THIRD EDITION

Understanding MOTOR CONTROLS

Stephen L. Herman

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Understanding Motor Controls, Third Edition
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TABLE OF CONTENTS

PREFACE

A Note from the Author

I have taught the subject of motor control for over 30 years. I have tried different methods and found that some are more successful than others. *Understanding Motor Controls* is the accumulation of this knowledge. I am sure other methods may work equally well, but the methods and information presented in this textbook have worked the best for me. My goal in writing this textbook is to present the subject of motor control in a way that the average student can understand. I have three main objectives:

- Teach the student how to interpret the logic of a schematic diagram.
- Teach the student how to properly connect a circuit using a schematic diagram.
- Teach the student how to troubleshoot a control circuit.

Understanding Motor Controls assumes that the student has no knowledge of motor controls. The student is expected to have knowledge of basic Ohm's law and basic circuits, such as series, parallel, and combination. The book begins with an overview of safety. A discussion of schematics (ladder diagrams) and wiring diagrams is presented early. The discussion of schematics and wiring diagrams is intended to help students understand the written language of motor controls. Standard NEMA symbols are discussed and employed throughout the book when possible. The operation of common control devices is presented to help students understand how these components function and how they are used in motor control circuits. Basic control circuits are presented in a manner that allows students to begin with simple circuit concepts and progress to more complicated circuits.

The textbook contains examples of how a schematic or ladder diagram is converted into a wiring diagram. A basic numbering system is explained and employed to aid students in making this conversion. This is the most effective method I have found of teaching a student how to make the transition from a circuit drawn on paper to properly connecting components in the field.

Understanding Motor Controls also covers solid-state controls for both DC and AC motors. Variable frequency drives and programmable logic controllers are covered in detail. I explain how to convert a ladder diagram into a program that can be loaded into a PLC. The book contains many troubleshooting problems that help the student understand the logic of a control system. Circuit design is also used to help the student develop the concepts of circuit logic.

Understanding Motor Controls contains 16 hands-on laboratory exercises that are designed to use off-the-shelf motor control components. A list of materials and suggested vendors is given for the components used in the exercises. The laboratory exercises begin with very basic concepts and connections and progress through more complicated circuits.

Supplements

An online Instructor Companion website contains an Instructor Guide with answers to end of chapter review questions, test banks, and Chapter presentations done in PowerPoint, and testing powered by Cognero.

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Stephen Vossler, Lansing Community College
Keith Dinwiddie, Ozarks Community College

New for the Third Edition

Updated Illustrations
Extended coverage of control components.
Comparison of NEMA symbols and IEC symbols.
Additional information concerning pressure switches.
Extended coverage of troubleshooting.
Coverage of relays with mercury wetted contacts.
Code references have been updated to the 2014 NEC.
Added information concerning troubleshooting motors.

SAFETY OVERVIEW

SAFETY OVERVIEW

Objectives

After studying this chapter the student will be able to:

- State basic safety rules.
- Describe the effects of electric current on the body.
- Discuss the origin and responsibilities of OSHA.
- Discuss material safety data sheets.
- Discuss lockout and tagout procedures.
- Discuss types of protective clothing.
- Explain how to properly place a straight ladder against a structure.
- Discuss different types of scaffolds.
- Discuss classes of fires.
- Discuss ground-fault circuit interrupters.
- Discuss the importance of grounding.

Safety is the job of each individual. You should be concerned not only with your own safety but with the safety of others around you. This is especially true for persons employed in the electrical field. Some general rules should be followed when working with electric equipment or circuits.

General Safety Rules

Never Work on an Energized Circuit If the Power Can Be Disconnected

When possible, use the following three-step check to make certain that power is turned off.

1. Test the **meter** on a known live circuit to make sure the meter is operating.
2. Test the circuit that is to become the **de-energized circuit** with the meter.
3. Test the meter on the known live circuit again to make certain the meter is still operating.

Install a warning tag at the point of **disconnection** so people will not restore power to the circuit. If possible, use a lock to prevent anyone from turning the power back on.

Think

Of all the rules concerning safety, this one is probably the most important. No amount of safeguarding or **idiot proofing** a piece of equipment can protect a person as well as taking time to think before acting. Many technicians have been killed by supposedly "dead" circuits. Do not depend on circuit breakers, fuses, or someone else to open a circuit. Test it yourself before you touch it. If you are working on high-voltage equipment, use insulated gloves and meter probes to measure the voltage being tested. *Think* before you touch something that could cost you your life.

Avoid Horseplay

Jokes and **horseplay** have a time and place but not when someone is working on an electric circuit or a piece of moving machinery. Do not be the cause of someone's being injured or killed and do not let someone else be the cause of your being injured or killed.

Do Not Work Alone

This is especially true when working in a hazardous location or on a live circuit. Have someone with you who can turn off the power or give **artificial respiration** and/or **cardiopulmonary resuscitation (CPR).** Several electric shocks can cause breathing difficulties and can cause the heart to go into fibrillation.

Work with One Hand When Possible

The worst kind of electric shock occurs when the current path is from one hand to the other, which permits the current to pass directly through the heart. A person can survive a severe shock between the hand and foot but it would cause death if the current path was from one hand to the other.

Learn First Aid

Anyone working on electric equipment, especially those working with voltages greater than 50 volts, should make an effort to learn first aid. A knowledge of first aid, especially CPR, may save your own or someone else's life.

Avoid Alcohol and Drugs

The use of alcohol and drugs has no place on a work site. Alcohol and drugs are not only dangerous to users and those who work around them; they also cost industry millions of dollars a year. Alcohol and drug abusers kill thousands of people on the highways each year and are just as dangerous on a work site as they are behind the wheel of a vehicle. Many industries have instituted testing policies to screen for alcohol and drugs. A person who tests positive generally receives a warning the first time and is fired the second time.

Effects of Electric Current on the Body

Most people have heard that it is not the voltage that kills but the current. This is true, but do not be misled into thinking that voltage cannot harm you. Voltage is the force that pushes the current though the circuit. It can be compared to the pressure that pushes water through a pipe. The more pressure available, the greater the volume of water flowing through the pipe. Students often ask how much current will flow through the body at a particular voltage. There is no easy answer to this question. The amount of current that can flow at a particular voltage is determined by the resistance of the current path. Different people have different resistances. A body has less resistance on a hot day when sweating, because salt water is a very good conductor. What one eats and drinks for lunch can have an effect on the body's resistance as can the length of the current path. Is the current path between two hands or from one hand to one foot? All of these factors affect body resistance.

Figure S–1 illustrates the effects of different amounts of current on the body. This chart is general— some people may have less tolerance to electricity and others may have a greater tolerance.

A current of 2 to 3 **milliamperes (mA)** (0.002 to 0.003 amperes) usually causes a slight tingling sensation, which increases as current increases and becomes very noticeable at about 10 milliamperes (0.010 amperes). The

Figure S–1 The effects of electric current on the body.

tingling sensation is very painful at about 20 milliamperes. Currents between 20 and 30 milliamperes cause a person to seize the line and be unable to let go of the circuit. Currents between 30 and 40 milliamperes cause muscular paralysis, and those between 40 and 60 milliamperes cause breathing difficulty. When the current increases to about 100 milliamperes, breathing is extremely difficult. Currents from 100 to 200 milliamperes generally cause death because the heart usually goes into **fibrillation,** a condition in which the heart begins to "quiver" and the pumping action stops. Currents above 200 milliamperes cause the heart to squeeze shut. When the current is removed, the heart usually returns to a normal pumping action. This is the operating principle of a defibrillator. The voltage considered to be the most dangerous to work with is 120 volts, because that generally causes a current flow of between 100 and 200 milliamperes through most people's bodies. Large amounts of current can cause severe electric burns that are often very serious because they occur on the inside of the body. The exterior of the body may not look seriously burned, but the inside may be severely burned.

On the Job

OSHA

OSHA is an acronym for Occupational Safety and Health Administration, U.S. Department of Labor. Created by congress in 1971, its mission is to ensure safe and healthful workplaces in the United States. Since its creation, workplace fatalities have been cut in half, and occupational injury and illness rates have declined by 40%. Enforcement of OHSA regulations is the responsibility of the Secretary of Labor.

OSHA standards cover many areas, such as the handling of hazardous materials, fall protection, protective clothing, and hearing and eye protection. Part 1910 Subpart S deals mainly with the regulations concerning electrical safety. These regulations are available in books and can be accessed at the OSHA website on the Internet at www.osha.org.

Hazardous Materials

It may become necessary to deal with some type of hazardous material. A hazardous material or substance is any substance that if exposed to may result in adverse effects on the health or safety of employees. Hazardous materials may be chemical, biological, or nuclear. OSHA sets standards for dealing with many types of hazardous materials. The required response is determined by the type of hazard associated with the material. Hazardous materials are required to be listed as such. Much information concerning hazardous materials is generally found on **Material Safety Data Sheets (MSDS).** (A sample MSDS is included at the end of the unit.) If you are working in an area that contains hazardous substances, always read any information concerning the handling of the material and any safety precautions that should be observed. After a problem exists is not the time to start looking for information on what to do.

Some hazardous materials require a Hazardous Materials Response Team (HAZMAT) to handle any problems. A HAZMAT is any group of employees designated by the employer that are expected to handle and control an actual or potential leak or spill of a hazardous material. They are expected to work in close proximity to the material. A HAZMAT is not always a fire brigade, and a fire brigade may not necessarily have a HAZMAT. On the other hand, HAZMAT may be part of a fire brigade or fire department.

Employer Responsibilities

Section 5(a)1 of the Occupational Safety and Health Act basically states that employers must furnish each of their employees a place of employment that is free of recognized hazards that are likely to cause death or serious injury. This places the responsibility for compliance on employers. Employers must identify hazards or potential hazards within the work site and eliminate them, control them, or provide employees with suitable protection from them. It is the employee's responsibility to follow the safety procedures set up by the employer.

To help facilitate these safety standards and procedures, OSHA requires that an employer have a competent person oversee implementation and enforcement of these standards and procedures. This person must be able to recognize unsafe or dangerous conditions and have the authority to correct or eliminate them. This person also has the authority to stop work or shut down a work site until safety regulations are met.

MSDS

MSDS stands for material safety data sheets, which are provided with many products. They generally warn users of any hazards associated with the product. They outline the physical and chemical properties of the product; list precautions that should be taken when using the product; and list any potential health hazards, storage consideration, flammability, reactivity, and, in some instances, radioactivity. They sometimes list the name, address, and telephone number of the manufacturer; the MSDS date and emergency telephone numbers; and, usually, information on first aid procedures to use if the product is swallowed or comes in contact with the skin. Safety data sheets can be found on many home products such as cleaning products, insecticides, and flammable liquids.

Trenches

It is often necessary to dig trenches to bury conduit. Under some conditions, these trenches can be deep enough to bury a person if a cave-in occurs. Safety regulations for the shoring of trenches is found in OSHA Standard 1926 Subpart P App C titled "Timber Shoring for Trenches." These procedures and regulations are federally mandated and must be followed. Some general safety rules should be followed, such as:

1. Do not walk close to trenches unless it is necessary. This can cause the dirt to loosen and increase the possibility of a cave-in.
2. Do not jump over trenches if it is possible to walk around them.
3. Place barricades around trenches (Figure S–2).
4. Use ladders to enter and exit trenches.

Confined Spaces

Confined spaces have a limited means of entrance or exit (Figure S–3). They can be very hazardous workplaces, often containing atmospheres that are extremely harmful or deadly. Confined spaces are very difficult to ventilate because of their limited openings. It is often necessary for a worker to wear special clothing and use a separate air supply. OSHA Section 12: "Confined Space Hazards," lists rules and regulations for working in a confined space. In addition, many industries have written procedures that must be followed when working in confined spaces. Some general rules include the following:

Figure S–2 Place a barricade around a trench and use a ladder to enter and exit the trench.

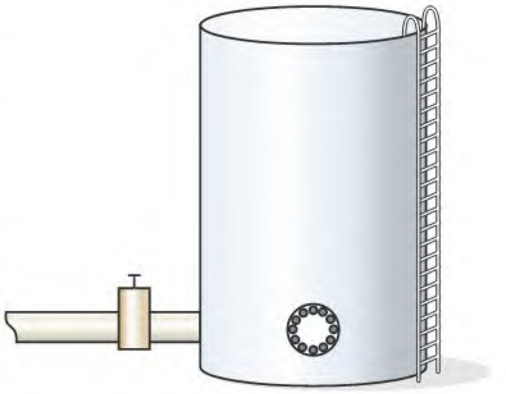

Figure S–3 A confined space is any space having a limited means of entrance or exit.

1. Have a person stationed outside the confined space to watch the person or persons working inside. The outside person should stay in voice or visual contact with the inside workers at all times. He or she should check air sample readings and monitor oxygen and explosive gas levels.
2. The outside person should never enter the space, even in an emergency, but should contact the proper emergency personnel. If he or she enters the space and become incapacitated, no one would be available to call for help.
3. Use only electric equipment and tools that are approved for the atmosphere found inside the confined area. It may be necessary to obtain a burning permit to operate tools that have open brushes and that spark when they are operated.
4. As a general rule, a person working in a confined space should wear a harness with a lanyard that extends to the outside person, so the outside person could pull him or her to safety if necessary.

Lockout and Tagout Procedures

Lockout and tagout procedures are generally employed to prevent someone from energizing a piece of equipment by mistake. This could apply to switches, circuit breakers, or valves. Most industries have their own internal policies and procedures. Some require that a tag similar to the one shown in Figure S–4 be placed on the piece

Figure S–4 Safety tag used to tagout equipment.

of equipment being serviced; some also require that the equipment be locked out with a padlock. The person performing the work places the lock on the equipment and keeps the key in his or her possession. A device that permits the use of multiple padlocks and a safety tag is shown in Figure S–5. This is used when more than one person is working on the same piece of equipment. Violating lockout and tagout procedures is considered an extremely serious offense in most industries and often results in immediate termination of employment. As a general rule, there are no first-time warnings.

After locking out and tagging a piece of equipment, it should be tested to make certain that it is truly de-energized before working on it. A simple three-step procedure is generally recommended for making certain that a piece of electric equipment is de-energized. A voltage tester or voltmeter that has a high enough range to safely test the voltage is employed. The procedure is as follows:

Figure S–5 The equipment can be locked out by several different people.

1. Test the voltage tester or voltmeter on a known **energized circuit** to make certain the tester is working properly.
2. Test the circuit you intend to work on with the voltage tester or voltmeter to make sure that it is truly de-energized.
3. Test the voltage tester or voltmeter on a known energized circuit to make sure that the tester is still working properly.

This simple procedure helps to eliminate the possibility of a faulty piece of equipment indicating that a circuit is de-energized when it is not.

Protective Clothing

Maintenance and construction workers alike are usually required to wear certain articles of protective clothing, dictated by the environment of the work area and the job being performed.

Head Protection

Some type of head protection is required on almost any work site. A typical electrician's hard hat, made of nonconductive plastic, is shown in Figure S–6. It has a pair of safety goggles attached that can be used when desired or necessary.

Eye Protection

Eye protection is another piece of safety gear required on almost all work sites. Eye protection can come in different forms, ranging from the goggles shown in Figure S–6 to the safety glasses with side shields shown in Figure S–7. Common safety glasses may or may not be prescription glasses, but almost all provide side protection (Figure S–7). Sometimes a full face shield may be required.

Hearing Protection

Section III, Chapter 5 of the OSHA Technical Manual includes requirements concerning hearing protection.

Figure S–6 Typical electrician's hard hat with attached safety goggles.

The need for hearing protection is based on the ambient sound level of the work site or the industrial location. Workers are usually required to wear some type of hearing protection when working in certain areas, usually in the form of earplugs or earmuffs.

Fire-Retardant Clothing

Special clothing made of fire-retardant material is required in some areas, generally certain industries as opposed to all work sites. **Fire-retardant clothing** is often required for maintenance personnel who work with high-power sources such as transformer installations and motor-control centers. An arc flash in a motor-control center can easily catch a person's clothes on fire. The typical motor-control center can produce enough energy during an arc flash to kill a person 30 feet away.

Gloves

Another common article of safety clothing is gloves. Electricians often wear leather gloves with rubber inserts when it is necessary to work on energized circuits (Figure S–8). These gloves are usually rated for a certain amount of voltage. They should be inspected for holes or tears before they are used. Kevlar gloves (Figure S–9) help protect against cuts when stripping cable with a sharp blade.

Safety Harness

Safety harnesses provide protection from falling. They buckle around the upper body with leg, shoulder, and chest straps; and the back has a heavy metal D-ring (Figure S–10). A section of rope approximately 6 feet

Figure S–7 Safety glasses provide side protection.

Figure S–8 Leather gloves with rubber inserts.

Figure S–9 Kevlar gloves protect against cuts.

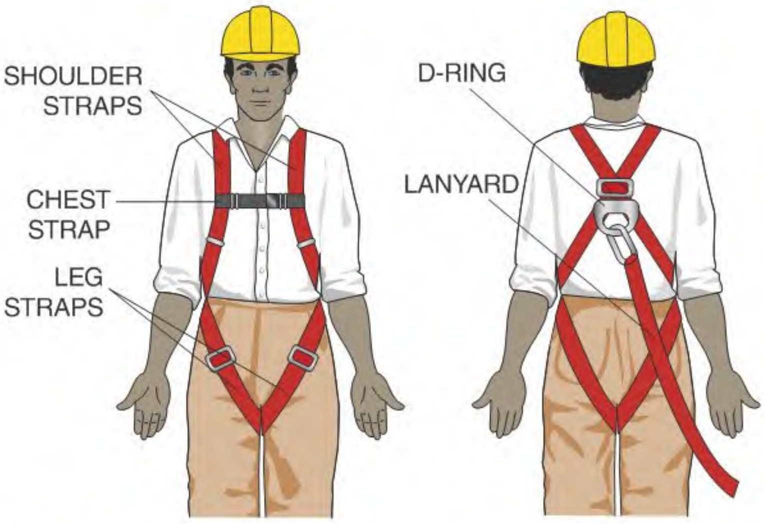

Figure S–10 Typical safety harness.

in length, called a lanyard, is attached to the D-ring and secured to a stable structure above the worker. If the worker falls, the lanyard limits the distance he or she can drop. A safety harness should be worn:

1. When working more than 6 feet above the ground or floor
2. When working near a hole or drop-off
3. When working on high scaffolding

A safety harness is shown in Figure S–11.

Figure S–11 Safety harness.

Ladders and Scaffolds

It is often necessary to work in an elevated location. When this is the case, ladders or scaffolds are employed. **Scaffolds** generally provide the safest elevated working platforms. They are commonly assembled on the work site from standard sections (Figure S–12). The bottom sections usually contain adjustable feet that can be used to level the sections. Two end sections are connected by X braces that form a rigid work platform (Figure S–13). Sections of scaffolding are stacked on top of each other to reach the desired height.

Rolling Scaffolds

Rolling scaffolds are used in areas that contain level floors, such as inside a building. The major difference between a rolling scaffold and those discussed previously is that it is equipped with wheels on the bottom section

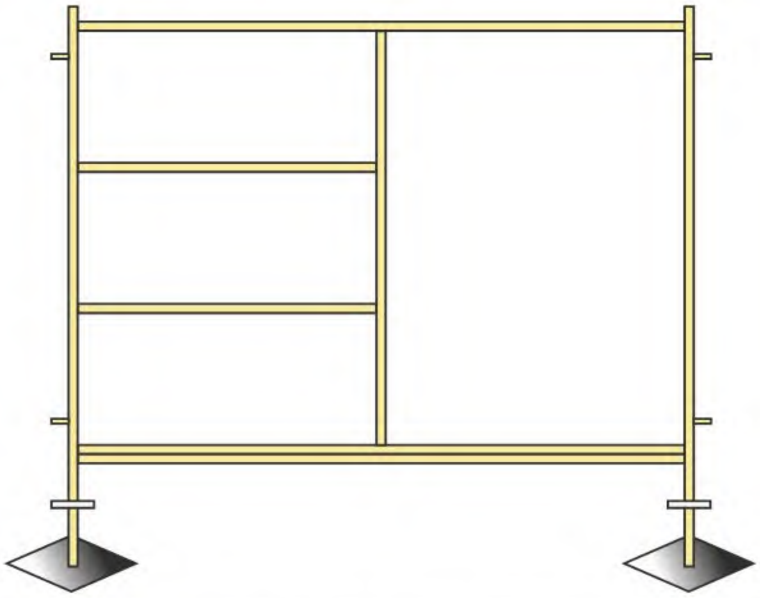

Figure S–12 Typical section of scaffolding.

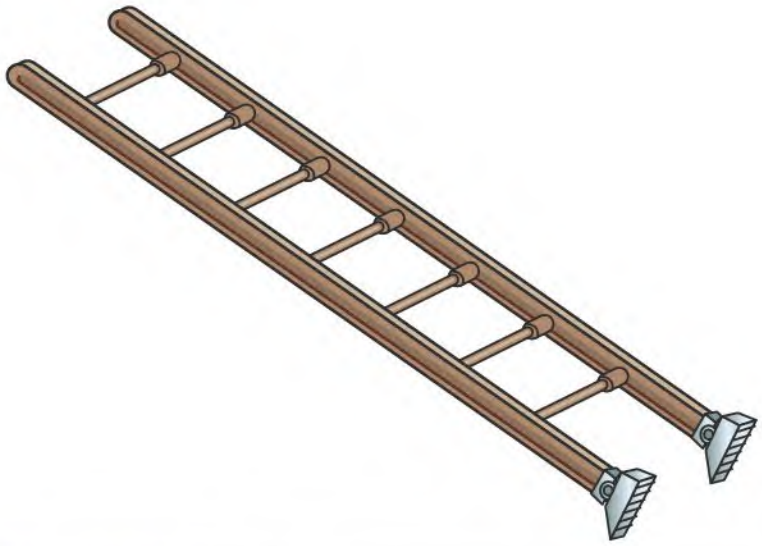

Figure S–14 Straight ladder.

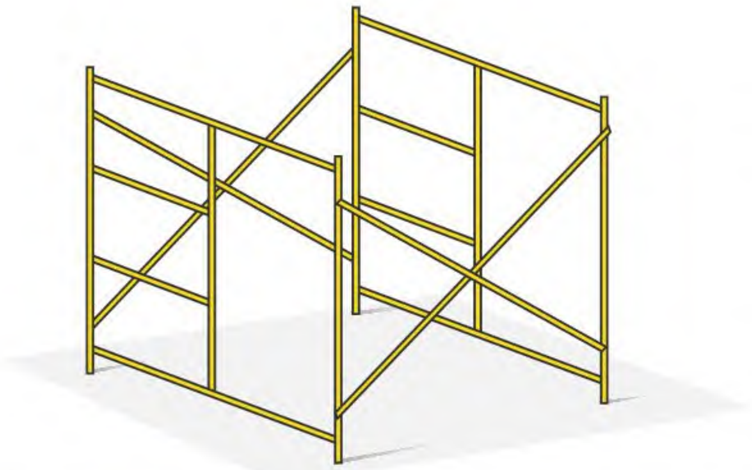

Figure S–13 X braces connect scaffolding sections together.

that permit it to be moved from one position to another. The wheels usually contain a mechanism that permits them to be locked after the scaffold is rolled to the desired location.

Hanging or Suspended Scaffolds

Hanging or suspended scaffolds are suspended by cables from a support structure. They are generally used on the sides of buildings to raise and lower workers by using hand cranks or electric motors.

Straight Ladders

Ladders can be divided into two main types, straight and step. Straight ladders are constructed by placing rungs between two parallel rails (Figure S–14). They generally contain safety feet on one end that help prevent the ladder from slipping. Ladders used for electrical work are usually wood or fiberglass; aluminum ladders are avoided because they conduct electricity. Regardless of the type of ladder used, you should check its load capacity before using it. This information is found on the side of the ladder. Load capacities of 200 pounds, 250 pounds, and 300 pounds are common. Do not use a ladder that does not have enough load capacity to support your weight plus the weight of your tools and the weight of any object you are taking up the ladder with you.

Straight ladders should be placed against the side of a building or other structure at an angle of approximately 76° (Figure S–15). This can be accomplished by moving the base of the ladder away from the structure a distance equal to one fourth the height of the ladder. If the ladder is 20 feet high, it should be placed 5 feet from the base of the structure. If the ladder is to provide access to the top of the structure, it should extend 3 feet above the structure.

Step Ladders

Step ladders are self-supporting, constructed of two sections hinged at the top (Figure S–16). The front section has two rails and steps, the rear portion two rails and braces. Like straight ladders, step ladders are designed to withstand a certain load capacity. Always check the load capacity before using a ladder. As a general rule, ladder manufacturers recommend that the top step not be used because of the danger of becoming unbalanced and falling. Many people mistakenly think the top step is the top of the ladder, but it is actually the last step before the ladder top.

