low voltage source from which of the following components?

A. Adjustable resistor
B. Rectifier
C. Isolation transformer
D. Small generator

82. **(True or False)** The low voltage control's supply voltage should come from the same power supply as the motor it is controlling.

A. True
B. False

83. Lockout guidance is provided by what instruction?

A. OPNAVINST 5010.23
B. OPNAVINST 5001.23
C. OPNAVINST 5100.32
D. OPNAVINST 5100.23

84. If a motor does not start when the main contacts of the controller close, which of the following conditions is/are the possible cause(s)?

A. Dirty start button contacts
B. Open holding coil
C. Open overload heater coil
D. Each of the above

85. If the controller contacts do not close when the start button is pressed, which of the following conditions is a possible cause?

A. Defective load
B. Grounded circuit
C. Over voltage
D. Shorted coil

86. If the controller contacts open when the start button is pressed, which of the following conditions is a possible cause?

A. Shorted coil
B. Wrong connection of the push button station
C. Over voltage
D. Open overload relay

87. If a magnetic coil is noisy while in operation, which of the following conditions is a possible cause?

A. Shorted contacts
B. Shorted coil
C. Grounded coil
D. Broken shaded pole

88. Grease used for lubricating motor bearings should have a melting point not less than how many degrees

A. 150°F
B. 212°F
C. 100°C
D. 150°C

89. What is the most common lubrication problem on newer motors?

A. Infrequent greasing
B. Over greasing
C. Under greasing
D. Grease melting

90. When using an external heating unit to dry moisture from a Class A insulated motor, you should not allow the motor windings to exceed what temperature?

A. 150°C
B. 100°C
C. 150°F
D. 100°F

91. What conditions indicates an overheated commutator?

A. Polished brown color on the surface of the commutator
B. Bluish color on the surface of the commutator
C. Uneven wear on the commutator
D. Worn out commutator brush

92. After you install an electric motor, how long should you initially leave the motor running with a load for observation?

A. 1 hour
B. 1/2 hour
C. 5 minutes
D. 15 minutes

93. The part where the brushes ride on the commutator should be what color?

A. Blue
B. Black
C. Brown
D. Red

94. How often do machines require a complete overhaul?

A. Monthly
B. Semi-annually
C. Quarterly
D. Annually

95. At the end of the first year of operation on a fractional horsepower motor, what is the minimum number of drops of oil added to the machine?

A. 30
B. 60
C. 70
D. 100

Trade Terms Introduced in this Chapter

Potential	The work done per unit charge in moving an infinitesimal point charge from a common reference point to the given point
Pitted	To become marked with pits or depressions
Arcing	A luminous bridge formed in a gap between two electrodes
Milliammeter	An instrument for measuring small electric currents, calibrated in milliamperes
Micrometer	An instrument for measuring small electric currents, calibrated in microamperes
Variable Resistor	Adjustable resistor used in applications that require the adjustment of current or the varying of resistance in an electrical circuit
Conduit	A structure containing one or more ducts
Infinity	The quality or state of being infinite
Hygroscopic	Absorbing or attracting moisture from the air
Deliquescent	To melt away
Armature	The part of an electric machine that includes the main current carrying winding and in which the electromotive force is induced
Commutator	A device for reversing the direction of current
Rotor	A rotating member of a machine
Stator	A portion of a machine that remains fixed with respect to rotating parts
Granules	A small particle

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

*Unified Facilities Criteria (*UFC*) 3-560-0*1 (Electrical Safety, Operation and Maintenance)

OSHA Regulations (Standards – 29 CFR)

American National Standards Institute (ANSI Z89.2-1971)

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