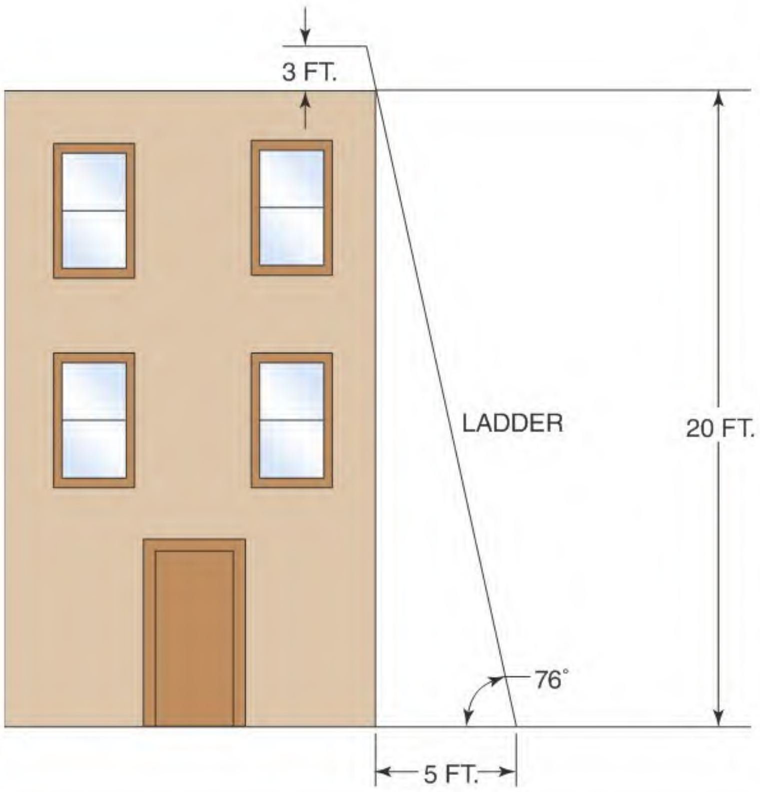

Figure S–15 A ladder should be placed at an angle of approximately 76°.

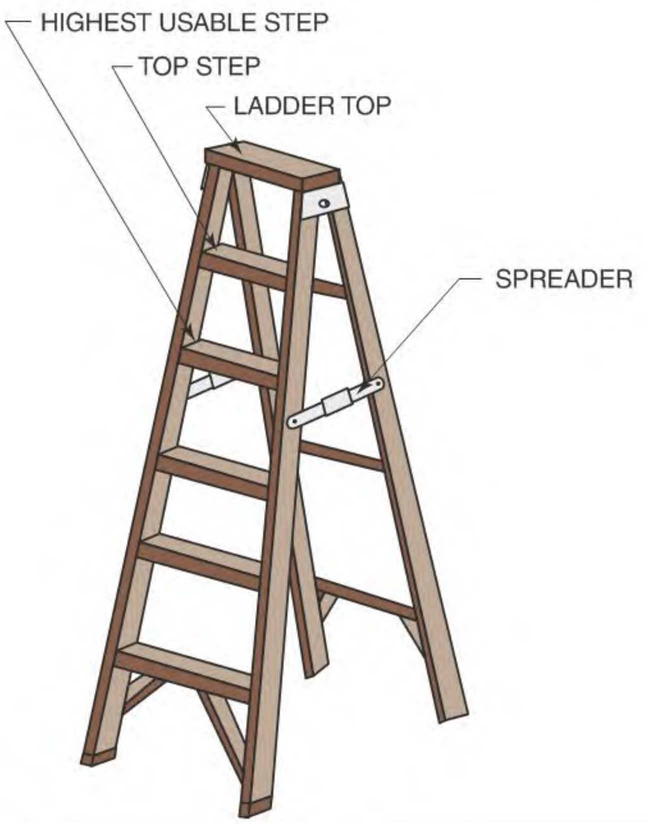

Figure S–16 Typical step ladder.

Fires

For a fire to burn, it must have three things: fuel, heat, and oxygen. Fuel is anything that can burn, including materials such as wood, paper, cloth, combustible dusts, and even some metals. Different materials require different amounts of heat for combustion to take place. If the temperature of any material is below its combustion temperature, it will not burn. Oxygen must be present for combustion to take place. If a fire is denied oxygen, it will extinguish.

Fires are divided into four classes: A, B, C, and D. Class A fires involve common combustible materials such as wood or paper. They are often extinguished by lowering the temperature of the fuel below the combustion temperature. Class A fire extinguishers often use water to extinguish a fire. A fire extinguisher listed as Class A only should never be used on an electrical fire.

Class B fires involve fuels such as grease, combustible liquids, or gases. A Class B fire extinguisher generally employs carbon dioxide (CO_2), which greatly lowers the temperature of the fuel and deprives the fire of oxygen. Carbon dioxide extinguishers are often used on electrical fires, because they do not destroy surrounding equipment by coating it with a dry powder.

Class C fires involve energized electric equipment. A Class C fire extinguisher usually uses a dry powder to smother the fire. Many fire extinguishers can be used on multiple types of fires; for example, an extinguisher labeled ABC could be used on any of the three classes of fire. The important thing to remember is never to use an extinguisher on a fire for which it is not rated. Using a Class A extinguisher filled with water on an electrical fire could be fatal.

Class D fires consist of burning metal. Spraying water on some burning metals actually can cause the fire to increase. Class D extinguishers place a powder on top of the burning metal that forms a crust to cut off the oxygen supply to the metal. Some metals cannot be extinguished by placing powder on them, in which case the powder should be used to help prevent the fire from spreading to other combustible materials.

Ground-Fault Circuit Interrupters

Ground-fault circuit interrupters (GFCI) are used to prevent people from being electrocuted. They work by sensing the amount of current flow on both the ungrounded (hot) and grounded (neutral) conductors supplying power to a device. In theory, the amount of current in both conductors should be equal but opposite in polarity (Figure S–17). In this example, a current of 10 amperes flows in both the hot and neutral conductors.

A ground fault occurs when a path to ground other than the intended path is established (Figure S–18).

Assume that a person comes in contact with a defective electric appliance. If the person is grounded, a current path can be established through the person's body. In the example shown in Figure S–18, it is assumed that a current of 0.1 ampere is flowing through the person. This means that the hot conductor now has a current of 10.1 amperes but the neutral conductor has a current of only 10 amperes. The GFCI is designed to detect this current difference to protect personnel by opening the circuit when it detects a current difference of approximately 5 milliamperes (0.005 ampere). The *National Electrical Code® (NEC®) 210.8* lists places where ground-fault protection is required in dwellings. The *National Electrical Code®* and *NEC®* are registered trademarks of the National Fire Protection Association, Quincy, MA.

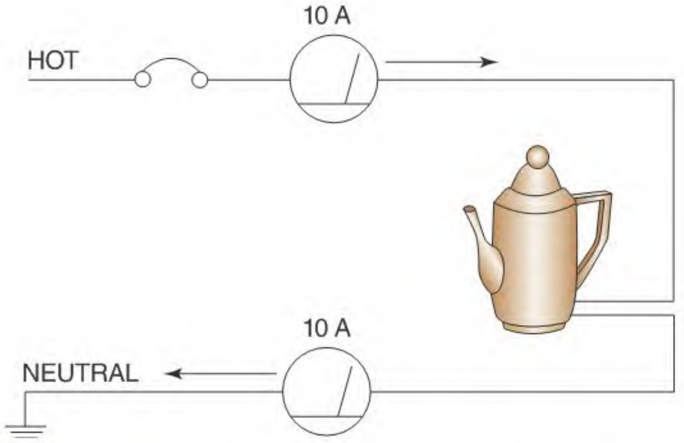

Figure S–17 The current in both the hot and neutral conductors should be the same but flowing in opposite directions.

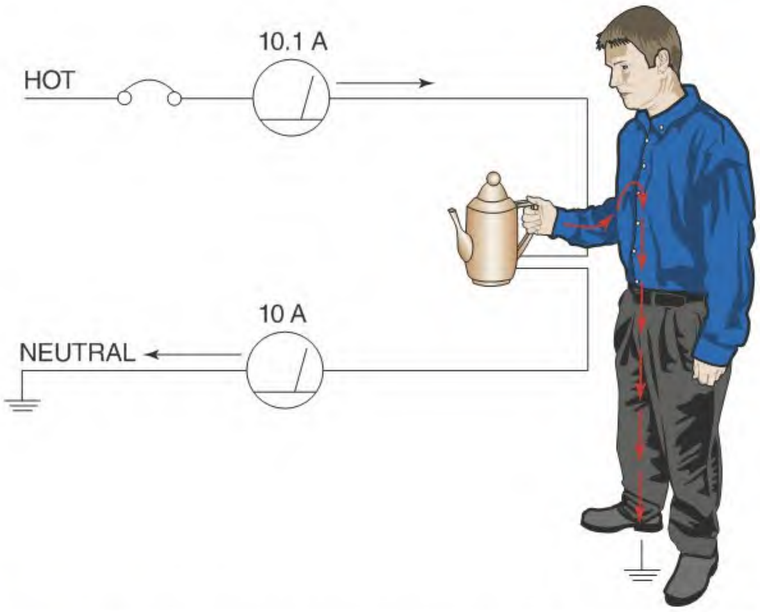

Figure S–18 A ground fault occurs when a path to ground other than the intended path is established.

GFCI Devices

Several devices can be used to provide ground-fault protection, including the ground-fault circuit breaker (Figure S–19). The circuit breaker provides ground-fault protection for an entire circuit, so any device connected to the circuit is ground-fault protected. A second method of protection, ground-fault receptacles (Figure S–20), provide protection at the point of attachment. They have some advantages over the GFCI circuit breaker. They can be connected so that they protect only the devices connected to them and do not protect any other outlets on the same circuit, or they can be connected so they provide protection to other outlets. Another advantage is that, because they are located at the point of attachment for the device, there is no stray capacitance loss between the panel box and the equipment is being protected. Long wire runs often cause nuisance tripping of GFCI circuit breakers. A third ground-fault protective device is the GFCI extension cord (Figure S–21). It can be connected into any standard electric outlet, and any devices connected to it are then ground-fault protected.

Figure S–19 Ground-fault circuit breaker.

Figure S–20 Ground-fault receptacle.

Figure S–21 Ground-fault extension.

Grounding

Grounding is one of the most important safety considerations in the electrical field. Grounding provides a low resistance path to ground to prevent conductive objects from existing at a high potential. Many electric appliances are provided with a three-wire cord. The third prong is connected to the case of the appliance and forces the case to exist at ground potential. If an ungrounded conductor comes in contact with the case, the grounding conductors conduct the current directly to ground. The third prong on a plug should never be cut off or defeated. Grounding requirements are far too numerous to list in this chapter, but *NEC® 250* covers the requirements for the grounding of electrical systems.

Review Questions

1. What is the most important rule of electrical safety?
2. Why should a person work with only one hand when possible?
3. What range of electric current generally causes death?
4. What is fibrillation of the heart?
5. What is the operating principle of a defibrillator?
6. Who is responsible for enforcing OSHA regulations?
7. What is the mission of OSHA?
8. What is an MSDS?
9. A padlock is used to lock out a piece of equipment. Who should have the key?
10. A ladder is used to reach the top of a building 16 feet tall. What distance should the bottom of the ladder be placed from the side of the building?
11. What is a ground fault?
12. What is the approximate current at which a ground-fault detector will open the circuit?
13. Name three devices used to provide ground-fault protection.
14. What type of fire is Class B?
15. What section of the NEC® covers grounding?

Table S–1 Heavy Duty Clear LO-VAC PVC Cement.

Section 1	**Identity of Material**
Trade Name	OATEY HEAVY DUTY CLEAR LO-VOC PVC CEMENT
Product Numbers	31850, 31851, 31853, 31854
Formula	PVC Resin in Solvent Solution
Synonyms	PVC Plastic Pipe Cement
Firm Name & Mailing Address	OATEY CO., 4700 West 160th Street, P.O. Box 35906 Cleveland, Ohio 44135, U.S.A. http://www.oatey.com
Oatey Phone Number	1-216-267-7100
Emergency Phone Numbers	For Emergency First Aid call 1-303-623-5716 COLLECT. For chemical transportation emergencies ONLY, call Chemtrec at 1-800-424-9300
Prepared By	Charles N. Bush, Ph.D.

Section 2	**Hazardous Ingredients**		
Ingredients	**%**	**Cas Number**	**Sec 313**
Acetone	0–5%	67-64-1	No
Amorphous Fumed Silica (Non-Hazardous)	1–3%	112945-52-5	No
Proprietary (Nonhazardous)	5–15%	N/A	No
PVC Resin (Nonhazardous)	10–16%	9002-86-2	No
Cyclohexanone	5–15%	108-94-1	No
Tetrahydrofuran	30–50%	109-99-9	No
Methyl Ethyl Ketone	20–35%	78-93-3	Yes

Section 3	**Known Hazards Under U.S. 29 CFR 1910.1200**				
Hazards	**Yes**	**No**	**Hazards**	**Yes**	**No**
Combustible Liquid		x	Skin Hazard	x	
Flammable Liquid	x		Eye Hazard	x	
Pyrophoric Material		x	Toxic Agent	x	
Explosive Material		x	Highly Toxic Agent		x
Unstable Material		x	Sensitizer		x
Water Reactive Material		x	Kidney Toxin	x	
Oxidizer		x	Reproductive Toxin	x	
Organic Peroxide		x	Blood Toxin		x
Corrosive Material		x	Nervous System Toxin	x	
Compressed Gas		x	Lung Toxin	x	
Irritant	x		Liver Toxin	x	
Carcinogen NTP/IARC/OSHA		x			

Table S–1 Continued

Section 4	**Emergency and First Aid Procedures—Call 1-303-623-5716 Collect**
Skin	If irritation arises, wash thoroughly with soap and water. Seek medical attention if irritation persists. Remove dried cement with Oatey Plumber's Hand Cleaner or baby oil.
Eyes	If material gets into eyes or if fumes cause irritation, immediately flush eyes with water for 15 minutes. If irritation persists, seek medical attention.
Inhalation	Move to fresh air. If breathing is difficult, give oxygen. If not breathing, give artificial respiration. Keep victim quiet and warm. Call a poison control center or physician immediately. If respiratory irritation occurs and does not go away, seek medical attention.
Ingestion	**DO NOT INDUCE VOMITING.** This product may be aspirated into the lungs and cause chemical pneumonitis, a potentially fatal condition. Drink water and call a poison control center or physician immediately. Avoid alcoholic beverages. Never give anything by mouth to an unconscious person.
Section 5	**Fire Fighting Measures**
Precautions	Do not use or store near heat, sparks, or flames. Do not smoke when using. Vapors may accumulate in low places and may cause flash fires.
Special Fire Fighting Procedures	For Small Fires: Use dry chemical, CO_2, water, or foam extinguisher. For Large Fires: Evacuate area and call Fire Department immediately.
Section 6	**Accidental Release Measures**
Spill or Leak Procedures	Remove all sources of ignition and ventilate area. Stop leak if it can be done without risk. Personnel cleaning up the spill should wear appropriate personal protective equipment, including respirators if vapor concentrations are high. Soak up spill with absorbent material such as sand, earth, or other noncombusting material. Put absorbent material in covered, labeled metal containers. Contaminated absorbent material may pose the same hazards as the spilled product.
Section 7	**Handling and Storage**
Precautions	**HANDLING & STORAGE:** Keep away from heat, sparks, and flames; store in cool, dry place. **OTHER:** Containers, even empties, will retain residue and flammable vapors.
Section 8	**Exposure Controls/Personal Protection**
Protective Equipment Types	**EYES:** Safety glasses with side shields. **RESPIRATORY:** NIOSH-approved canister respirator in absence of adequate ventilation. **GLOVES:** Rubber gloves are suitable for normal use of the product. For long exposures to pure solvents chemical resistant gloves may be required. OTHER: Eye wash and safety shower should be available.
Ventilation	**LOCAL EXHAUST:** Open doors and windows. Exhaust ventilation capable of maintaining emissions at the point of use below PEL. If used in enclosed area, use exhaust fans. Exhaust fans should be explosion-proof or set up in a way that flammable concentrations of solvent vapors are not exposed to electrical fixtures or hot surfaces.

Table S–1 Continued

Section 9	**Physical and Chemical Properties**			
NFPA Hazard Signal	Health 2	Stability 1	Flammability 3	Special None
HMIS Hazard Signal	Health 3	Stability 1	Flammability 4	Special None
Boiling Point	151 Degrees F/66 C			
Melting Point	N/A			
Vapor Pressure	145 mmHg @ 20 Degrees C			
Vapor Density (Air = 1)	2.5			
Volatile Components	70–80%			
Solubility In Water	Negligible			
PH	N/A			
Specific Gravity	0.95 ± 0.015			
Evaporation Rate	(BUAC = 1) = 5.5 − 8.0			
Appearance	Clear Liquid			
Odor	Ether-Like			
Will Dissolve In	Tetrahydrofuran			
Material Is	Liquid			


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Section 1

BASIC CONTROL CIRCUITS AND COMPONENTS

Chapter 1

GENERAL PRINCIPLES OF MOTOR CONTROL

Objectives

After studying this chapter the student will be able to:

- State the purpose and general principles of motor control.
- Discuss the differences between manual and automatic motor control.
- Discuss considerations when installing motors or control equipment.
- Discuss the basic functions of a control system.
- Discuss surge protection for control systems.

Several factors should be considered when selecting the motor needed to perform a specific task and the control components that govern the operation of the motor. An electrician should not only be capable of properly installing a motor, but he or she should also be capable of maintaining the equipment and troubleshooting a control circuit when necessary. This textbook is designed to give students the skills they need to succeed in an industrial environment.

Many years ago, machines were operated by a line shaft (Figure 1–1). A central prime mover, whether a steam engine, electric motor, or water wheel, powered all the machines by connecting them to the line shaft with belts. Although this concept worked, the number of machines that could be operated at the same time was limited and control of the machine processes was very difficult. Some applications not only called for the machine to start and stop, but also to reverse direction, increase or decrease speed, and brake to a stop. The advent of connecting individual power sources to each machine changed the world of motor control forever.

Installation of Motors and Control Equipment

When installing electric motors and equipment, several factors should be considered. When a machine is installed, the motor, machine, and controls are all interrelated and must be considered as a unit. Some machines have the motor or motors and control equipment mounted on the machine itself when it is delivered from the manufacturer, and the electrician's job is generally to make a simple power connection to the machine. A machine of this type is shown in Figure 1–2. Other types of machines require separately mounted motors that are connected by belts, gears, or chains. Some

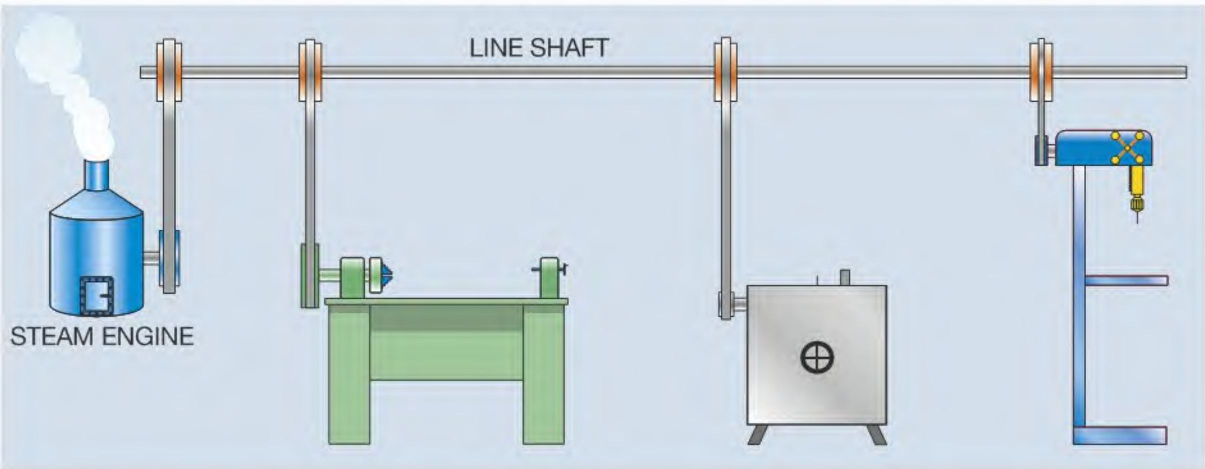


Figure 1–1 Power machines driven by a line shaft.

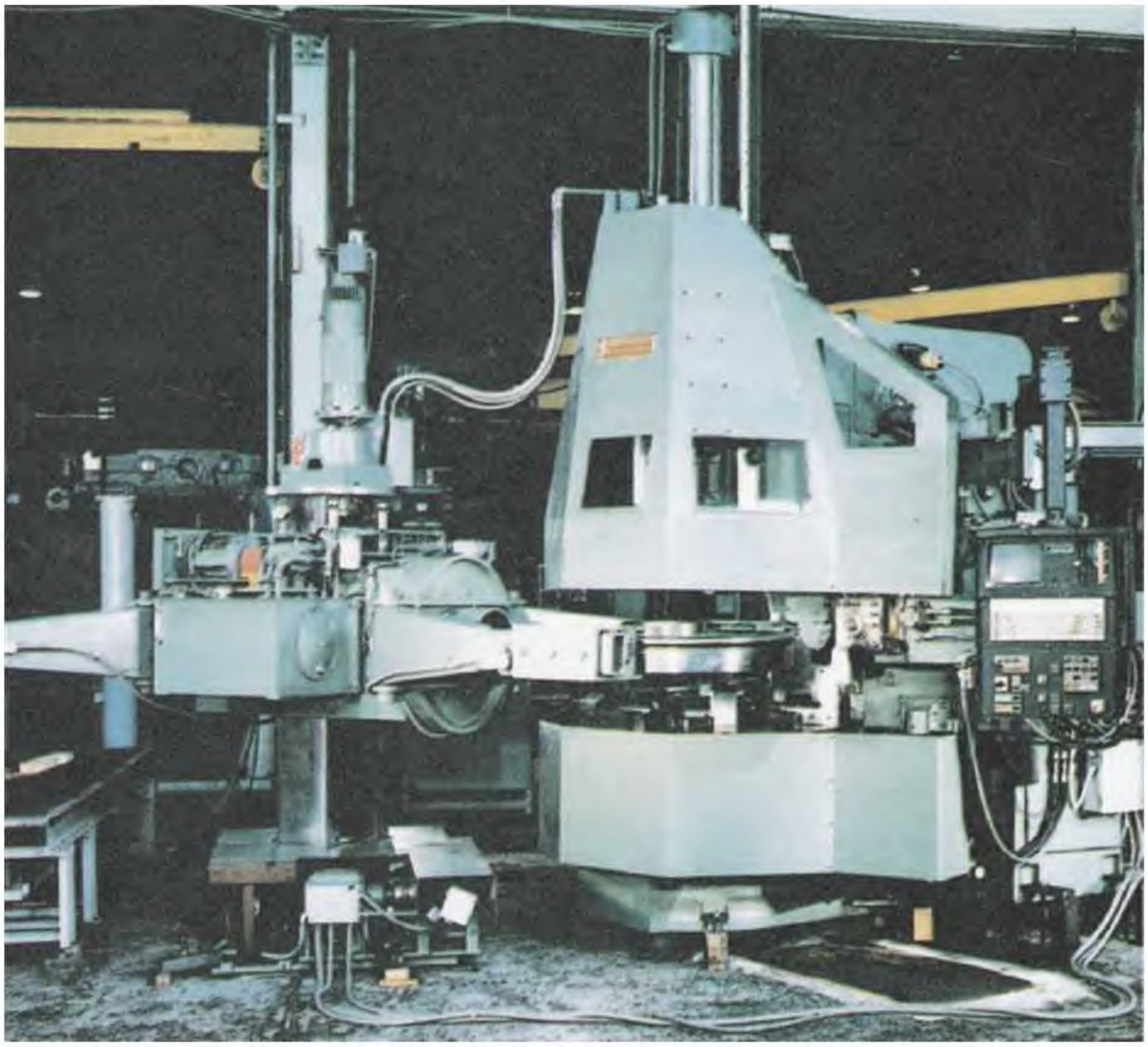


Figure 1–2 Machine was delivered with self-contained motors and controls.

machines also require the connection of pilot-sensing devices such as photo switches, limit switches, or pressure switches. Regardless of how easy or complex the connection is, several factors must be considered.

Power Source

One of the main considerations when installing a machine is the power source. Does the machine require single phase or three phase power to operate? What is the horsepower of the motor or motors to be connected? What is the amount of in-rush current that can be expected when the motor starts? Will the motor require some type of reduced voltage starter to limit in-rush current? Is the existing power supply capable of handling the power requirement of the machine or will it be necessary to install a new power system?

The availability of power can vary greatly from one area of the country to another. Companies that supply power to heavily industrialized areas can generally permit larger motors to be started across-the-line than companies that supply power to areas that have light industrial needs. In some areas the power company may permit a motor of several thousand horsepower to be started across-the-line, and in other areas the power company may require a reduced voltage starter for motors rated no more than one hundred horsepower.

Motor Connections

When connecting motors, several factors should be considered, such as **horsepower, service factor (SF),** marked temperature rise, **voltage,** full load current rating, and NEMA Code letter. This information is found on the motor nameplate. The conductor size, fuse or circuit breaker size, and overload size are generally determined using the *National Electrical Code*® *(NEC*®*)* and/or local codes. Local codes generally supersede the *National Electrical Code*® and should be followed when they apply. Motor installation based on the *NEC*® will be covered in this textbook.

Controller Type

Different operating conditions require different types of control. Some machines simply require the motor to start and stop. Some machines require a soft start, which means bringing the motor up to speed over a period of time instead of all at once. This is especially true of gear-driven machines or motors that must start heavy inertia loads, such as flywheels or centrifuges. Other machines may require variable speed or the application of a brake when the motor is stopped. Inching and jogging may also be a consideration. Regardless of the specific conditions, all control systems should be able to start and stop the motor, and also provide overload protection for the motor and short-circuit protection for the circuit.

Environment

Another consideration is the type of environment in which the motor and control system operates. Can the controls be housed in a general purpose enclosure similar to the one shown in Figure 1–3, or is the system subject to moisture or dust? Are the motor and controls to be operated in a hazardous area that requires explosion-proof enclosures similar to that shown in Figure 1–4? Some locations may contain corrosive vapor or liquid, or extremes of temperature. All of these conditions should be considered when selecting motors and control components.

Codes and Standards

Another very important consideration is the safety of the operator and persons that work around the machine. In 1970, the Occupational Safety and Health Act (OSHA) was established. In general, OSHA requires employers to provide an environment that is free of recognized hazards that are likely to cause serious injury.

Another organization that exhibits much influence on the electrical field is Underwriters Laboratories (UL). Insurance companies established Underwriters

Courtesy Schneider Electric USA, Inc.

Figure 1–3 Manual starter in a general purpose enclosure.

Figure 1–4 Magnetic starter in an explosion-proof enclosure.

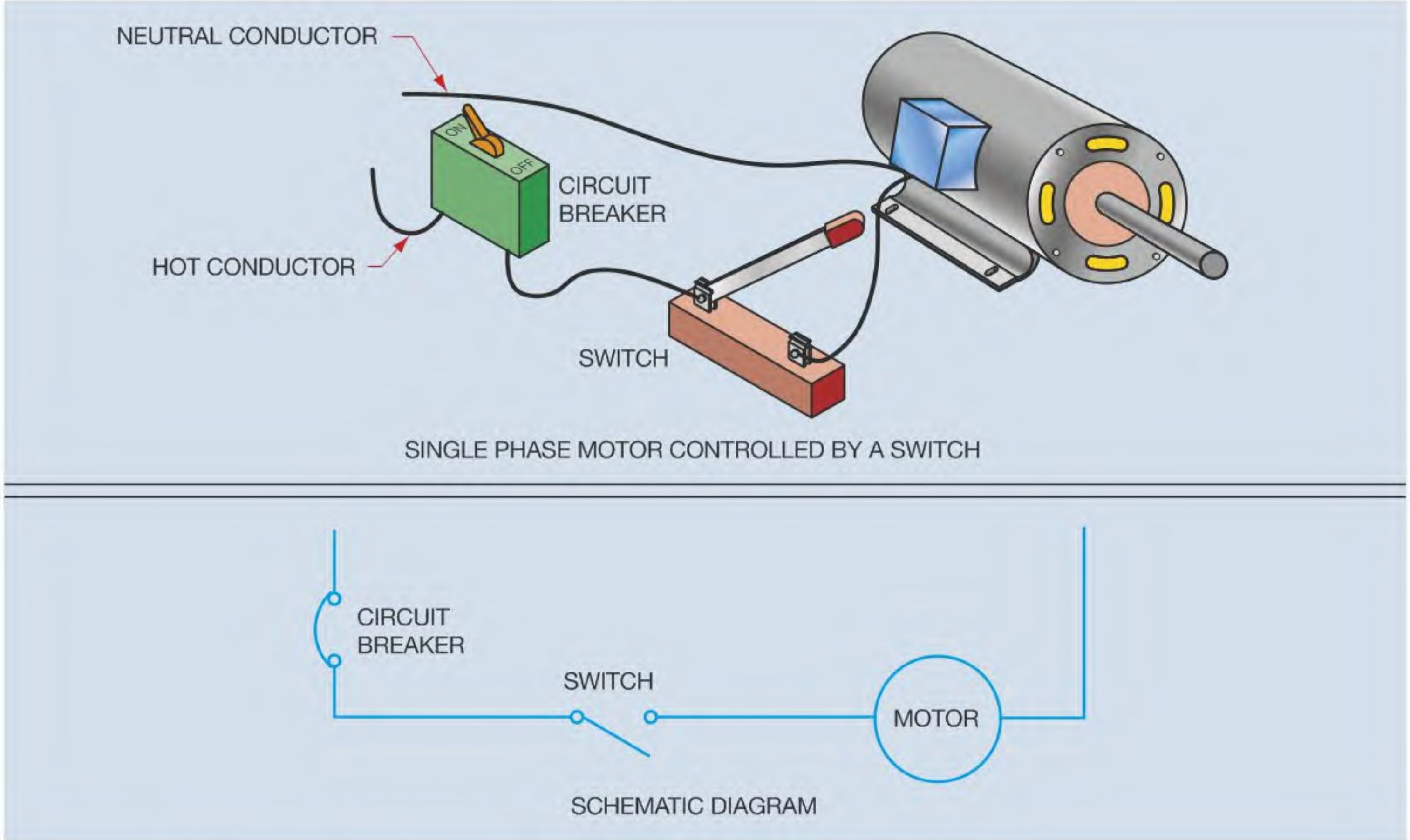


Figure 1–5 Pictorial and schematic diagram of a single phase motor controlled by a switch.

Laboratories in an effort to reduce the number of fires caused by electrical equipment. UL tests equipment to determine if it is safe under different conditions. Approved equipment is listed in its annual publication, which is kept current with bimonthly supplements.

A previously mentioned document is the ***National Electrical Code®***. The ***NEC®*** is published by the National Fire Protection Association. The *NEC®* establishes rules and specifications for the installation of electrical equipment. The *National Electrical Code®* is not a law unless it is made law by a local authority.

Two other organizations that have a great influence on control equipment are the **National Electrical Manufacturers Association (NEMA)** and the **International Electrotechnical Commission (IEC)**. Both of these organizations will be discussed later in the textbook.

Types of Control Systems

Motor control systems can be divided into three major types: manual, semiautomatic, and automatic. Manual controls are characterized by the fact that the operator must go to the location of the controller to initiate any change in the state of the control system. **Manual controllers** are generally very simple devices that connect the motor directly to the line. They may or may not provide overload protection or low voltage release. Manual control may be accomplished by simply connecting a switch in series with the motor (Figure 1–5).

Semiautomatic control is characterized by the use of push buttons, limit switches, pressure switches, and other sensing devices to control the operation of a magnetic contactor or starter. The starter actually connects the motor to the line and the push buttons and other pilot devices control the coil of the starter. This permits the actual control panel to be located away from the motor or starter. The operator must still initiate certain actions, such as starting and stopping, but he or she does not have to go to the location of the motor or starter to perform the action. A typical control panel is shown in Figure 1–6. A schematic and wiring diagram of a START–STOP push button station is shown in Figure 1–7. A **schematic diagram** shows components in their electrical sequence without regard for physical location. A **wiring diagram** is basically a pictorial representation of the control components with connecting wires. Although the

Figure 1–6 Typical operator's control panel.

two circuits shown in Figure 1–7 look different, electrically they are the same.

Automatic control is very similar to semiautomatic control, in that pilot-sensing devices are employed to operate a magnetic contactor or starter that actually controls the motor. With automatic control, however, an operator does not have to initiate certain actions. Once the control conditions have been set, the system continues to operate on its own. A good example of an automatic control system is the heating and cooling system found in many homes. Once the thermostat has been set to the desired temperature, the heating or cooling system operates without further attention of the home owner. The control circuit contains sensing devices that automatically shut the system down in the event of an unsafe condition such as motor overload, excessive current, or no pilot light or ignition in gas heating systems.

Functions of Motor Control

Motor control systems perform some basic functions. The ones listed are by no means the only ones, but are very common. These basic functions will be discussed in greater detail in this book. It is important to not only understand these basic functions of a control system but also to know how control components are employed to achieve the desired circuit logic.

Starting

Starting the motor is one of the main purposes of a motor control circuit. Several methods can be employed depending on the requirements of the circuit. The simplest method is **across-the-line** starting. This is accomplished by connecting the motor directly to the

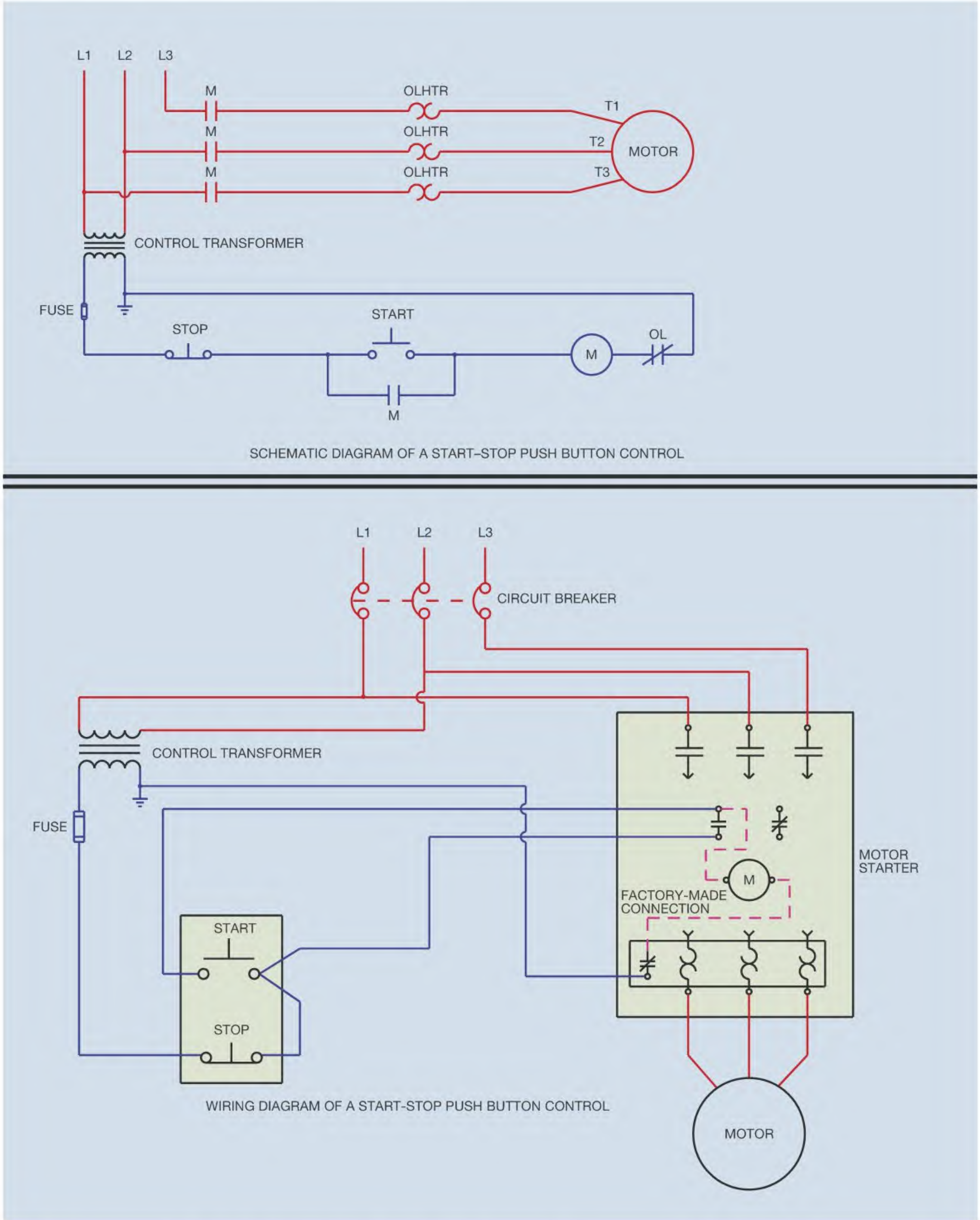


Figure 1–7 Schematic and wiring diagram of a start-stop push button control.

power line. Some situations, however, may require the motor to start at a low speed and accelerate to full speed over some period of time. This situation is often referred to as **ramping.** In other situations it may be necessary to limit the amount of current or torque during starting. Some of these methods will be discussed later in the textbook.

Stopping

Another function of the control system is to stop the motor. The simplest method is to disconnect the motor from the power line and permit it to coast to a stop. Some conditions, however, may require that the motor be stopped more quickly, or that a brake hold a load when the motor is stopped.

Jogging or Inching

Jogging and **inching** are methods employed to move a motor with short jabs of power—generally to move a motor or load into some desired position. The difference between jogging and inching is that jogging is accomplished by momentarily connecting the motor to full line voltage and inching is accomplished by momentarily connecting the motor to reduced voltage.

Speed Control

Some control systems require variable speed. There are several ways to accomplish variable speed. One of the most common is with variable frequency control for alternating current motors, or by controlling the voltage applied to the armature and fields of a direct current motor. Another method may involve the use of a direct current clutch. These methods will be discussed in more detail later in this textbook.

Motor and Circuit Protection

One of the major functions of most control systems is to provide protection for both the circuit components and the motor. Fuses and circuit breakers are generally employed for circuit protection, and overload relays are used to protect the motor. The different types of overload relays will be discussed later.

Surge Protection

Another concern in many control circuits is the voltage spikes or surges produced by collapsing magnetic fields when power to the coil of a relay or contactor is turned off. These collapsing magnetic fields can induce voltage spikes that are hundreds of volts (Figure 1–8). These high voltage surges can damage electronic components connected to the power line. Voltage spikes are of greatest concern in control systems that employ computer controlled devices, such as programmable logic controllers and measuring instruments used to sense temperature, pressure, and so on. Coils connected to alternating current often have a metal oxide varistor (**MOV**) connected across the coil (Figure 1–9). Metal oxide varistors are voltage-sensitive resistors. They have the ability to change their resistance value in accord with the amount of voltage applied to them. The MOV will have a voltage rating greater than that of the coil they are connected across. An MOV connected across a coil intended to operate on 120 volts, for example, will have a rating of about 140 volts. As long as the voltage applied to the MOV is below its voltage rating, it will exhibit an extremely high amount of resistance, generally several million ohms. The current flow through the MOV is called **leakage current** and is so small that it does not affect the operation of the circuit.

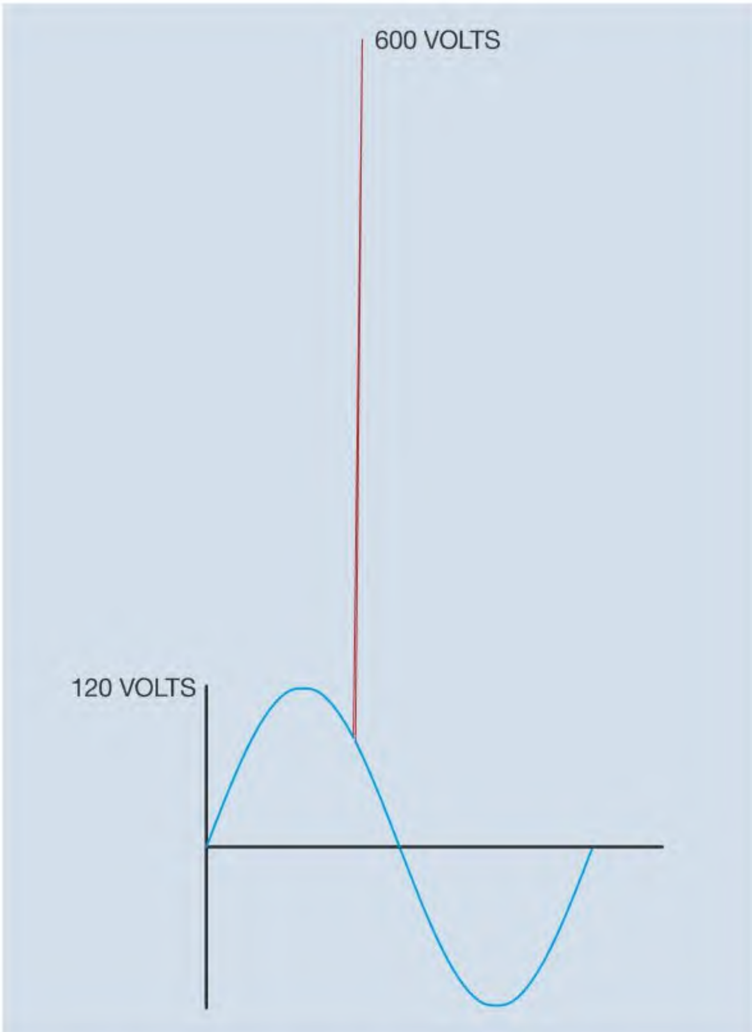


Figure 1–8 Voltage spikes can be hundreds of volts.

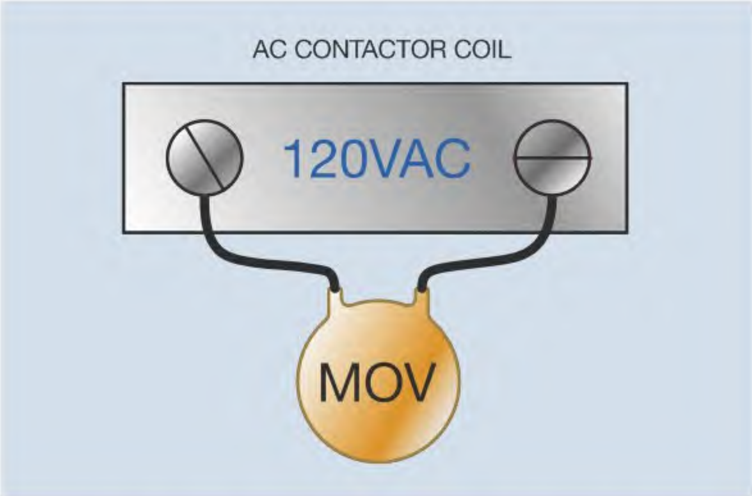


Figure 1–9 A metal oxide varistor is used to eliminate voltage spikes on alternating current coils.

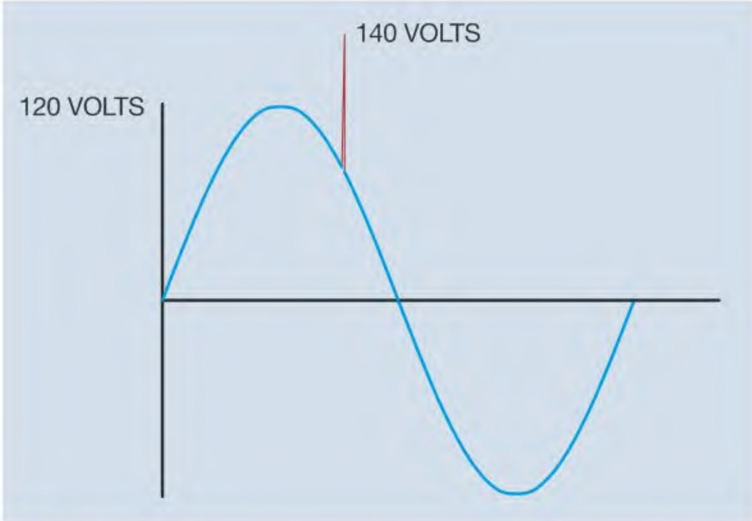


Figure 1–10 The metal oxide varistor limits the voltage spike to 140 volts.

If the voltage across the coil becomes greater than the voltage rating of the MOV, the resistance of the MOV suddenly changes to a very low value, generally in the range of 2 to 3 ohms. This effectively short-circuits the coil and prevents the voltage from becoming any higher than the voltage rating of the MOV (Figure 1–10). Metal oxide varistors change resistance value very quickly—generally in the range of 3 to 10 nanoseconds. When the circuit voltage drops below the MOV's voltage rating, it will return to its high resistance value. The MOV dissipates the energy of the voltage spike as heat.

Diodes are used to suppress the voltage spikes produced by coils that operate on direct current. The diode is connected reverse bias to the voltage connected to the coil, Figure 1–11. During normal operation, the diode blocks the flow of current, permitting all the circuit current to flow through the coil. When the power is disconnected, the magnetic field around the coil collapses and induces a voltage into the coil. Because the induced voltage is opposite in polarity to the applied voltage, (**Lenz's Law**), the induced voltage causes the diode to become forward biased. A silicon diode exhibits a forward voltage drop of approximately 0.7 volt. This limits the induced voltage to a value of about 0.7 volt. The energy of the voltage spike is dissipated as heat by the diode.

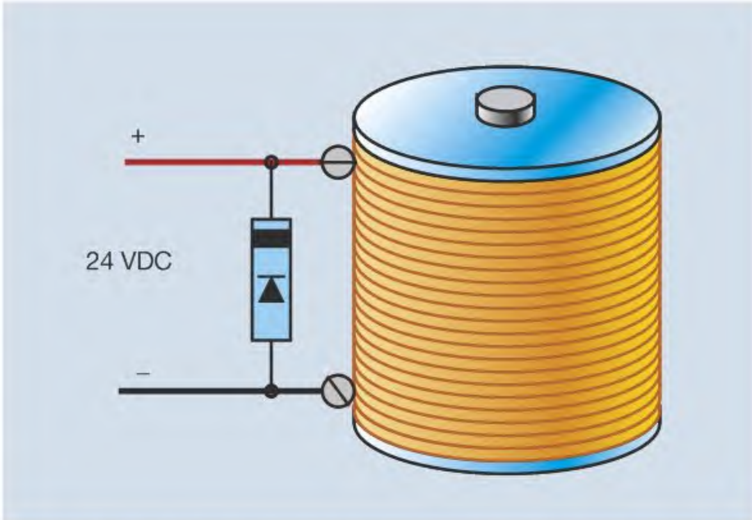


Figure 1–11 A diode is used to prevent voltage spikes on direct current coils.

Safety

Probably the most important function of any control system is to provide protection for the operator and persons that may be in the vicinity of the machine. Protection varies from one type of machine to another depending on the specific function of the machine. Many machines are provided with both mechanical and electrical safeguards.

Review Questions

1. When installing a motor control system, list four major factors to consider concerning the power system.
2. Where is the best place to look to find specific information about a motor, such as horsepower, voltage, full load current, service factor, and full load speed?
3. Is the *National Electrical Code®* a law?
4. Explain the difference between manual control, semiautomatic control, and automatic control.

5. What is the simplest of all starting methods for a motor?
6. Explain the difference between jogging and inching.
7. What is the most common method of controlling the speed of an alternating current motor?
8. What agency requires employers to provide a workplace free of recognized hazards for its employees?
9. What is meant by the term *ramping*?
10. What is the most important function of any control system?

Chapter 2

SYMBOLS AND SCHEMATIC DIAGRAMS

Objectives

After studying this chapter the student will be able to:

» Discuss symbols used in the drawing of schematic diagrams.

» Determine the difference between switches that are drawn normally open, normally closed, normally open held closed, and normally closed held open.

» Draw standard NEMA control symbols.

» State rules that apply to schematic or ladder diagrams.

» Interpret the logic of simple ladder diagrams.

When you learned to read, you were first taught a set of symbols that represented different sounds. This set of symbols is called the alphabet. Schematics and wiring diagrams are the written language of motor controls. Before you can learn to properly determine the logic of a control circuit, it is necessary to first learn the written language. Unfortunately, there is no actual standard used for motor control symbols. Different manufacturers and companies often use their own set of symbols for their in-house schematics. Also, schematics drawn in other countries may use an entirely different set of symbols to represent different control components. European schematics often contain symbols adopted by the International Electrotechnical Commission (IEC). Although symbols can vary from one manufacturer to another, or from one country to another, once you have learned to interpret circuit logic, it is generally possible to determine what the different symbols represent by the way they are used in the schematic. The most standardized set of symbols in the United States is provided by the National Electrical Manufacturer's Association (NEMA). It is these symbols that will be discussed in this chapter.

Push Buttons

One of the most commonly used symbols in control schematics is the push button. Push buttons can be shown as normally closed or normally open. Most are momentary contact devices in that they make or break connection as long as pressure is applied to them. When pressure is removed, they return to their normal position. Push buttons contain both movable and stationary contacts. The stationary contacts are connected to terminal screws. The normally open push button symbol is characterized by drawing the movable contact above and not touching the stationary contacts (Figure 2–1). Because the movable contact is not touching the stationary contacts the circuit is open and current cannot flow from one stationary contact to the other. The normally closed push button symbol is characterized by drawing the movable contact below and touching the two stationary contacts as shown in Figure 2–1. Because the movable contact is touching the two stationary contacts there is a complete circuit and current can flow from one stationary contact to the other.

Normally Closed Push Buttons

The movable contact of the normally closed push button makes contact with the two stationary contacts when no pressure is applied to the button as shown in Figure 2–2. Because the movable contact touches the two stationary contacts a complete circuit exists and current can flow from one stationary contact to the other. If pressure is applied to the button, the movable contact moves away from the two stationary contacts and opens the circuit. When pressure is removed from the button, a spring causes the movable contact to return and bridge the two stationary contacts.

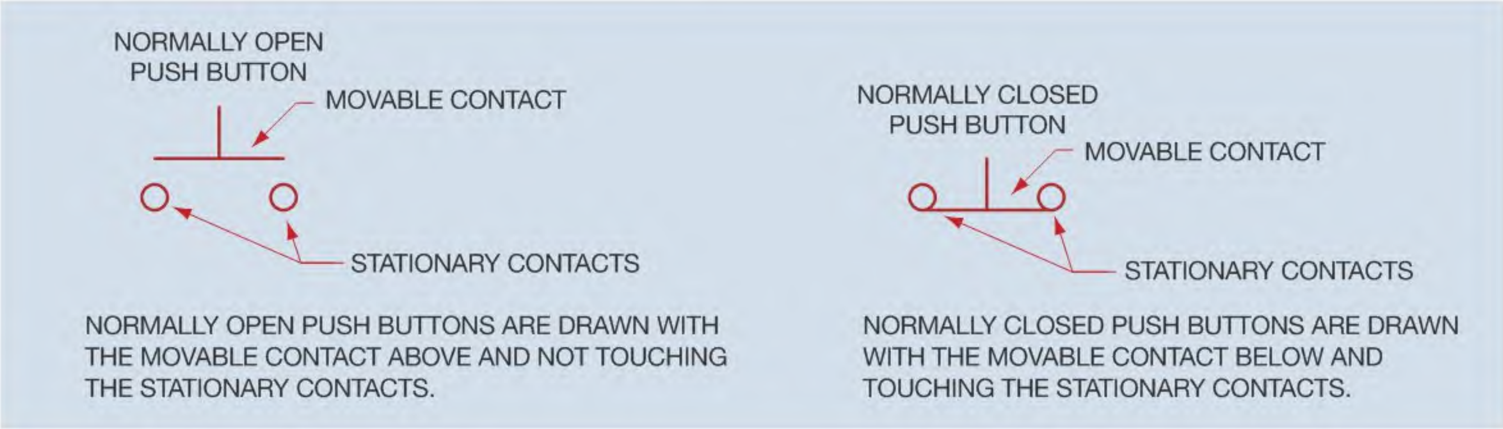


Figure 2–1 NEMA standard push button symbols.

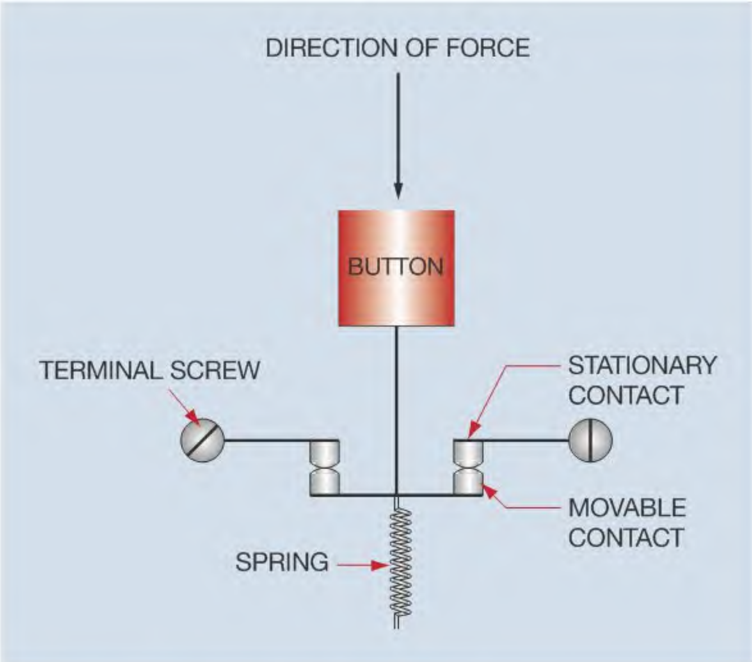


Figure 2–2 The movable contact bridges the two stationary contacts.

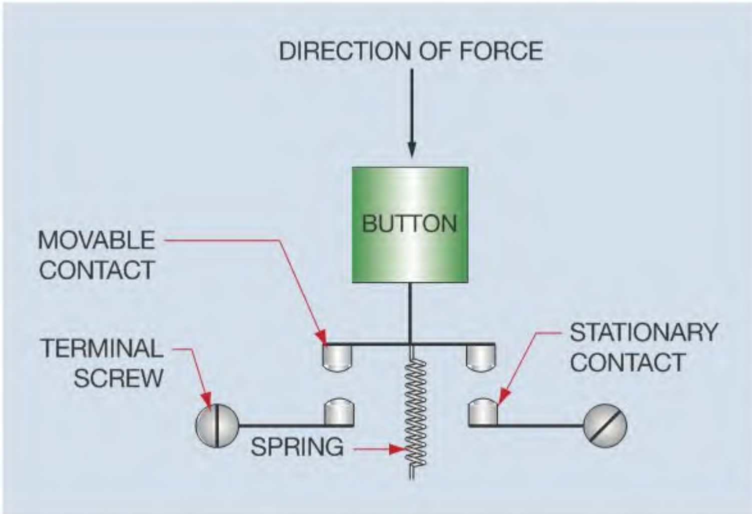


Figure 2–3 The movable contact does not bridge the two stationary contacts.

The normally closed push button symbol shown in Figure 2–1 is characterized by drawing the movable contact below and touching the two stationary contacts.

Normally Open Push Button

The normally open push button is similar to the normally closed except that the movable contact does not make connection with the two stationary contacts in its normal position (Figure 2–3). The normally open push button symbol is characterized by drawing the movable contact above and not touching the two stationary contacts as shown in Figure 2–1. When the button is pressed, the movable contact moves down and bridges the two stationary contacts to form a complete circuit. When pressure is removed from the button, a spring returns the movable contact to its original position and a circuit no longer exists between the two stationary contacts.

Double Acting Push Buttons

Another very common push button found throughout industry is the double acting push button. Double acting push buttons contain both normally open and normally closed contacts (Figure 2–4). When pressure is applied to the button, the movable contacts break connection with the two normally closed stationary contacts, creating an open circuit. The movable contacts then bridge the two normally open stationary contacts, creating a complete circuit. When pressure is removed from the button, a spring causes the movable contacts to return to their normal position. Double acting push buttons contain four terminal screws, two for the normally closed contacts and two for the normally open contacts. When connecting these push buttons, it is important to make certain that the wires are connected to the correct set of contacts. A schematic symbol for a double acting push button is shown in Figure 2–5. The symbol for double acting push buttons can actually be drawn in several ways (Figure 2–6). The symbol on the left is drawn with two movable contacts connected by a common shaft. When

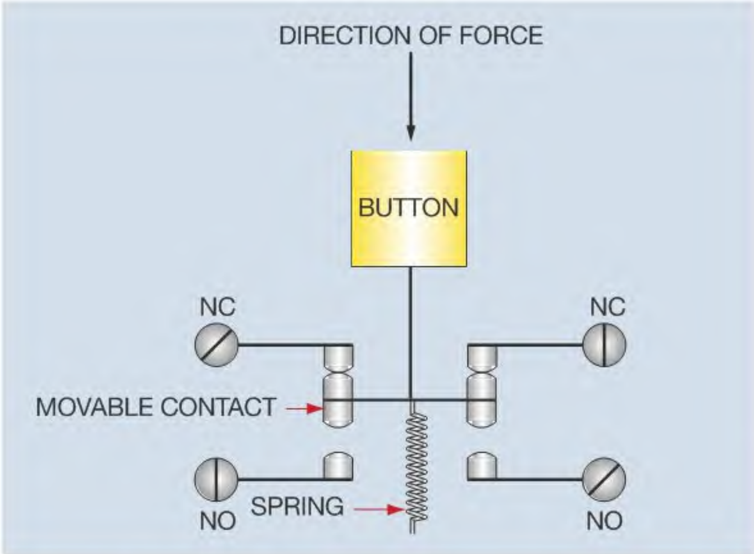


Figure 2–4 Double acting push buttons contain both normally open and normally closed contacts.

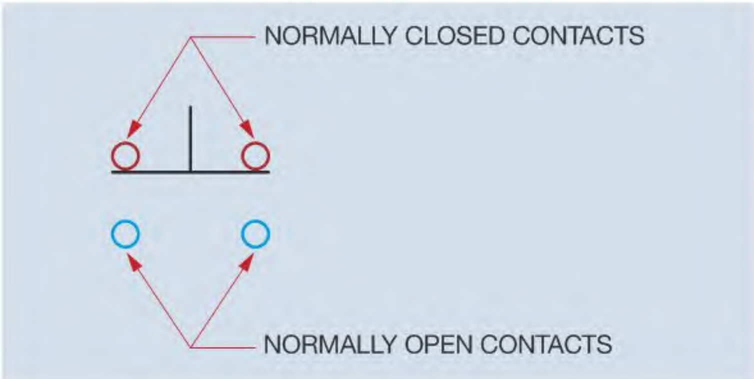


Figure 2–5 Double-acting push button.

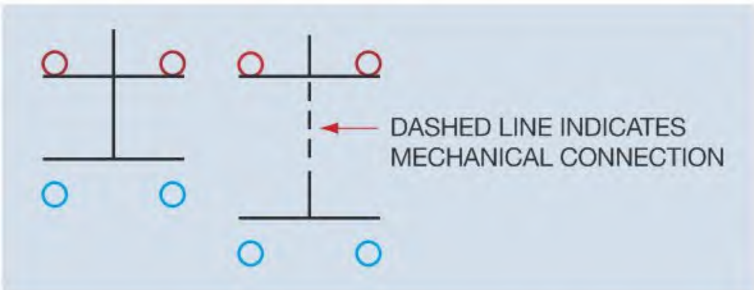


Figure 2–6 Other symbols used to represent double-acting push buttons.

the button is pressed, the top movable contact breaks away from the two stationary contacts at the top to open the circuit, and the bottom movable contact bridges to two bottom stationary contacts to complete the circuit.

The symbol on the right is very similar to the one on the left in that it shows two separate movable contacts. The right hand symbol, however, connects the two push button symbols together with a dashed line. When components are connected together with a dashed line in a schematic diagram, it indicates that the components are mechanically connected together. If one is pressed, all that are connected

Figure 2–7 Double acting push buttons have four terminal screws.

by the dashed line are pressed at the same time. A typical double acting push button is shown in Figure 2–7.

Stacked Push Buttons

A circuit employing the use of multiple push buttons is shown in Figure 2–8. This circuit illustrates the control of three separate motors. An emergency stop button can be used to de-energize all three motors at the same time. When the emergency stop button is pressed, three normally closed push buttons open to disconnect power to all three motors, and a normally open push button energizes control relay CR. The normally closed CR contact opens and disconnects power to the main control circuit. A normally open CR contact is used as a holding contact to maintain connection to CR coil after the emergency stop button is released, and a separate normally open CR contact closes to turn on a red indicator light. The red light indicates that the emergency stop was activated. The circuit will remain in this condition until the reset button is pressed. In this circuit, four separate push buttons are controlled at the same time. Push buttons that contain multiple contacts are often called stacked push buttons. *Stacked push buttons* are made by connecting multiple contact units together, and controlling them with a single push button (Figure 2–9).

Mushroom Head Push Buttons

The button portion of most push buttons generally exhibits a small surface area and some are slightly recessed to help prevent accidental activation as shown in Figure 2–7. Mushroom head push buttons, however, have a button with a large surface area that extends above the button to make them very accessible. They are often used as an emergency stop button. A mushroom head push button is shown in Figure 2–10. The schematic symbol for a mushroom head push button is shown in Figure 2–11.

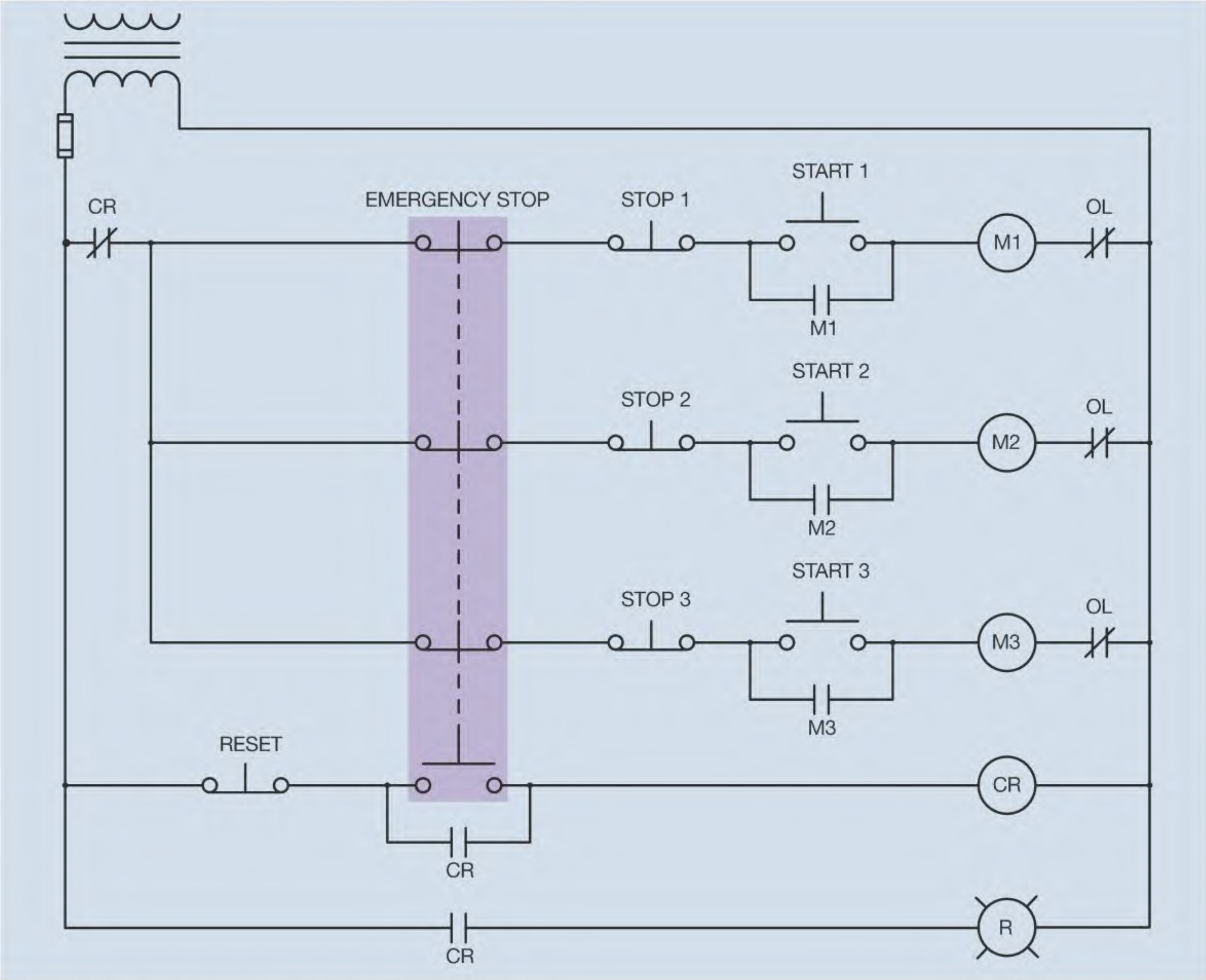


Figure 2–8 An emergency stop button stops all three motors.

Figure 2–9 Stacked push buttons are made by connecting multiple contact sets together. Components Courtesy of Wholesale Electric Supply.

Figure 2–10 Mushroom head push button.

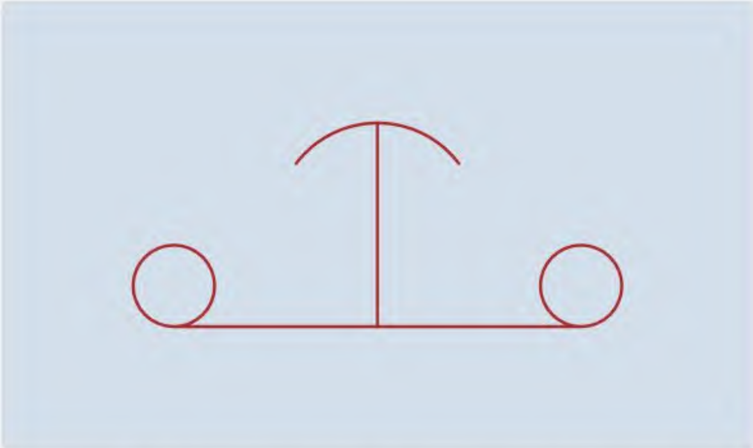


Figure 2–11 Schematic symbol for a mushroom head push button.

Figure 2–12 Push-pull button.

Push-Pull Buttons

Another push button that has found wide use is the push-pull button (Figure 2–12). Some push-pull buttons contain both normally open and normally closed contacts similar to double acting push buttons, but the contact arrangement is different. Push-pull button can provide both the start and stop function in one push button, eliminating the space needed for a second push button. The symbol for a push-pull button of this type is shown in Figure 2–13. A circuit employing a push-pull button in a start-stop control circuit is shown in Figure 2–14. When the button is pulled, the normally closed contact

Figure 2–13 The push-pull button contains one set of normally closed contacts and one set of normally open contacts.

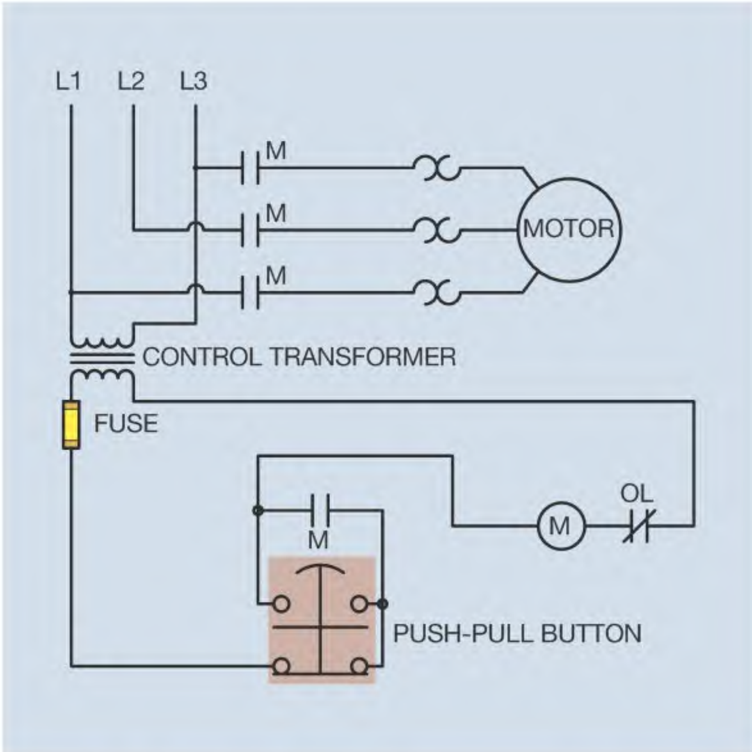


Figure 2–14 A push-pull button is used in a start-stop control circuit.

remains closed, and the normally open contact bridges the two stationary contacts to complete a circuit to the coil of M starter. A set of normally open M contacts close to maintain the circuit when the button is released. When the button is pushed, the normally closed contacts open and open the circuit to the coil of M starter.

Push-pull button that contain two normally open contacts or two normally closed contacts are also available. The symbol for a push-pull button that contains two normally open contacts is shown in Figure 2–15. Push-pull buttons of this type are often used for run-jog controls. A run-jog circuit using a push-pull button is shown in Figure 2–16. To make the motor run, pull the button. When the button is pulled, a circuit is completed to control relay CR, causing both CR contacts to close. One CR contact maintains the circuit around the normally open contacts of the push-pull button, and the

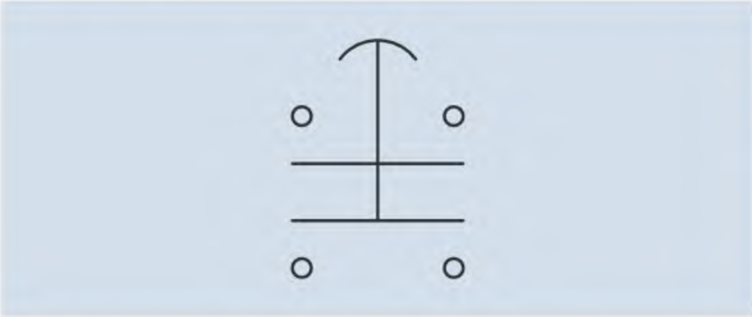


Figure 2–15 Push-pull buttons also contain two normally open contacts.

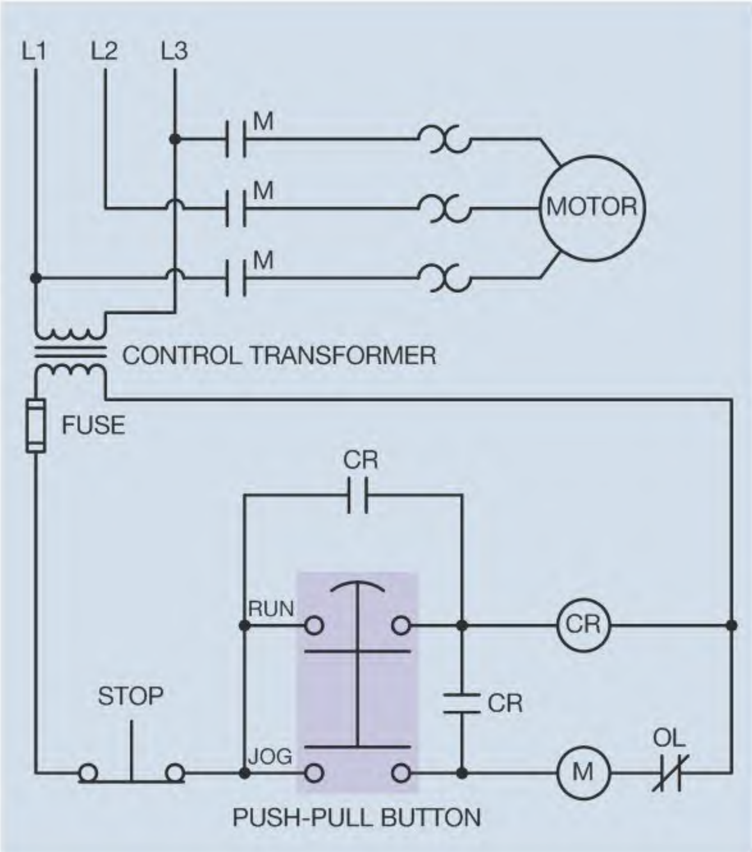


Figure 2–16 A push-pull button with two normally open contacts is used to control a run-jog circuit.

other supplies power to the coil of M starter. A separate stop button is used to stop the motor. If the push-pull button is pressed, a circuit is completed directly to M starter coil. Because there are no M contacts to hold the circuit, when the button is released the circuit to M coil is open and the motor stops running.

Illuminated Push Buttons

Illuminated push buttons are another example of providing a second function in a single space (Figure 2–17). They are often used to indicate that a motor is running, stopped, or tripped on overload. Most illuminated push buttons are equipped with a small transformer to reduce the control voltage to a much lower value (Figure 2–18). Lens caps of different colors are available. The schematic symbol for an illuminated push button is shown in Figure 2–19.

Figure 2–17 Illuminated push button.

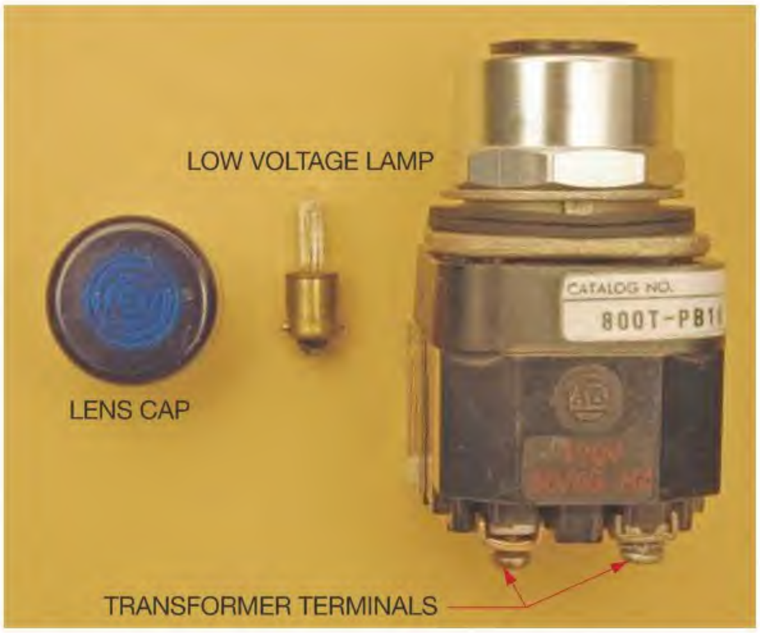


Figure 2–18 Illuminated push buttons generally employ a small transformer to reduce the control voltage to a lower value.

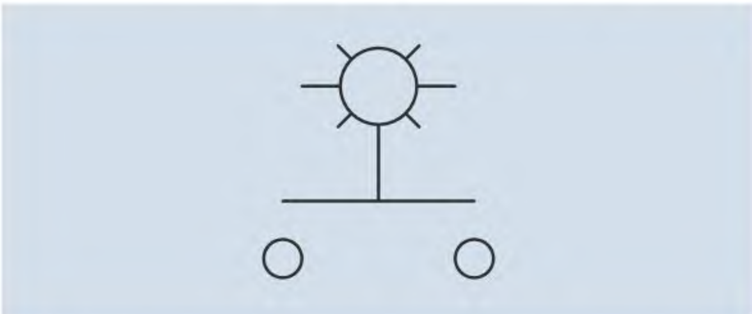


Figure 2–19 Schematic symbol for an illuminated push button.

Hand-Off-Automatic Switches

Hand-off-automatic (HOA) switches are generally used to select the function of a motor controller either manually or automatically. They can be a stand-alone control as shown in Figure 2–20, or incorporated into a start-stop push button station as shown in Figure 2–21. A single-break HOA switch used to control the coil of a motor starter is shown in Figure 2–22. If the HOA switch is set in the off position, no current can flow to the coil of the starter. If set in the hand position, the coil is connected directly to the power line and the motor will run continuously. If the HOA switch is set in the auto position, the starter coil is controlled by a float switch.

Figure 2–20 Hand-off-automatic switch.

Hand-off-automatic or selector switches often contain double break contacts as shown in Figure 2–23. Switches of this type are generally provided with a chart showing the contact connections. The X indicates that the contacts are closed and the O indicates that they

Figure 2–21 HOA switch incorporated with a start-stop push button control.

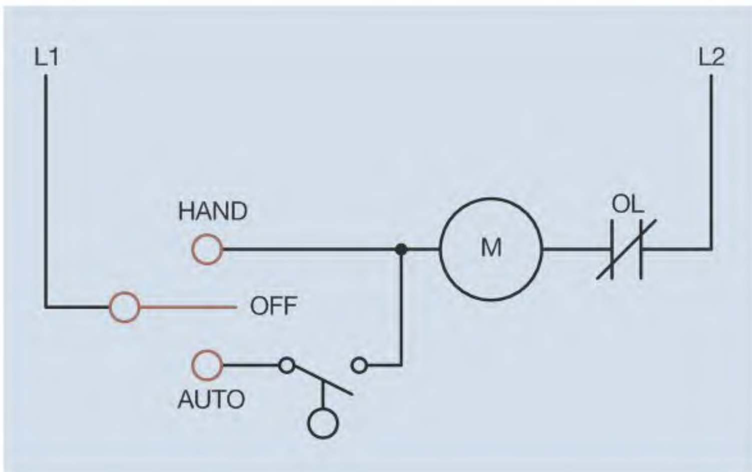
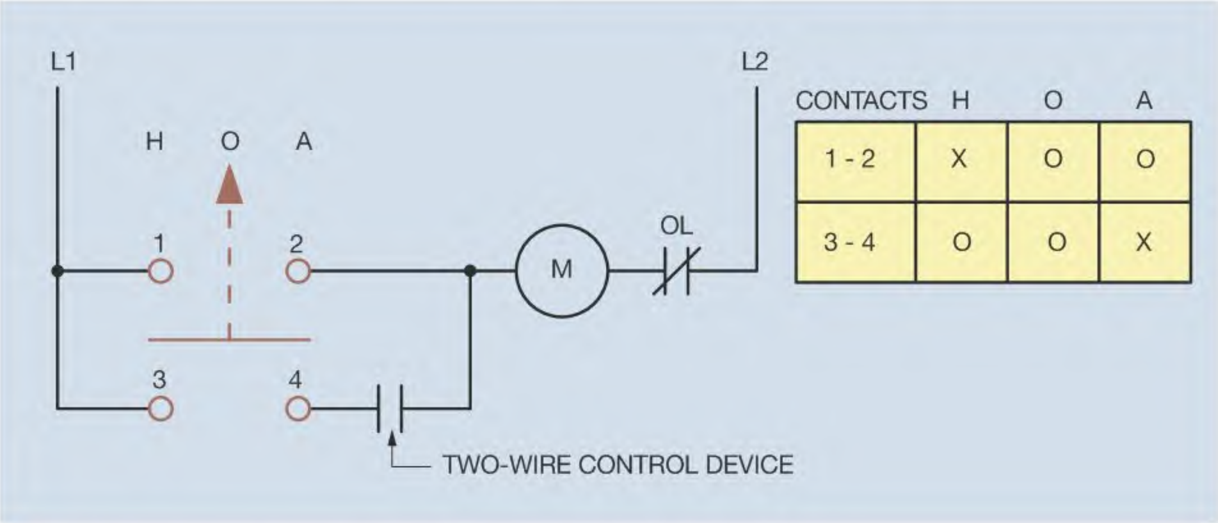
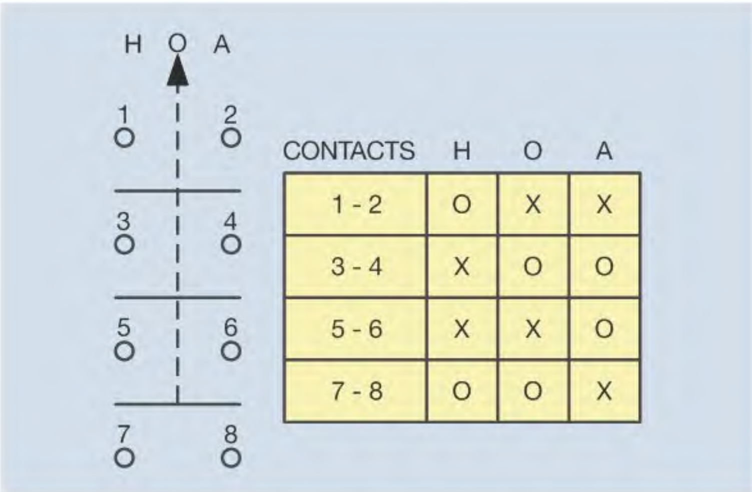


Figure 2–22 A single-break HOA switch controls the coil of a motor starter.



CONTACTS	H	O	A
1 - 2	X	O	O
3 - 4	O	O	X

Figure 2–23 Selector switches often contain double break contacts.



CONTACTS	H	O	A
1 - 2	O	X	X
3 - 4	X	O	O
5 - 6	X	X	O
7 - 8	O	O	X

Figure 2–24 Selector switch with multiple double break contacts.

are open. Some contact connection charts use an X to indicate a complete circuit and a blank space instead of O to indicate an open circuit. When the switch is set in the hand position, contacts 1 and 2 are closed, and contacts 3 and 4 are open. When the switch is set in the off position, both sets of contacts are open, and when the switch is set in the auto position contacts 1 and 2 are open, and contacts 3 and 4 are closed. Selector switches often contain multiple sets of contacts as shown in Figure 2–24. A selector switch with multiple sets of contacts is shown in Figure 2–25.

Figure 2–25 Selector switch with multiple contacts.

Selector Push Buttons

Selector push buttons combine the operation of a selector switch and push button in the same unit (Figure 2–26). The selector switch is controlled by turning the push button sleeve. Some selector push buttons permit the sleeve to be set in any of three positions and others permit the sleeve to be set in only two positions. The push button sleeve

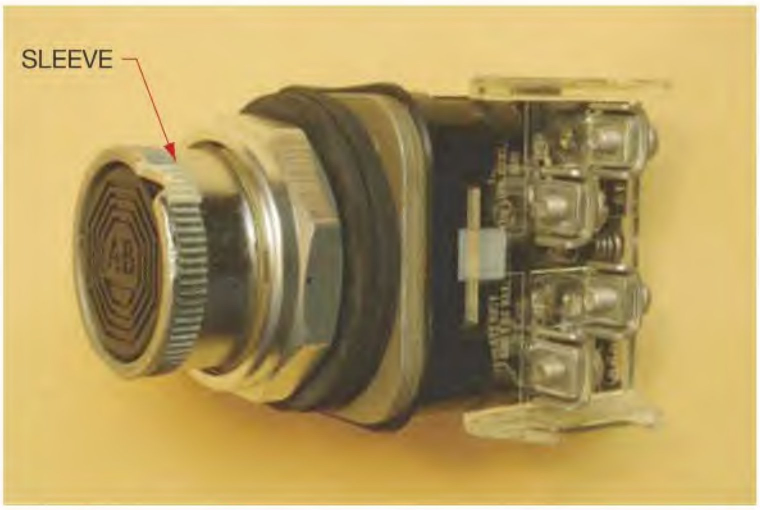


Figure 2–26 Selector push button.

shown in Figure 2–26 may be set in either of two positions. Different contact blocks are available that permit different contact settings. The contact block shown in Figure 2–27 contains two sets of bridge type contacts designated as A and B. A chart indicating contact connections for different conditions is shown in Figure 2–28. To better understand the chart and how this selector push button works, refer to Figures 2–29 A, B, C, and D.

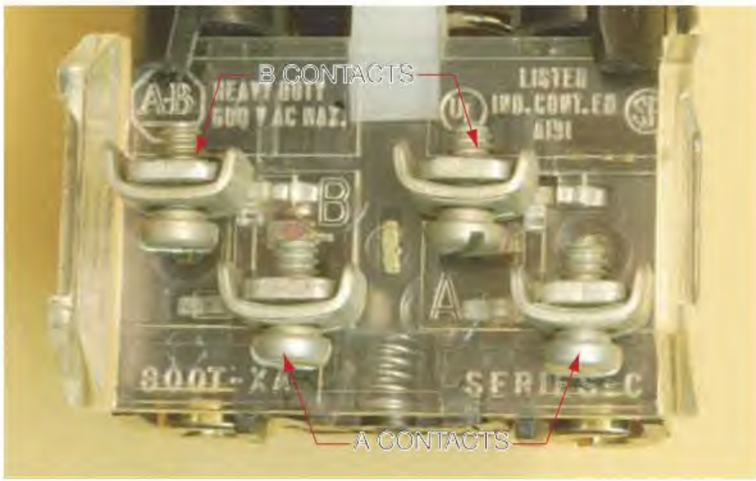


Figure 2–27 Contact block of selector push button.

	SLEEVE LEFT		SLEEVE RIGHT	
	PF	PD	PF	PD
B	O	O	X	O
A	O	X	O	X

PF = PUSH BUTTON FREE
PD = PUSH BUTTON DEPRESSED
X = CONTACTS CLOSED
O = CONTACTS OPEN

Figure 2–28 Contact chart for selector push button.

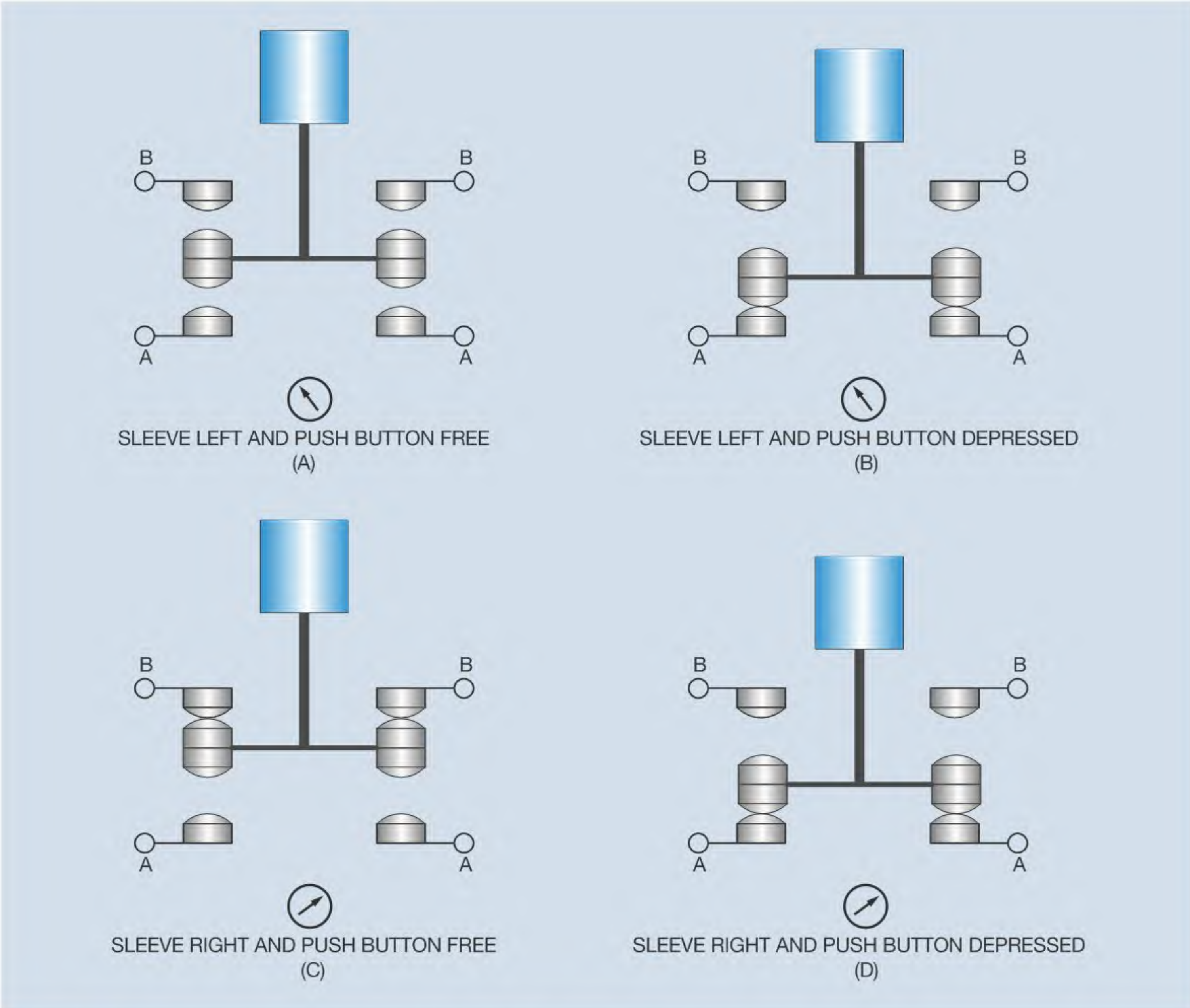


Figure 2–29 Contact connections for different settings of the selector push button.

Switch Symbols

Switch symbols are employed to represent many common control sensing devices. There are four basic symbols: **normally open (NO)**, **normally closed (NC)**, **normally open held closed (NOHC)**, and **normally closed held open (NCHO)**. To understand how these switches are drawn, it is necessary to begin with how normally open and normally closed switches are drawn (Figure 2–30). Normally open switches are drawn with the movable contact *below and not touching* the stationary contact. Normally closed switches are drawn with the movable contact *above and touching* the stationary contact.

The normally open held closed and normally closed held open switches are shown in Figure 2–31. Note that the movable contact of the normally open held closed switch is drawn below the stationary contact. The fact that the movable contact is drawn *below* the stationary contact indicates that the switch is normally open. Because the movable contact is touching the stationary contact, however, a complete circuit does exist because something is holding the contact closed. A very good example of this type of switch is the low pressure switch found in many air conditioning circuits (Figure 2–32). The low pressure switch is being held closed by the refrigerant in the sealed system. If the refrigerant should leak out, the pressure will drop low enough to permit the contact to return to its normal open position. This contact would open the circuit and de-energize coil C, causing both C contacts to open and disconnect the compressor from the power line. Although the schematic indicates that the switch is closed during normal operation, it would have to be connected as an open switch when it is wired into the circuit.

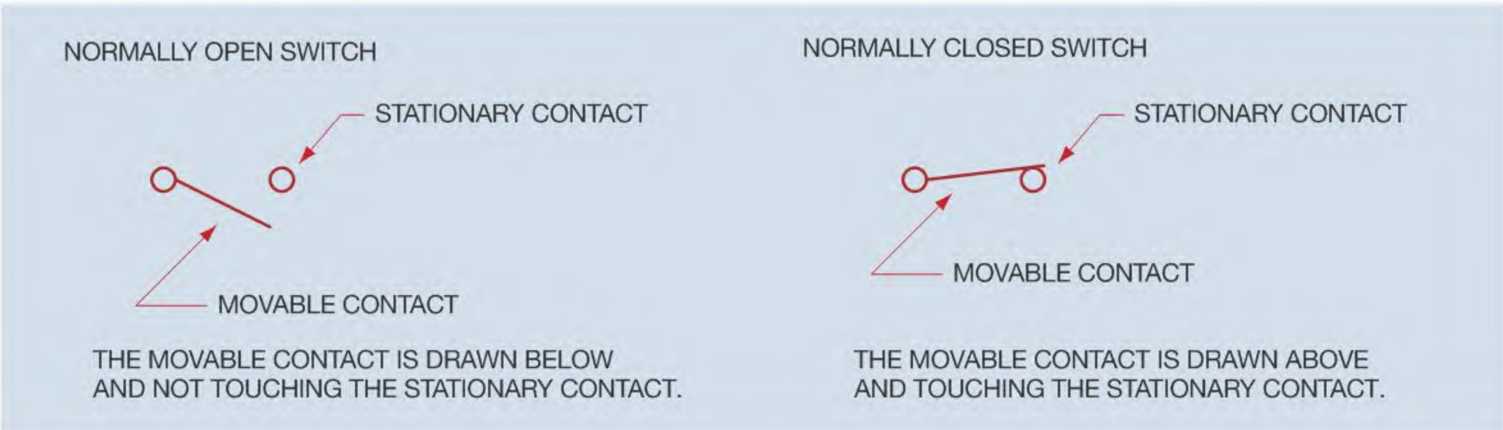


Figure 2–30 Normally open and normally closed switches.

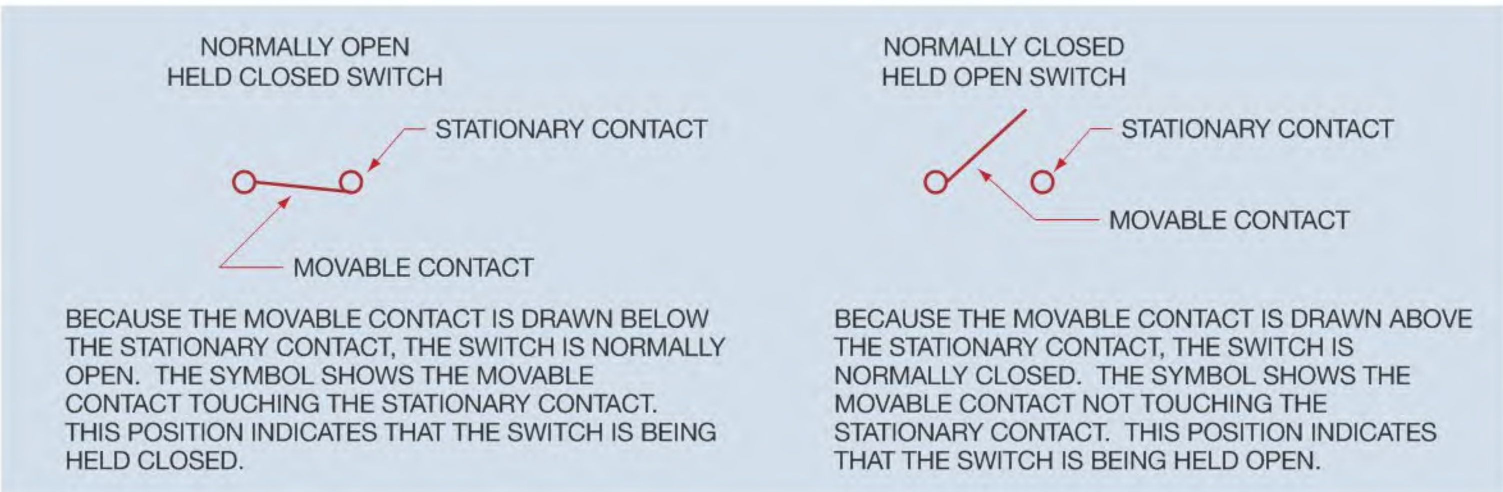


Figure 2–31 Normally open held closed and normally closed held open switches.

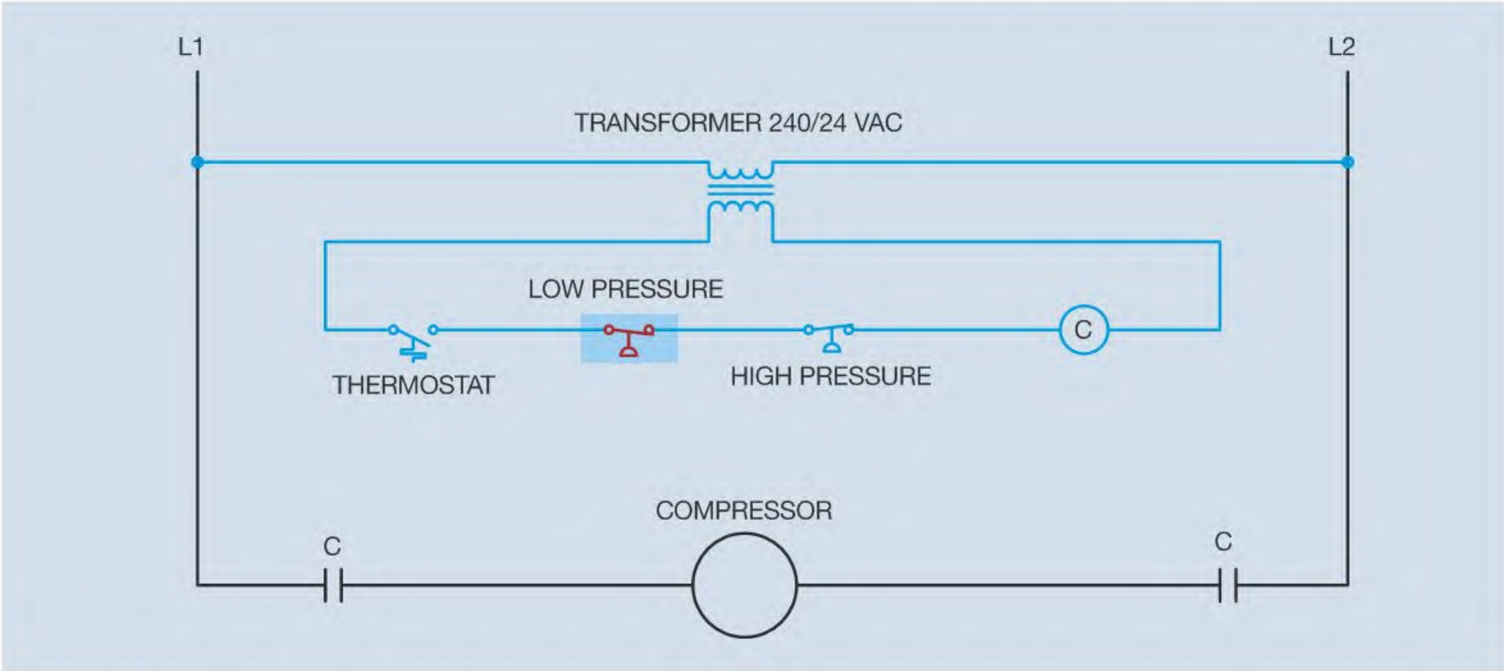


Figure 2–32 If system pressure drops below a certain value, the normally open held closed low pressure switch opens and de-energizes coil C.

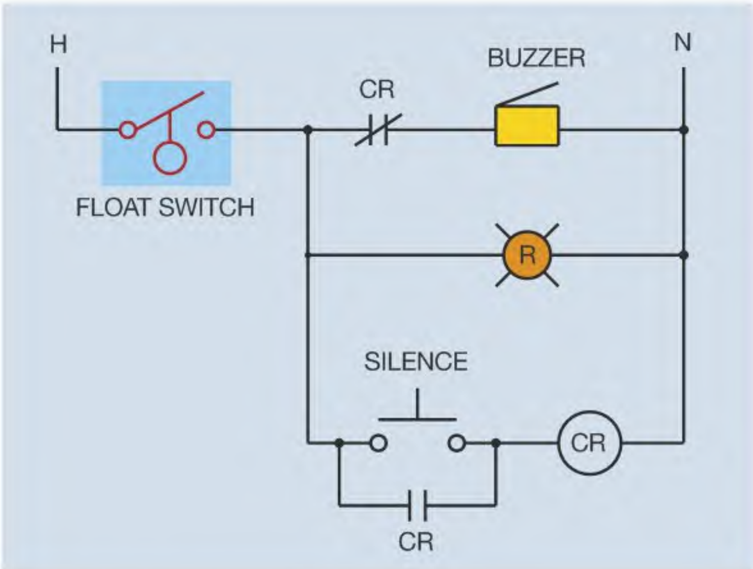


Figure 2–33 Low water warning circuit.

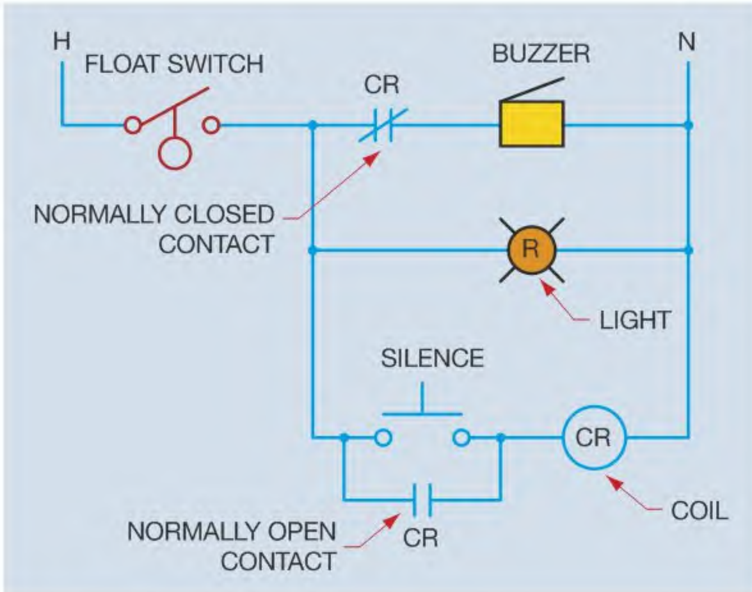


Figure 2–34 Circuit with labeled components.

The normally closed held open switch is shown open in Figure 2–31. Although the switch is shown open, it is actually a normally closed switch because the movable contact is drawn *above* the stationary contact, indicating that something is holding the switch open. A good example of how this type of switch can be used is shown in Figure 2–33. This circuit is a low water warning circuit for a steam boiler. The float switch is held open by the water in the boiler. If the water level should drop sufficiently, the contacts will close and energize a buzzer and warning light.

Basic Schematics

To understand the operation of the circuit shown in Figure 2–33, you must understand some basic rules concerning schematic or ladder diagrams.

1. Schematics show components in their electrical sequence without regard for physical location. The schematic in Figure 2–33 has been redrawn in Figure 2–34. Labels have been added and show a coil labeled CR and one normally open and one normally

closed contact labeled CR. All of these components are physically located on control relay CR.

2. Schematics are always drawn to show components in their de-energized or off state.
3. Any contact that has the same label or number as a coil is controlled by that coil. In this example, both CR contacts are controlled by CR coil.
4. When a coil energizes, all contacts controlled by it change position. Any normally open contacts will close and normally closed contacts will open. When the coil is de-energized the contacts will return to their normal state.

Referring to Figure 2–34, if the water level drops far enough, the float switch closes and completes a circuit through the normally closed contact to the buzzer and to the warning light connected in parallel with the buzzer. At this time both the buzzer and warning light are turned on. If the silence push button is pressed, coil CR will energize and both CR contacts change position. The normally closed contact opens and turns off the buzzer. The warning light, however, remains on as long as the low water level exists. The normally open CR contact connected in parallel with the silence push button closes. This contact is generally referred to as a holding, sealing, or maintaining contact. Its function is to maintain a current path to the coil when the push button returns to its normal open position. The circuit remains in this state until the water level becomes high enough to reopen the float switch. When the float switch opens, the warning light and CR coil turn off. The circuit is now back in its original de-energized state.

Sensing Devices

Motor control circuits depend on sensing devices to determine what conditions are occurring. They act very much like the senses of the body. The brain is the control center of the body. It depends on input information such as sight, touch, smell, and hearing to determine what is happening around it. Control systems are very similar in that they depend on such devices as temperature switches, float switches, limit switches, flow switches, etc, to know the conditions that exist in the circuit. These sensing devices are covered in greater detail later in the textbook. The four basic types of switches are used in conjunction with other symbols to represent some of these different kinds of sensing switches.

Limit Switches

Limit switches are drawn by adding a wedge to one of the four basic switches (Figure 2–35). The wedge represents the bumper arm. Common industrial limit switches are shown in Figure 2–36.

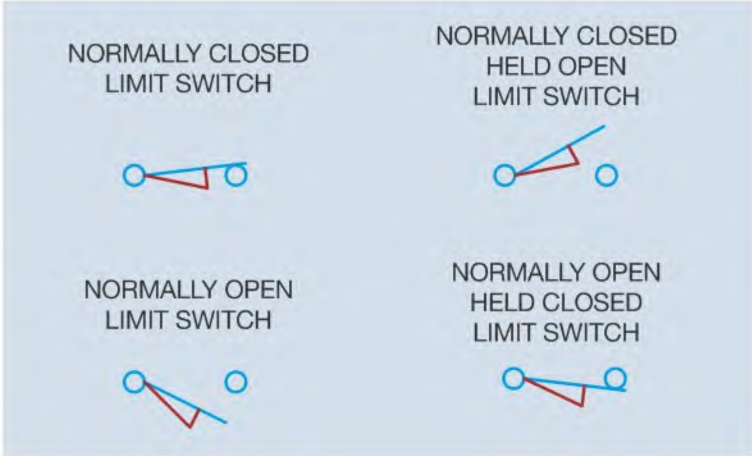


Figure 2–35 Limit switches.

Courtesy of Honeywell International, Inc.

Figure 2–36 Typical industrial limit switches.

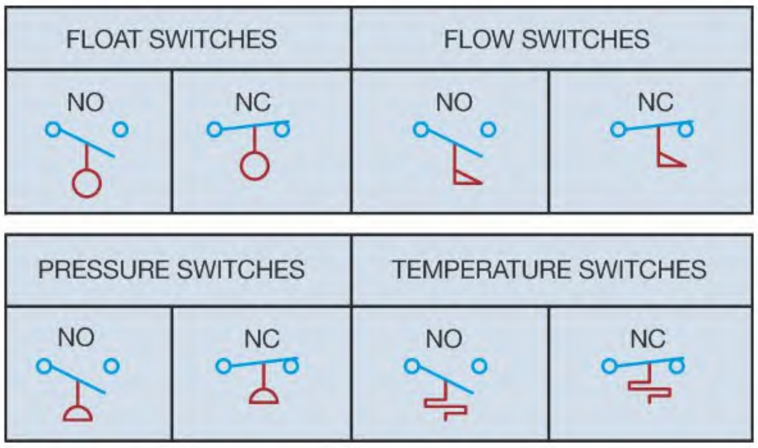


Figure 2–37 Schematic symbols for sensing switches.

Float, Pressure, Flow, and Temperature Switches

The symbol for a float switch illustrates a ball float. It is drawn by adding a circle to a line (Figure 2–37). The flag symbol of the flow switch represents the paddle that senses movement. The flow switch symbol is used for both liquid and air flow switches. The symbol for a pressure switch is a half circle connected to a line. The flat part of the semicircle represents a diaphragm. The symbol for a temperature switch represents a bimetal helix. The helix contracts and expands with a change of temperature. Any of these symbols can be used with any of the four basic switches.

There are many other types of sensing switches that do not have a standard symbol. Some of these are photo switches, proximity switches, sonic switches, Hall effect switches, and others. Some manufacturers employ a special type of symbol and label the symbol to indicate the type of switch. An example of this is shown in Figure 2–38.

Coils

The most common coil symbol used in schematic diagrams is the circle. The reason is that letters and/or numbers may be written in the circle to identify the coil. Contacts controlled by the coil are given the same number. Several standard coil symbols are shown in Figure 2–39.

Timed Contacts

Timed contacts are either normally open or normally closed. They are not drawn as normally open held closed or normally closed held open. The two basic types of timers are **on delay** and **off delay**. Timed contact symbols use an arrow to point in the direction that the contact will move at the end of the time cycle. Timers will be discussed in detail in a later chapter. Standard timed contact symbols are shown in Figure 2–40.

Contact Symbols

Another very common symbol used on control schematics is the contact symbol. The symbol is two parallel lines connected by wires (Figure 2–41). The normally open contacts are drawn to represent an open connection. The normally closed contact symbol is the same as the normally open symbol with the exception that a diagonal line is drawn through the contacts. The diagonal line indicates that a complete current path exists.

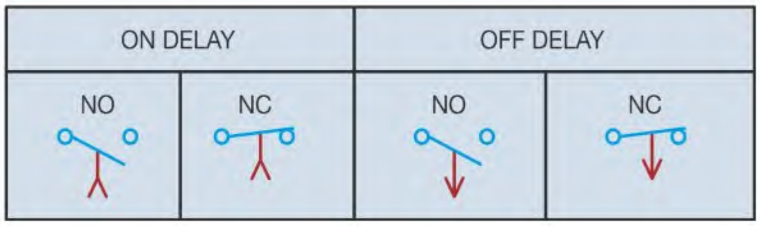


Figure 2–40 Timed contact symbols.

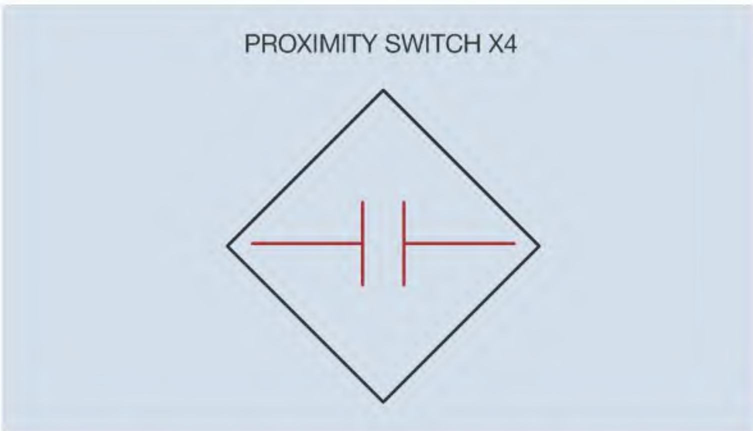


Figure 2–38 Special symbols are often used for sensing devices that do not have a standard symbol.

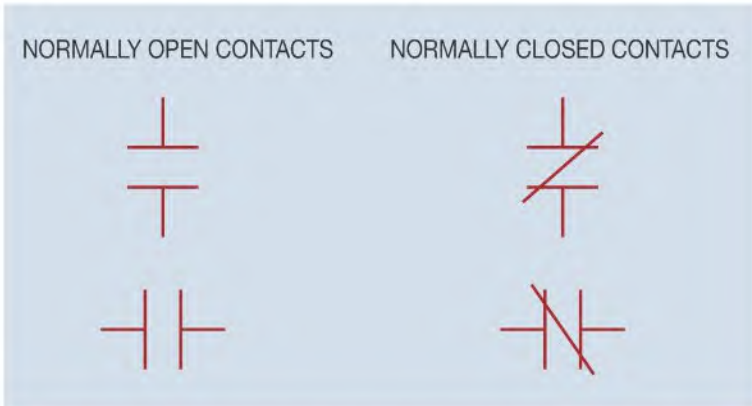


Figure 2–41 Normally open and normally closed contact symbols.

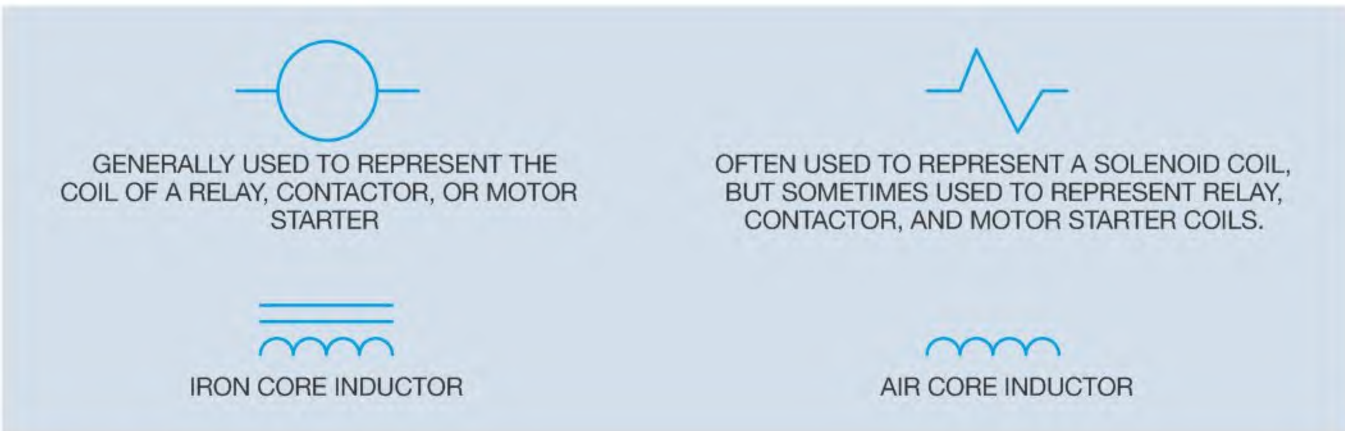


Figure 2–39 Common coil symbols.

Other Symbols

Not only does NEMA have standard symbols for coils and contacts, but there are also symbols for transformers, motors, capacitors, and special types of switches. Figure 2–42 shows both common control and electrical symbols in a chart.

IEC Symbols

Many schematic diagrams provided by European companies employ the use of symbols adopted by the International Electrotechnical Commission (IEC). These Symbols can be confusing to electricians working in the United States and Canada. Table 2–1 provides a comparison of NEMA symbols and IEC symbols.

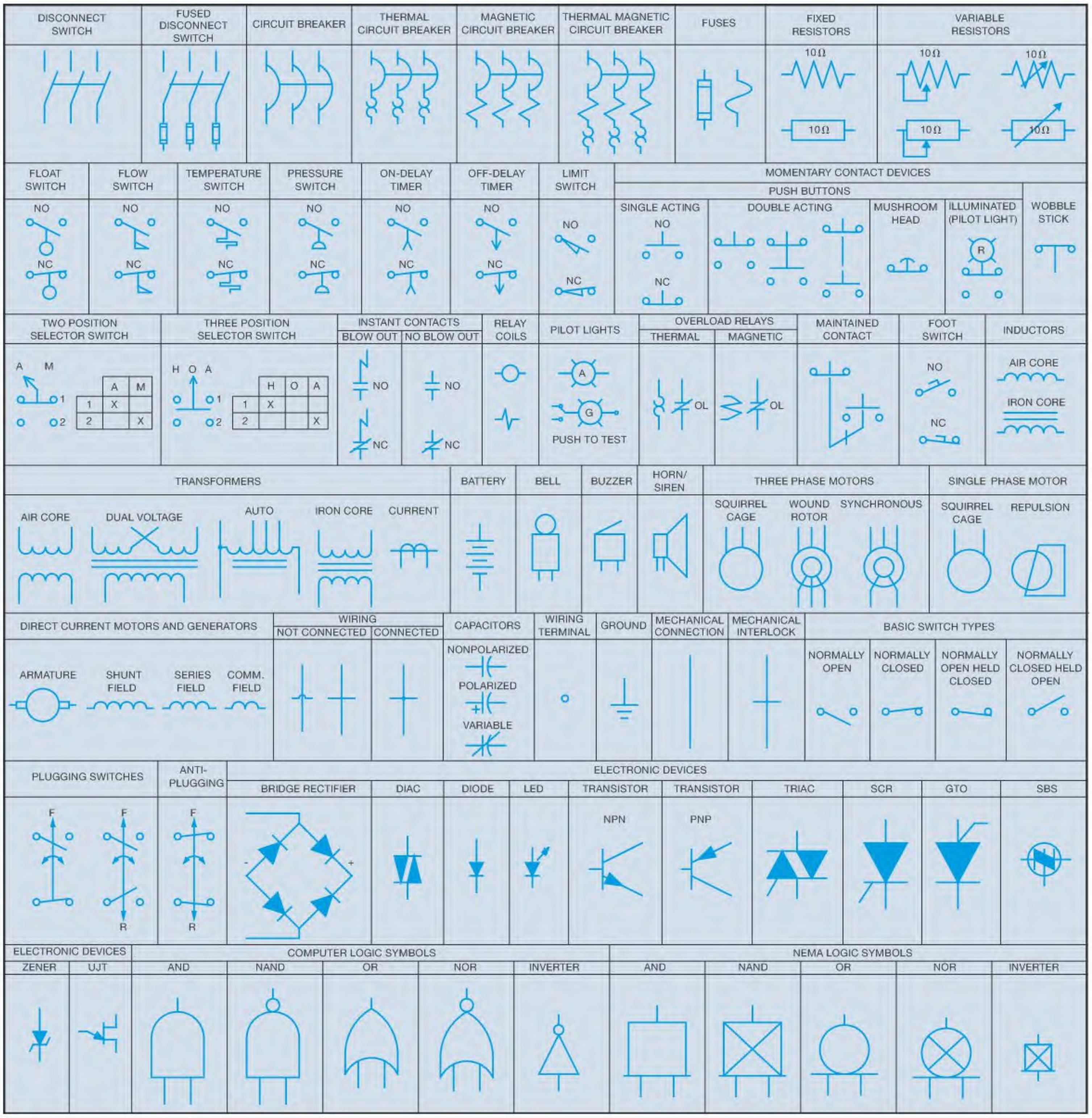
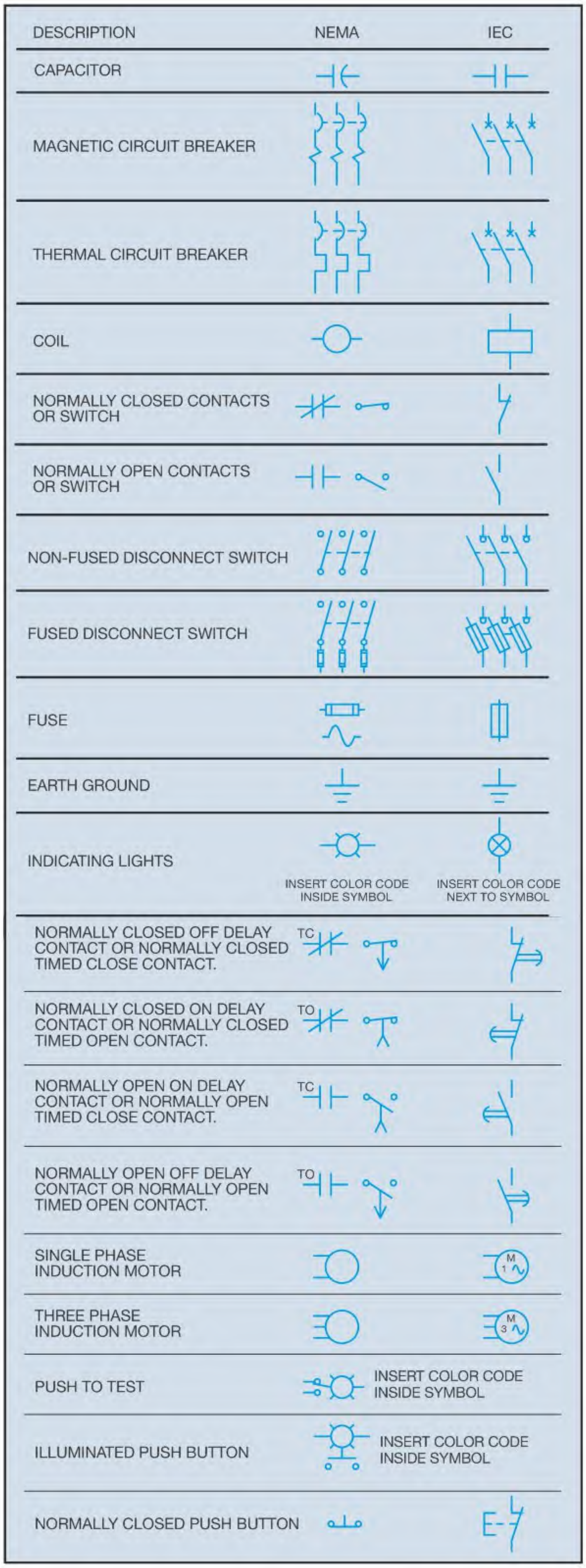


Figure 2–42 Common control and electrical symbols.



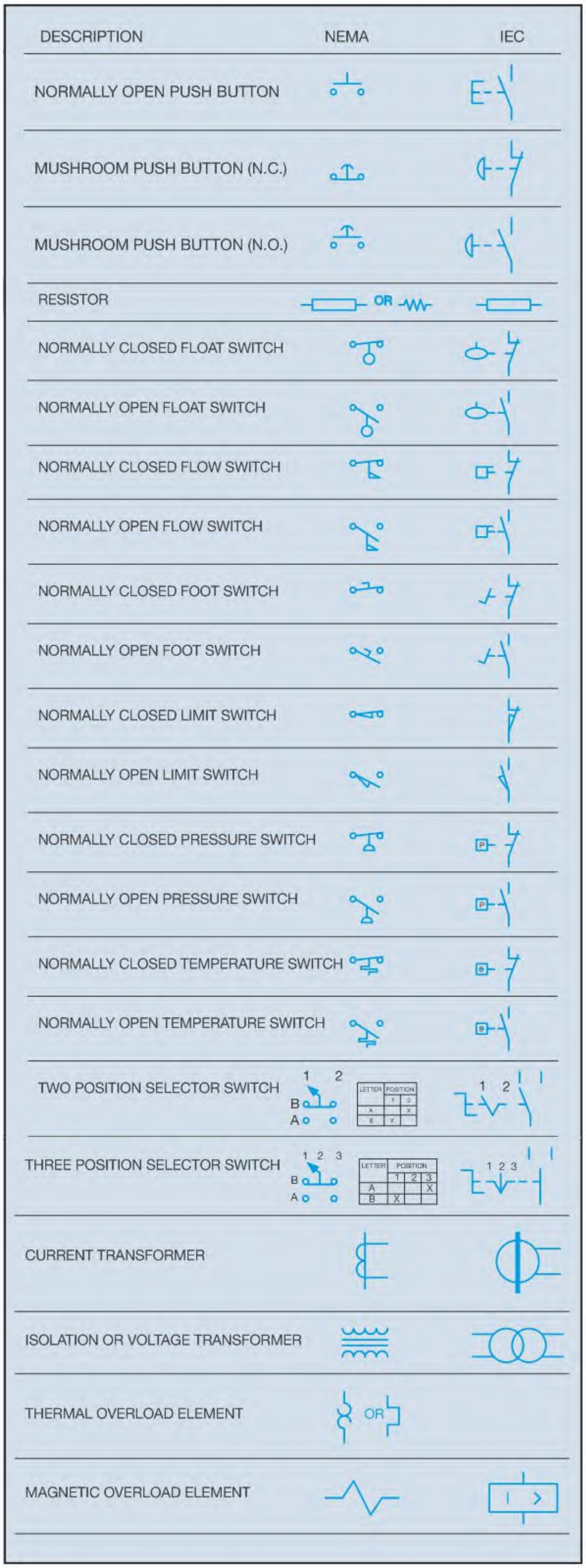
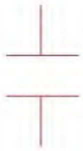


Table 2–1 NEMA symbols as compared to IEC symbols.

Review Questions

1. The symbol shown is:
   a. Polarized capacitor
   b. Normally closed switch
   c. Normally open held closed switch
   d. Normally open contact



2. The symbol shown is:
   a. Normally closed float switch
   b. Normally open held closed float switch
   c. Normally open float switch
   d. Normally closed held open float switch

3. The symbol shown is:
   a. Iron core transformer
   b. Auto transformer
   c. Current transformer
   d. Air core transformer

4. The symbol shown is:
   a. Normally open pressure switch
   b. Normally open flow switch
   c. Normally open float switch
   d. Normally open temperature switch

5. The symbol shown is:
   a. Double-acting push button
   b. Two position selector switch
   c. Three position selector switch
   d. Maintained contact push button

6. If you were installing the circuit in Figure 2–33, what type of push button would you use for the silence button?
   a. Normally closed
   b. Normally open
7. Referring to the circuit in Figure 2–33, should the float switch be connected as a normally open or normally closed switch?
8. Referring to the circuit in Figure 2–33, what circuit component controls the actions of the two CR contacts?
9. Why is a circle most often used to represent a coil in a motor control schematic?
10. When reading a schematic diagram, are the control components shown as they should be when the machine is turned off or de-energized, or are they shown as they should be when the machine is in operation?

Chapter 3

MANUAL STARTERS

Objectives

After studying this chapter the student will be able to:

- Discuss the operation of manual motor starters.
- Discuss low voltage release.
- Connect a manual motor starter.

Manual starters are characterized by the fact that the operator must go to the location of the starter to initiate any change of action. There are several different types of manual starters. Some look like a simple toggle switch with the addition of an overload heater. Others are operated by push buttons and may or may not be capable of providing low voltage protection.

Fractional Horsepower Single Phase Starters

One of the simplest manual motor starters resembles a simple toggle switch with the addition of an overload heater (Figure 3–1). The toggle switch lever is mounted on the front of the starter and is used to control the on and off operation of the motor. In addition to being an on and off switch, it also provides overload protection for the motor. An overload heater symbol has been added to the photograph to indicate where the overload heater should be connected. A schematic diagram showing the overload heater connected in series with the switch is shown in Figure 3–2. When current flows, the heater produces heat in proportion to the amount of motor current. If the heater is sized correctly, it will never get hot enough to open the circuit under normal operating conditions. If the motor should become overloaded, however, current increases causing a corresponding increase in the heat production by the heater. If the heat becomes great enough, it causes a mechanical mechanism to trip and open the switch contacts and disconnect the motor from the power line. If the starter trips on overload, the switch lever moves to a center position. The starter must be reset before the motor can be restarted by moving the lever to the full OFF position. This action is basically the same as resetting a tripped circuit breaker. The starter shown in this example has only one line contact and is generally used to protect motors intended to operate on 120 volts.

Starters that are intended to protect motors that operate on 240 volts should contain two load contacts (Figure 3–3). Although a starter that contains only one contact would control the operation of a 240-volt motor, it could create a hazardous situation. If the motor were switched off and an electrician tried to disconnect the motor, one power line would still be connected directly to the motor. *Section 430.103* of the *National Electrical Code® (NEC®)* requires that a disconnecting means open all ungrounded supply conductors to a motor.

Manual starters of this type are intended to control fractional horsepower motors only. Motors of 1 horsepower or less are considered fractional horsepower. Starters of this type are across-the-line starters. This means that they connect the motor directly to the power line. Some motors can draw up to 600 percent of rated full load current during starting. These starters generally do not contain large enough contacts to handle the current surge of multi-horsepower motors.

Figure 3–1 Single phase manual motor starter.

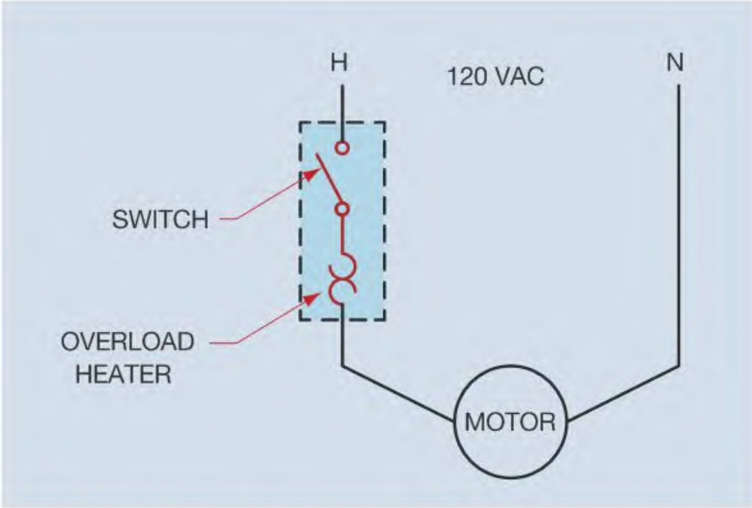


Figure 3–2 Schematic diagram of a single pole manual starter.

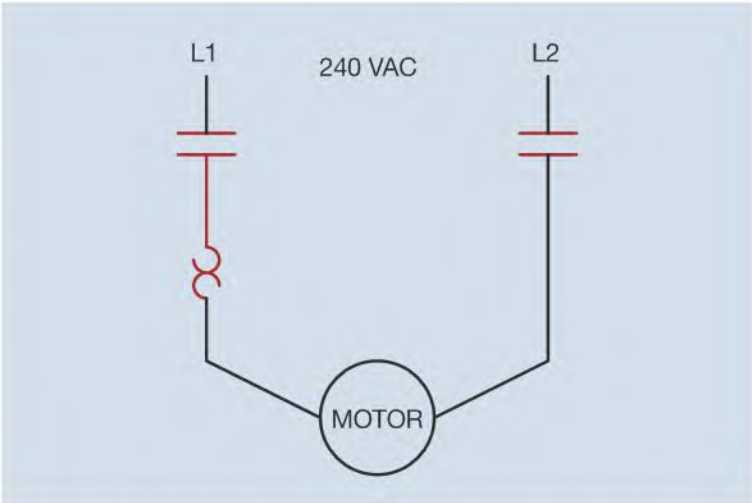


Figure 3–3 Schematic diagram of a two pole manual starter.

Another factor to consider when using a starter of this type is that it does not provide low voltage release. Most manual starters are strictly mechanical devices and do not contain an electrical coil. The contacts are mechanically opened and closed. This simply means that if the motor is in operation and the power fails, the motor will restart when the power is restored. This can be an advantage in some situations where the starter controls unattended devices such as pumps, fans, blowers, air conditioning, and refrigeration equipment. This feature saves the maintenance electrician from having to go around the plant and restart all the motors when power returns after a power failure.

This automatic restart feature can also be a disadvantage on equipment such as lathes, milling machines, saws, drill presses, and any other type of machine that may have an operator present. The unexpected and sudden restart of a piece of equipment could cause injury.

Mounting

Mounting this type of starter is generally very simple because it requires very little space. The compact design of this starter permits it to be mounted in a single gang switch or conduit box or directly on a piece of machinery. The open type starter can be mounted in the wall and covered with a single gang switch cover plate. The ON and OFF markings on the switch lever make it appear to be a simple toggle switch.

Like larger starters, fractional horsepower starters can be obtained in different enclosures. Some are simple sheet metal and are intended to be mounted on the surface or on a piece of machinery. If the starter is to be mounted in an area containing hazardous vapors or gasses, it may require an explosion-proof enclosure (Figure 3–4). Other areas that are subject to high moisture may require a waterproof enclosure (Figure 3–5). For areas that have a high concentration of flammable dust, the starter may be housed in a dust-proof enclosure similar to the one shown in Figure 3–6.

Automatic Operation

It is sometimes necessary to combine the manual starter with other sensing devices to obtain the proper control desired. When using some type of sensing pilot device to

Figure 3–4 Explosion-proof enclosure.

Figure 3–5 Waterproof enclosure.

Figure 3–6 Dust-proof enclosure.

directly control the operation of a motor, you must make sure that the pilot device is equipped with contacts that can handle the rated current of the motor. These devices are generally referred to as line voltage devices. Line voltage devices have larger contacts than sensing pilot devices intended for use in a motor control circuit that employs a magnetic motor starter. The smaller pilot devices intended for use with magnetic motor starters have contacts that are typically rated from 1 to 3 amperes. Line voltage devices may have contacts rated for 15 to 20 amperes. A good example of how a line voltage sensing device can be used in conjunction with the manual starter is shown in Figure 3–7. In this circuit, a line voltage thermostat is used to control the operation of a blower motor. When the temperature rises to a sufficient level, the thermostat contacts close, connecting the motor directly to the power line if the manual starter contacts are closed. When the temperature drops, the thermostat contact opens and turns off the motor. A line voltage thermostat is shown in Figure 3–8.

Another circuit that permits the motor to be controlled either manually or automatically is shown in Figure 3–9. In this circuit a manual/automatic switch is used to select either manual or automatic operation of a pump. The pump is used to fill a tank when the water falls to a certain level. The schematic is drawn to assume that the tank is full of water during normal operation.

In the manual position, the pump is controlled by turning the starter on or off. An amber pilot light indicates when the manual starter contacts are closed or turned on. If the manual/automatic switch is moved to the automatic position, as in Figure 3–10, a line voltage float switch controls the operation of the pump motor. When water in the tank drops low enough, the float switch contact closes and starts the pump motor. When water rises to a high enough level, the float switch contact opens and disconnects the pump motor from the line.

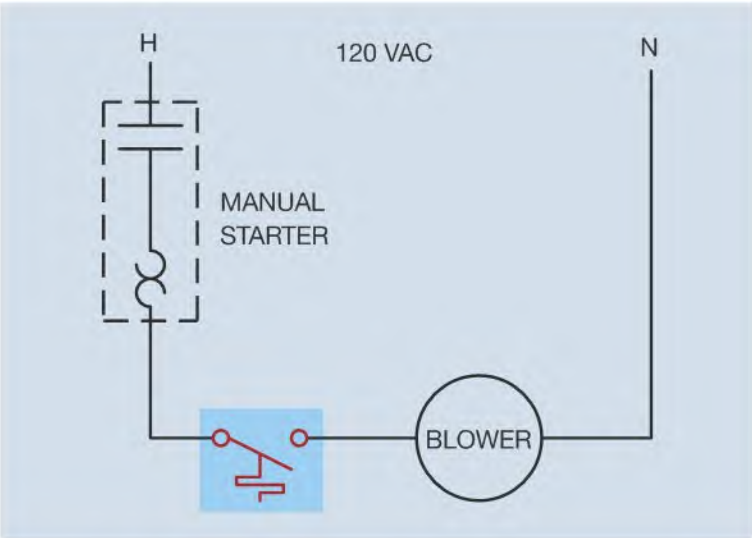


Figure 3–7 A line voltage thermostat controls the operation of a blower motor.

Figure 3–8 Line voltage thermostat.

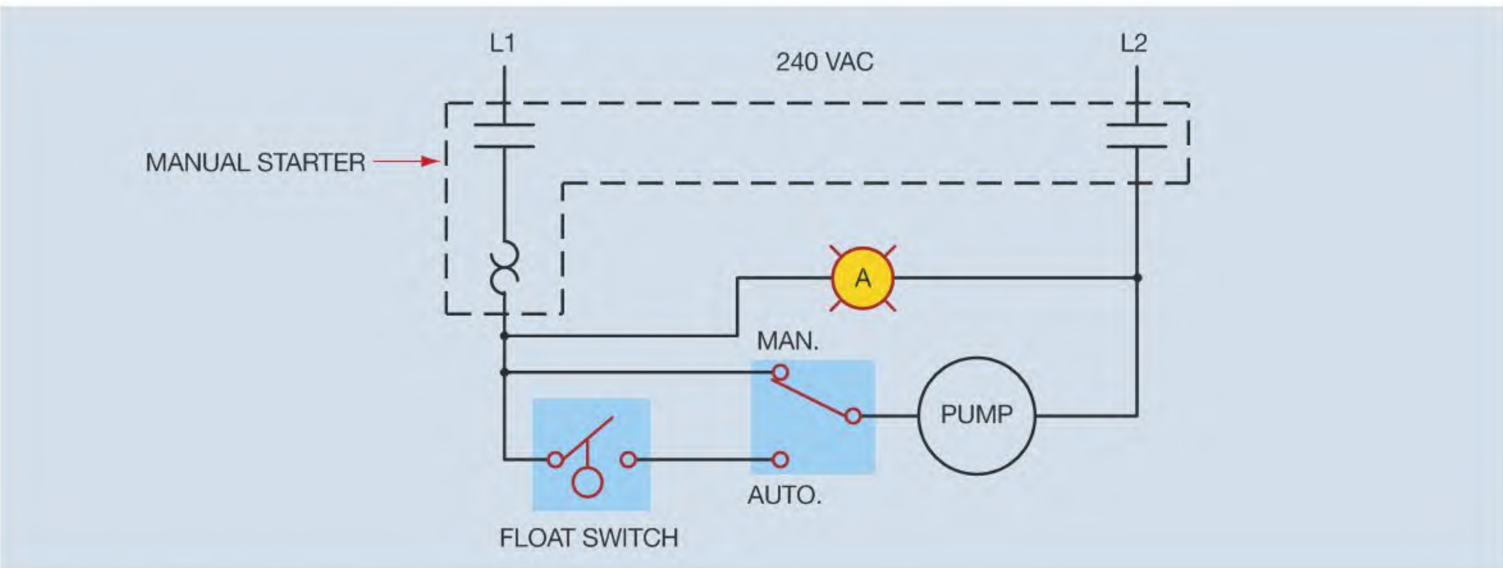


Figure 3–9 Pump can be controlled either manually or automatically.

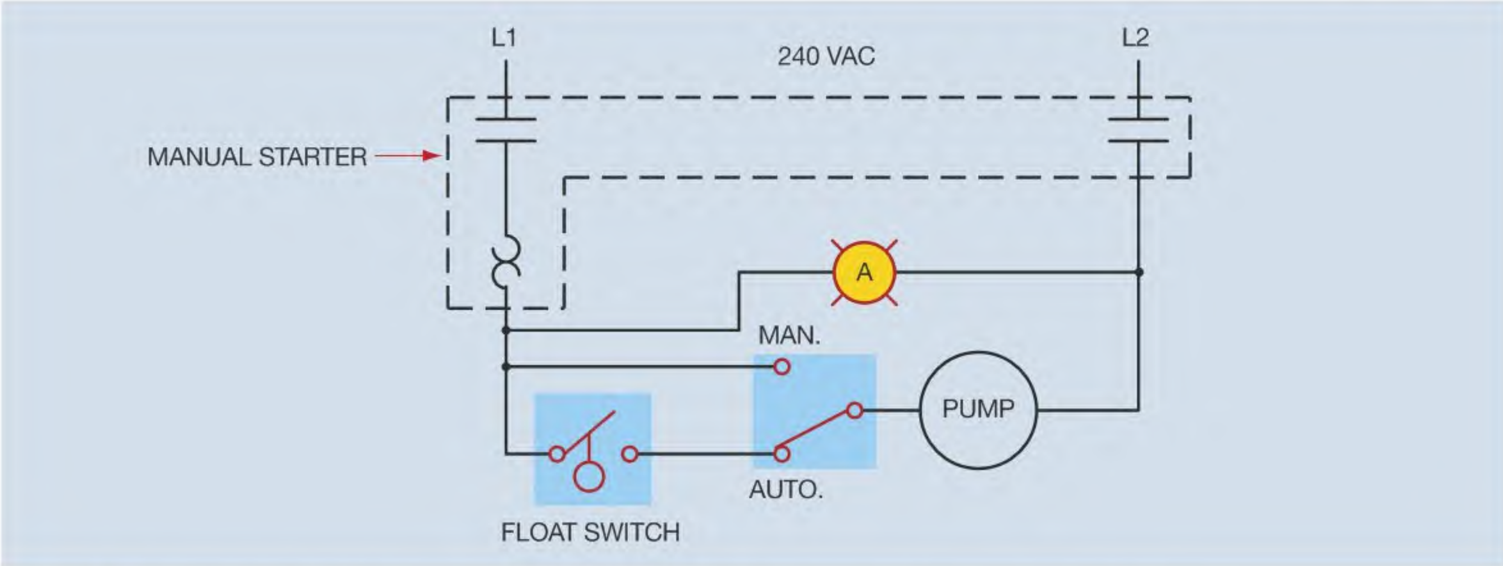


Figure 3–10 Moving the switch to the automatic position permits the float switch to control the pump.

Manual Push Button Starters

Manual push button line voltage starters are manufactured with two or three line voltage contacts. The two contact models are intended to control single phase motors that operate on 240 volts, or direct current motors. The starters that contain three contacts are intended to control three phase motors. Push button type manual starters are integral, not fractional, horsepower starters. Generally, they can control single phase motors rated up to 5 horsepower, direct current motors up to 2 horsepower, and three phase motors up to 10 horsepower. A typical three contact manual push button starter is shown in Figure 3–11. A schematic diagram for this type of starter is shown in Figure 3–12.

If any one of the overloads should trip, a mechanical mechanism opens the load contacts and disconnects the motor from the line. Once the starter has tripped on overload, it must be reset before the motor can be restarted. After allowing enough time for the overload heaters to cool, resetting the starter is accomplished by pressing the STOP push button with more than normal pressure. This extra pressure causes the mechanical mechanism to reset so that the motor can restart when the START push button is pressed. These starters are economical and are generally used with loads that are not started or stopped at frequent intervals. Although this type of starter provides overload protection, it does not provide low voltage release. If the power should fail and then be restored, the motor this starter controls will restart without warning.

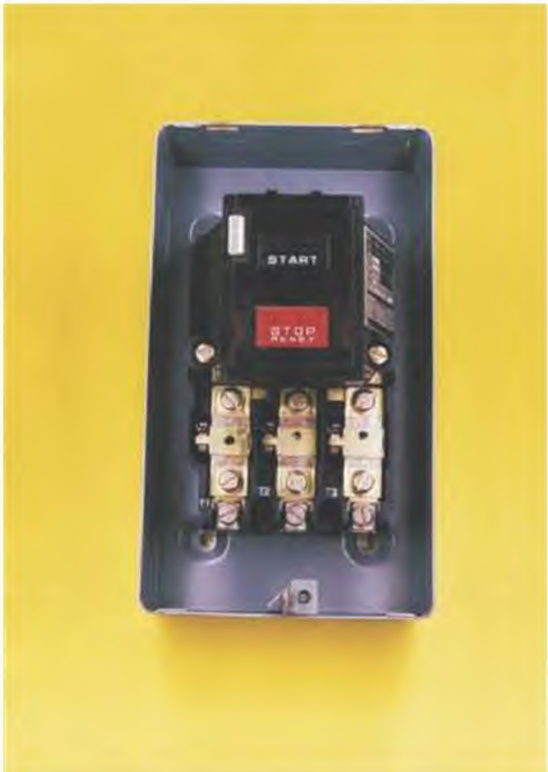


Figure 3–11 Three phase line voltage manual starter.

Manual Starter with Low Voltage Release

Integral horsepower manual starters with low voltage release will not restart after a power failure without being reset. This is accomplished by connecting a

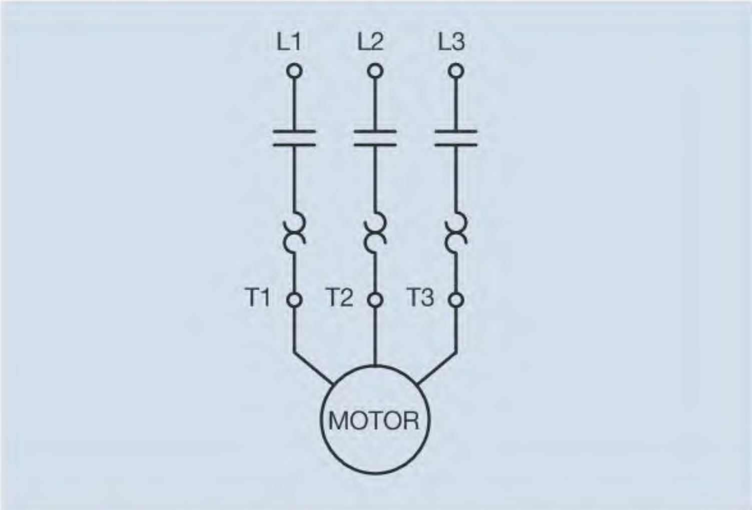


Figure 3–12 Schematic diagram for a three pole line voltage manual starter.

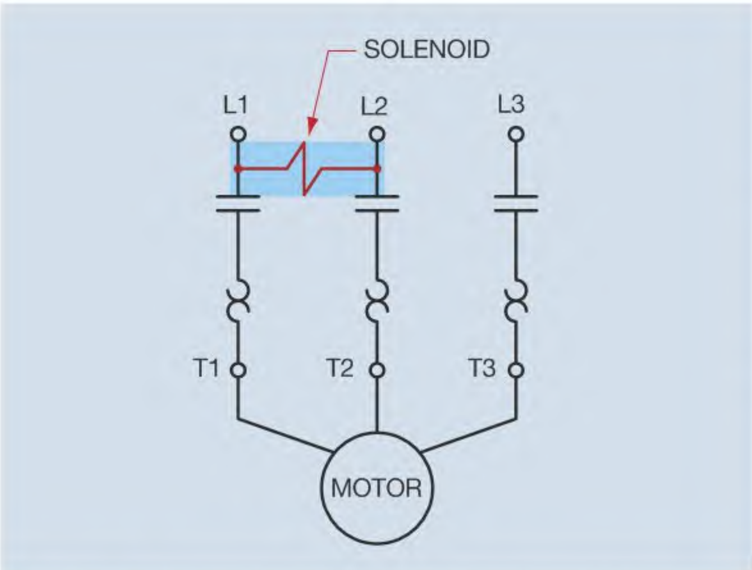


Figure 3–13 Solenoid provides low voltage release for the manual starter.

solenoid across the incoming power lines (Figure 3–13). As long as power is supplied to the starter, the solenoid holds a spring-loaded mechanism in place. As long as the mechanism is held in place, the load contacts can be closed when the START button is pressed. If the power is interrupted, the spring-loaded mechanism mechanically opens the contacts and prevents them from being reclosed until the starter has been manually reset. This starter will not operate unless power is present at the line terminal. This starter should not be confused with magnetic starters controlled by a coil. Magnetic type starters are designed to be used with other pilot control devices that control the operation of the starter. A manual starter with low voltage release is shown in Figure 3–14.

Courtesy Schneider Electric USA, Inc.

Figure 3–14 Manual starter with low voltage release.

Troubleshooting

Anytime a motor has tripped on overload, the electrician should check the motor and circuit to determine why the overload tripped. The first step is generally to determine whether the motor is actually overloaded. Some common causes of motor overloads are bad bearings in either the motor or the load the motor operates. Shorted windings in the motor can cause the motor to draw excessive current without being severe enough to blow a fuse or trip a circuit breaker. The simplest way to determine if the motor is overloaded is to find the motor full load current on the nameplate and then check the running current with an ammeter (Figure 3–15). If checking a single phase motor, it is necessary to check only one of the incoming lines. If checking a three phase motor, each line should be checked individually. The current flow in each line of a three phase motor should be relatively the same. A small amount of variation is not uncommon, but if the current is significantly different in any of the lines, it is an indication of internally shorted windings. Overloads are generally set to trip at 115 percent to 125 percent of motor full load current, depending on the motor. If the ammeter reveals that the motor is drawing excessive current, the reason must be determined before the motor can be put back into operation.

Excessive current is not the only cause for an overload trip. Thermal overloads react to heat. Any heat source can cause an overload to trip. If the motor is not drawing an excessive amount of current, the electrician should determine any other sources of heat. Loose

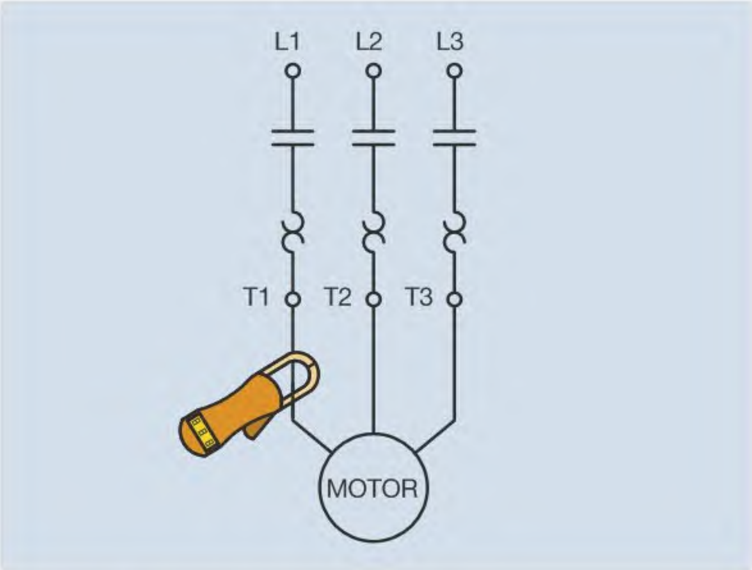


Figure 3–15 Checking motor current.

connections are one of the greatest sources of heat. Check the wires for insulation that has been overheated close to terminal screws. Any loose connection on the starter can cause an overload trip. Make sure that all connections are tight. Another source of heat is ambient or surrounding air temperature. In hot climates, the surrounding air temperature combined with the heat caused by motor current can be enough to cause the overload to trip. It may be necessary to set a fan that blows on the starter to help remove excess heat. Manual starters that are installed in a switchbox inside a wall are especially susceptible to ambient temperature problems. In this case it may be necessary to install some type of vented cover plate.

Review Questions

1. A manual motor starter controls a single phase 120 volt motor. The motor is not running, and the switch handle on the starter is found to be in the center position. What does this indicate?
2. Referring to the above question, what action is necessary to restart the motor and how is it accomplished?
3. A single phase motor operates on 240 volts. Why should a starter that contains two load contacts be used to control this motor?
4. A push button manual starter has tripped on overload. Explain how to reset the starter so the motor can be restarted.
5. What is meant by the term *line voltage* on some pilot sensing devices?
6. Explain the difference between manual motor starters that provide low voltage release and those that do not.
7. What is the simplest way to determine if a motor is overloaded?
8. Refer to the circuit shown in Figure 3–7. What type of switch is connected in series with the motor and is the switch normally open, normally closed, normally open held closed, or normally closed held open?
9. Refer to the circuit shown in Figure 3–10. When would the amber pilot light be turned on?
   a. When the manual/automatic switch is set in the manual position.
   b. When the float switch contacts are closed.
   c. Anytime the manual starter is turned on.
   d. Only when the manual/automatic switch is set in the manual position.
10. Refer to the circuit shown in Figure 3–10. Is the float switch normally open, normally closed, normally open held closed, or normally closed held open?

Chapter 4

OVERLOAD RELAYS

Objectives

After studying this chapter the student will be able to:

» Discuss differences between fuses and overloads.

» List different types of overload relays.

» Describe how thermal overload relays operate.

» Describe how magnetic overload relays operate.

» Describe how dashpot overload relays operate.

Overloads should not be confused with fuses or circuit breakers. **Fuses** and **circuit breakers** are designed to protect the circuit from a direct ground or short-circuit condition. Overloads are designed to protect the motor from an overload condition. Assume, for example, that a motor has a full load current rating of 10 amperes. Also assume that the motor is connected to a circuit that is protected by a 20 ampere circuit breaker (Figure 4–1). Now assume that the motor becomes overloaded and has a current draw of 15 amperes. The motor is drawing 150 percent of full load current. This much of an overload will overheat the motor and damage the windings. Because the current is only 15 amperes, the 20 ampere circuit breaker will not open the circuit to protect the motor. Overload relays are designed to open the circuit when the current becomes 115 percent to 125 percent of the motor full load current. The setting of the overload depends on the properties of the motor that is to be protected.

Overload Properties

All **overload relays** must possess certain properties in order to protect a motor.

1. *They must have some means of sensing motor current*. Some overload relays do this by converting motor current into a proportionate amount of heat and others sense motor current by the strength of a magnetic field.
2. *They must have some type of time delay*. Motors typically have a current draw of 300 percent to 800 percent of motor full load current when they start. Motor starting current is referred to as **locked rotor current**. Because overload relays are generally set to trip at 115 percent to 125 percent of full load motor current, the motor could never start if the overload relay tripped instantaneously.
3. *Overload relays are divided into two separate sections: the current sensing section and the contact section.* The current sensing section is connected in series with the motor and senses the amount of motor current. This section is typically connected to voltages that range from 120 volts to 600 volts. The contact section is part of the control circuit and operates at the control circuit voltage. Control circuit voltages generally range from 24 volts to 120 volts.

Dual Element Fuses

Some fuses are intended to provide both short circuit protection and overload protection. These fuses are called dual element time delay fuses. They contain two sections (Figure 4–2). The fuse link is designed to open quickly under a large amount of excessive current. This link protects the circuit against direct grounds and short circuits. The second contains a solder link that is connected to a spring. The solder

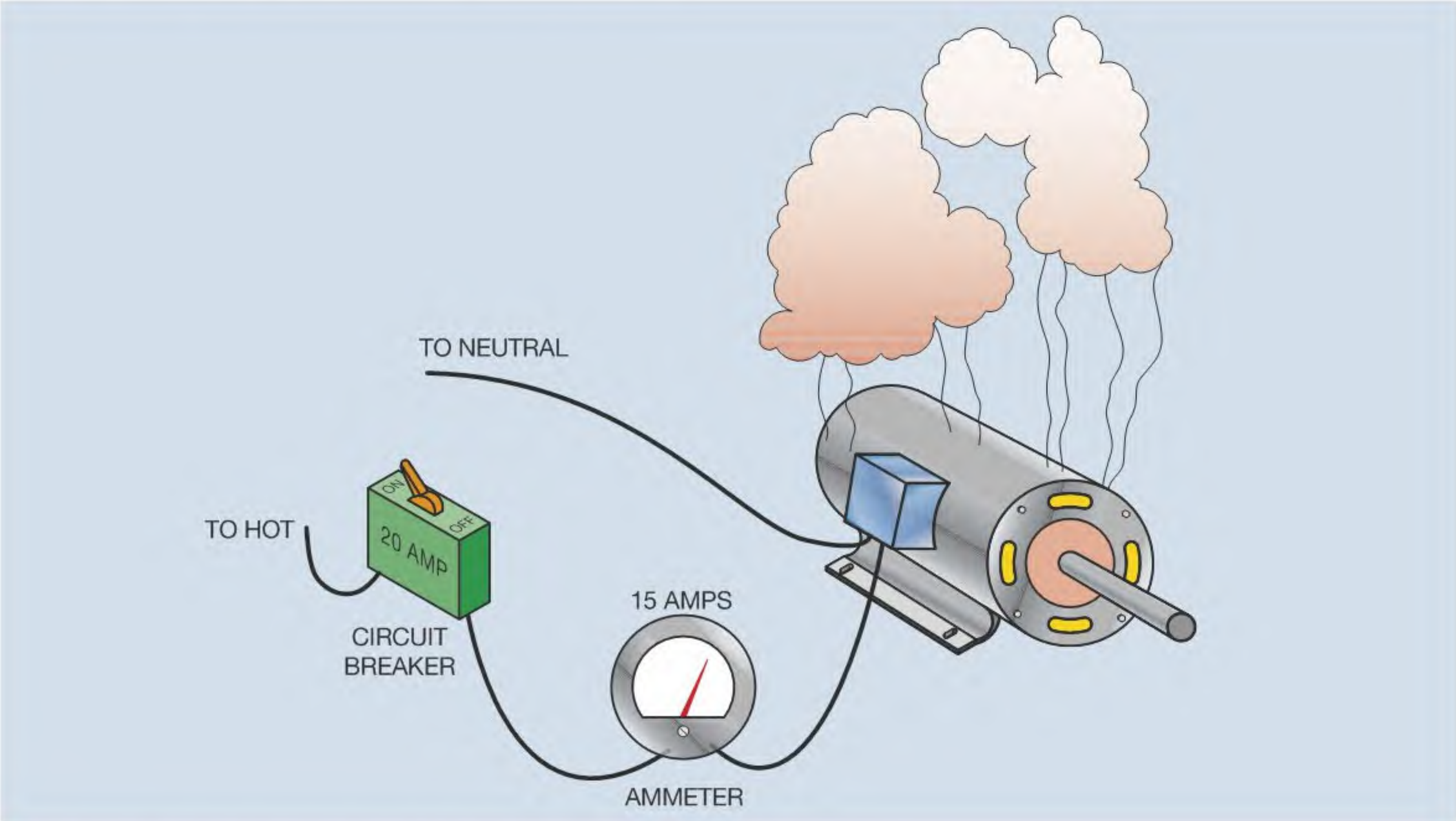


Figure 4–1 The circuit breaker does not protect the motor from an overload.

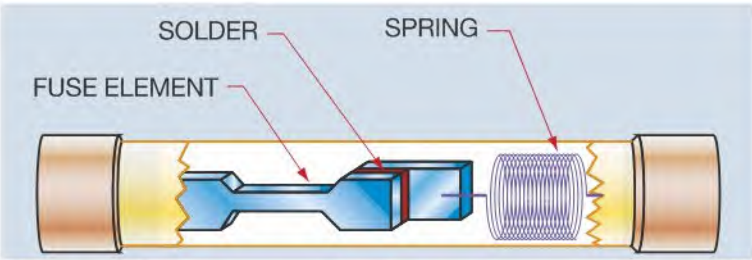


Figure 4–2 Dual element time delay fuse.

is a highly controlled alloy designed to melt at a particular temperature. If motor current becomes excessive, the solder melts and the spring pulls the link apart. The necessary time delay is achieved because of the time it takes for the solder to melt, even under a large amount of current. If motor current returns to normal after starting, the solder will not get hot enough to melt.

Thermal Overload Relays

There are two major types of overload relays: thermal and magnetic. Thermal overloads operate by connecting a heater in series with the motor. The amount of heat produced depends on motor current. Thermal overloads can be divided into two types: solder melting type or **solder pot**, and **bimetal strip**. Because thermal overload relays operate on the principle of heat, they are sensitive to ambient (surrounding air) temperature. They trip faster when located in a warm area than in a cool area.

Solder Melting Type

Solder melting type overloads are often called *solder pot overloads*. A brass shaft is placed inside a brass tube. A serrated wheel is connected to one end of the brass shaft. A special alloy solder that melts at a very specific temperature keeps the brass shaft mechanically connected to the brass tube (Figure 4–3). The serrated wheel keeps a set of spring-loaded contacts closed (Figure 4–4). An electric heater is placed around or close to the brass tube. The heater is connected in series with the motor. Motor current causes the heater to produce heat. If the current is great enough for a long enough period of time, the solder melts and permits the brass shaft to turn inside the tube, causing the contact to open. The fact that time must elapse before the solder can become hot enough to melt provides the delay for this overload relay. A large overload

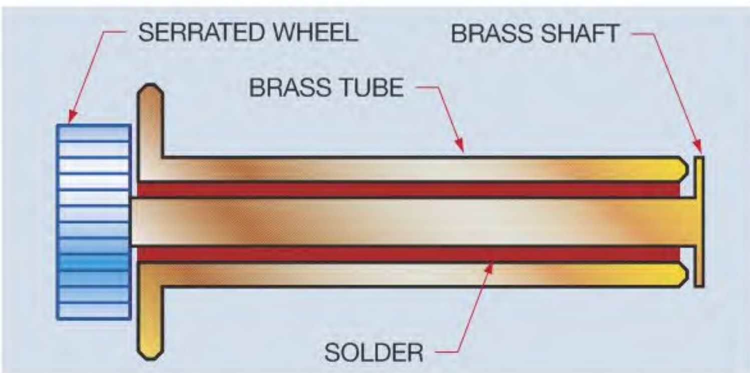


Figure 4–3 Construction of a typical solder pot overload.

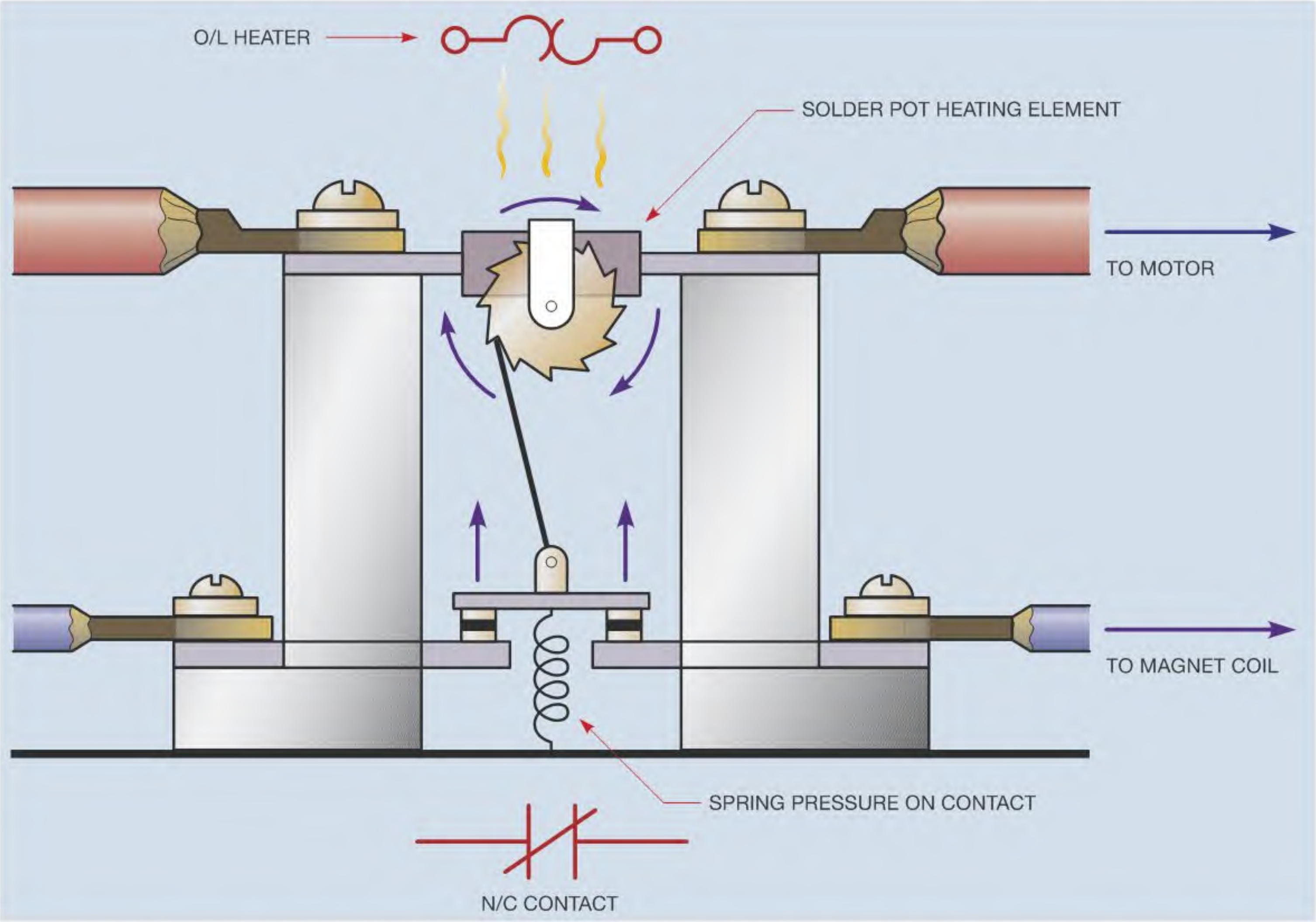


Figure 4–4 Melting alloy thermal overload relay. Spring pushes contact open as heat melts alloy allowing ratchet wheel to turn freely. Note electrical symbols for heater and normally closed contact.

causes the solder to melt faster and causes the contacts to open quicker than a smaller amount of overload current.

Manufacturers construct overload heaters differently, but all work on the same principle. Two different types of melting alloy heater assemblies are shown in Figures 4–5 A and B. A typical melting alloy type overload relay is shown in Figure 4–6. After the overload relay has tripped, it is necessary to allow the relay to cool for 2 or 3 minutes before it can be reset. This cool-down time is necessary to permit the solder to become hard again after it has melted.

The current setting can be changed by changing the heater. Manufacturers provide charts that indicate what size heater should be installed for different amounts of motor current. It is necessary to use the chart that corresponds to the particular type of overload relay. Not

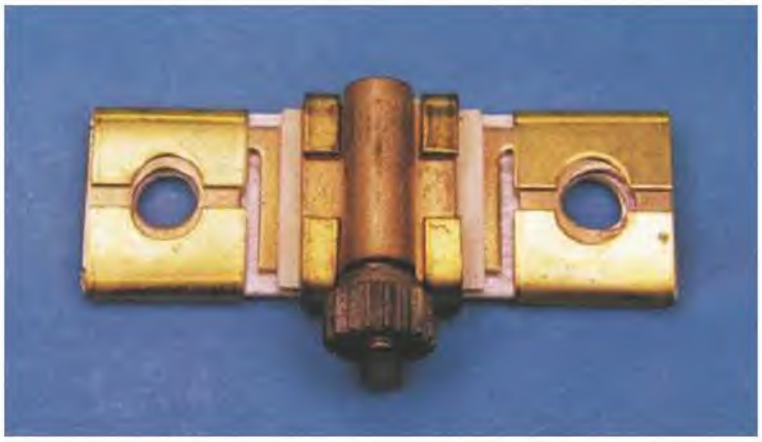


Figure 4–5A Melting alloy type overload heater.

Figure 4–5B Melting alloy type overload heater.

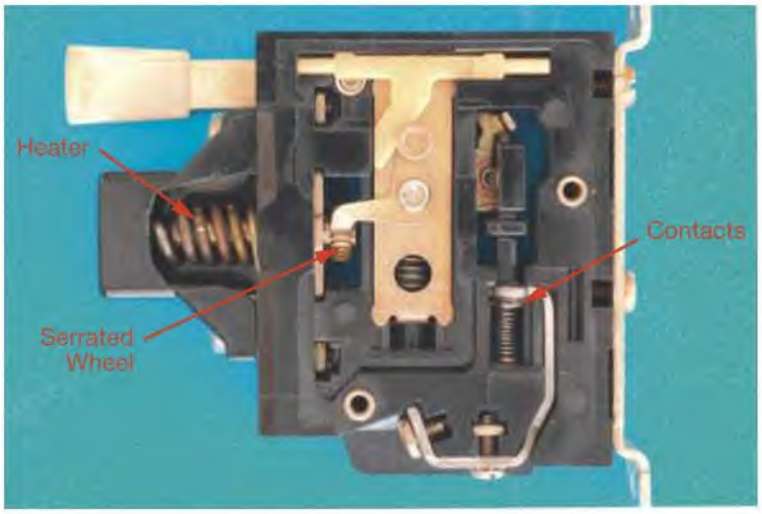


Figure 4–6 Typical melting alloy type overload relay.

all charts present the information in the same manner. Be sure to read the instructions contained with the chart when selecting heater sizes. A typical overload heater chart is shown in Figure 4–7.

Bimetal Strip Overload Relay

The second type of thermal overload relay is the bimetal strip overload. Like the melting alloy type, it operates on the principle of converting motor current into a proportionate amount of heat. The difference is that the heat causes a bimetal strip to bend or warp. A bimetal strip is made by bonding together two different types of metal that expand at different rates (Figure 4–8). Because the metals expand at different rates, the strip bends or warps with a change of temperature (Figure 4–9). The amount of warp is determined by:

OVERLOAD HEATER SELECTION FOR NEMA STARTER SIZES 00–1. HEATERS ARE CALIBRATED FOR 115% OF MOTOR FULL LOAD CURRENT. FOR HEATERS THAT CORRESPOND TO 125% OF MOTOR FULL LOAD CURRENT USE THE NEXT SIZE LARGER HEATER.

HEATER CODE	MOTOR FULL LOAD CURRENT	HEATER CODE	MOTOR FULL LOAD CURRENT	HEATER CODE	MOTOR FULL LOAD CURRENT
XX01	0.25–0.27	XX18	1.35–1.47	XX35	6.5–7.1
XX02	0.28–0.31	XX19	1.48–1.62	XX36	7.2–7.8
XX03	0.32–0.34	XX20	1.63–1.78	XX37	7.9–8.5
XX04	0.35–0.38	XX21	1.79–1.95	XX38	8.6–9.4
XX05	0.39–0.42	XX22	1.96–2.15	XX39	9.5–10.3
XX06	0.43–0.46	XX23	2.16–2.35	XX40	10.4–11.3
XX07	0.47–0.50	XX24	2.36–2.58	XX41	11.4–12.4
XX08	0.51–0.55	XX25	2.59–2.83	XX42	12.5–13.5
XX09	0.56–0.62	XX26	2.84–3.11	XX43	13.6–14.9
XX10	0.63–0.68	XX27	3.12–3.42	XX44	15.0–16.3
XX11	0.69–0.75	XX28	3.43–3.73	XX45	16.4–18.0
XX12	0.76–0.83	XX29	3.74–4.07	XX46	18.1–19.8
XX13	0.84–0.91	XX30	4.08–4.39	XX47	19.9–21.7
XX14	0.92–1.00	XX31	4.40–4.87	XX48	21.8–23.9
XX15	1.01–1.11	XX32	4.88–5.3	XX49	24.0–26.2
XX16	1.12–1.22	XX33	5.4–5.9		
XX17	1.23–1.34	XX34	6.0–6.4		

Figure 4–7 Typical overload heater chart.

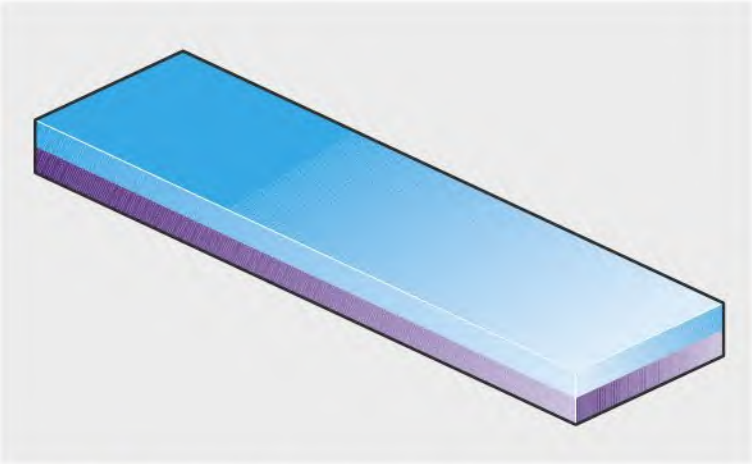


Figure 4–8 A bimetal strip is constructed by bonding two different metals together.

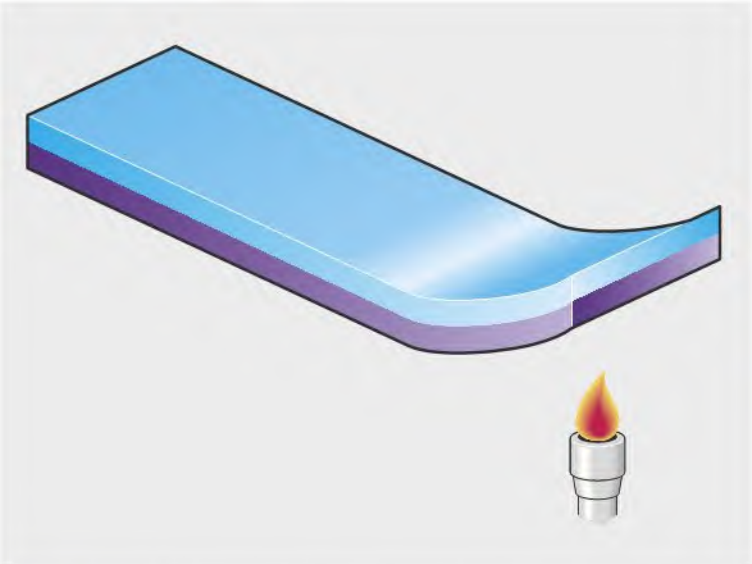


Figure 4–9 A bimetal strip warps with a change of temperature.

1. The type of metals used to construct the bimetal strip.
2. The difference in temperature between the two ends of the strip.
3. The length of the strip.

The overload heater heats the bimetal strip when motor current flows through it. The heat causes the bimetal strip to warp. If the bimetal strip becomes hot enough, it causes a set of contacts to open (Figure 4–10). Once the overload contact has opened, about 2 minutes of cool-down time is needed to permit the bimetal strip to return to a position that permits the contacts to reclose. The time delay factor for this overload relay is the time required for the bimetal strip to warp a sufficient amount to open the normally closed contact. A large amount of overload current causes the bimetal strip to warp at a faster rate and open the contact sooner.

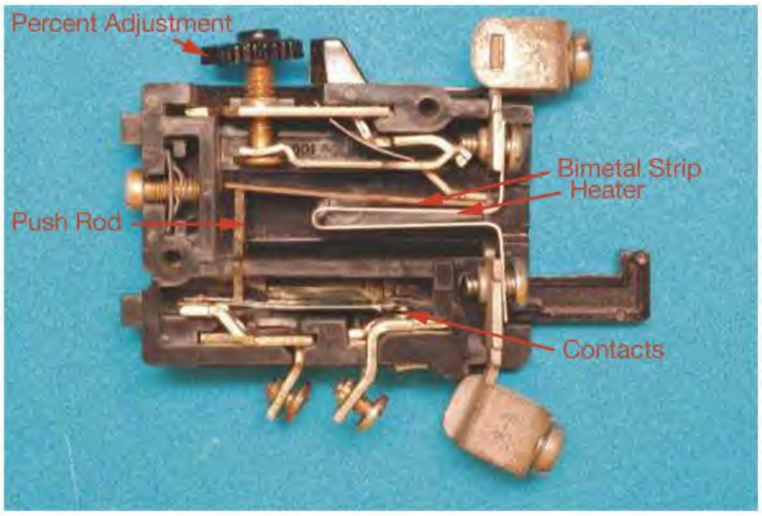


Figure 4–10 Bimetal strip type overload relay.

Most bimetal strip type overload relays have a couple of features that are not available with solder melting type overload relays. As a general rule, the trip range can be adjusted by turning the knob shown in Figure 4–10. This knob adjusts the distance the bimetal strip must warp before opening contacts. This adjustment permits the sensitivity to be changed due to changes in ambient air temperature. If the knob is set in the 100 percent position (Figure 4–11), the

Figure 4–11 An adjustment knob permits the full load motor current to be adjusted between 85 percent and 115 percent.

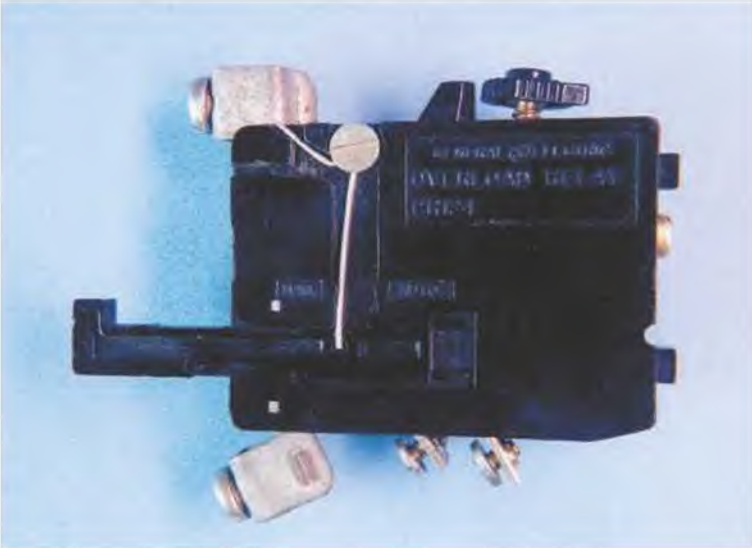


Figure 4–12 Many bimetal strip type overload relays can be set for manual or automatic reset.

overload operates at the full load current rating as determined by the size overload heater installed. In cold winter months, this setting may be too high to protect the motor. The knob can be adjusted to operate at any point from 100 percent to 85 percent of the motor full load current. In hot summer months, the motor may nuisance trip due to high ambient temperatures. The adjustment knob permits the overload relay to also be adjusted between 100 percent and 115 percent of motor full load current.

Another difference is that many bimetal strip type overload relays can be set for either manual or automatic reset. A spring located on the side of the overload relay permits this setting (Figure 4–12). When set in the manual position, the contacts must be reset manually by pushing the reset lever. This is probably the most common setting for an overload relay. If the overload relay has been adjusted for automatic reset, the contacts will reclose by themselves after the bimetal strip has cooled sufficiently. This may be a safety hazard if it could cause the sudden restarting of a machine. Overload relays should be set in the automatic reset position only when there is no danger of someone being hurt or equipment being damaged when the overload contacts suddenly reclose.

Three Phase Overloads

The overload relays discussed so far are intended to detect the current of a single conductor supplying power to a motor (Figure 4–13). An application for this type of overload relay is to protect a single phase or direct current motor. *Section 430.37* and *Table 430.37* of the *National Electrical Code*® requires only one overload sensor device to protect a direct current motor or a single phase motor whether it operates on 120 volts or 240 volts. Three phase motors, however, must have an overload sensor (heaters or magnetic coils) in each of the three phase lines. Some motor starters accomplish this by employing three single overload relays to sense the current in each of the three phase lines (Figure 4–14). When this is done, the normally closed contact of each overload relay is connected in series as shown in Figure 4–15. If any one of the relays should open its normally closed contact, power to the starter coil is interrupted and the motor is disconnected from the power line.

Overload relays are also made that contain three overload heaters and one set of normally closed contacts (Figure 4–16). These relays are generally used

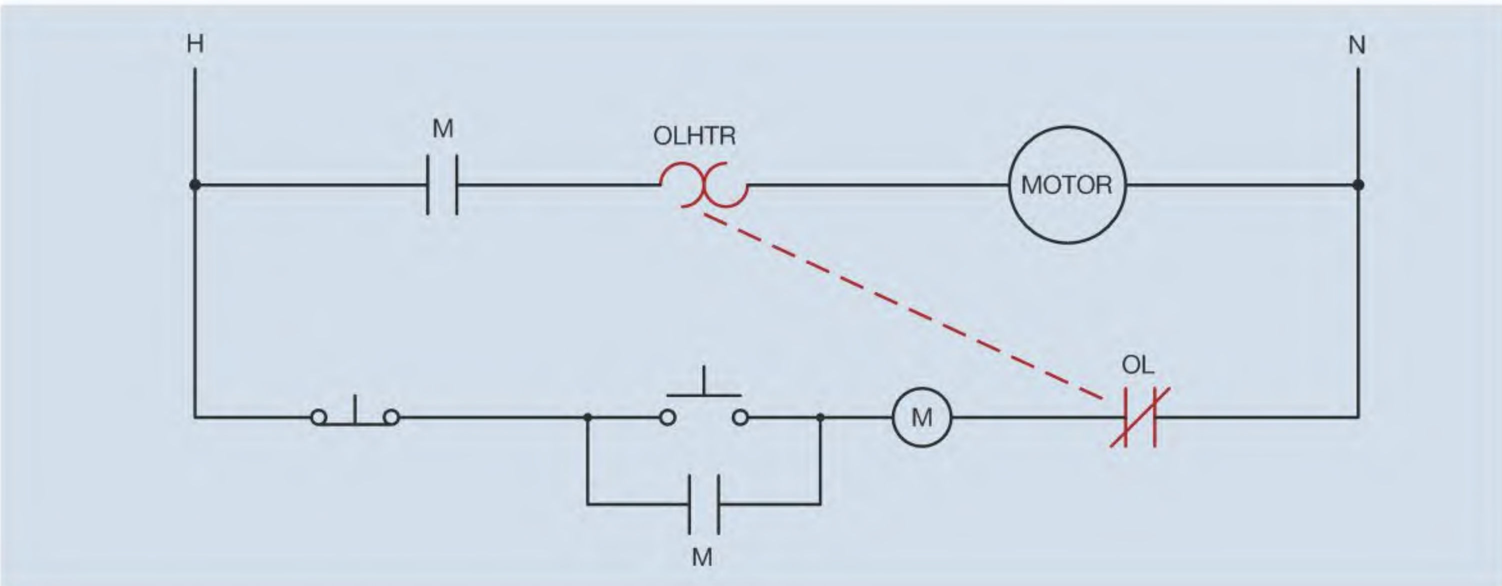


Figure 4–13 A single overload relay is used to protect a single phase motor.

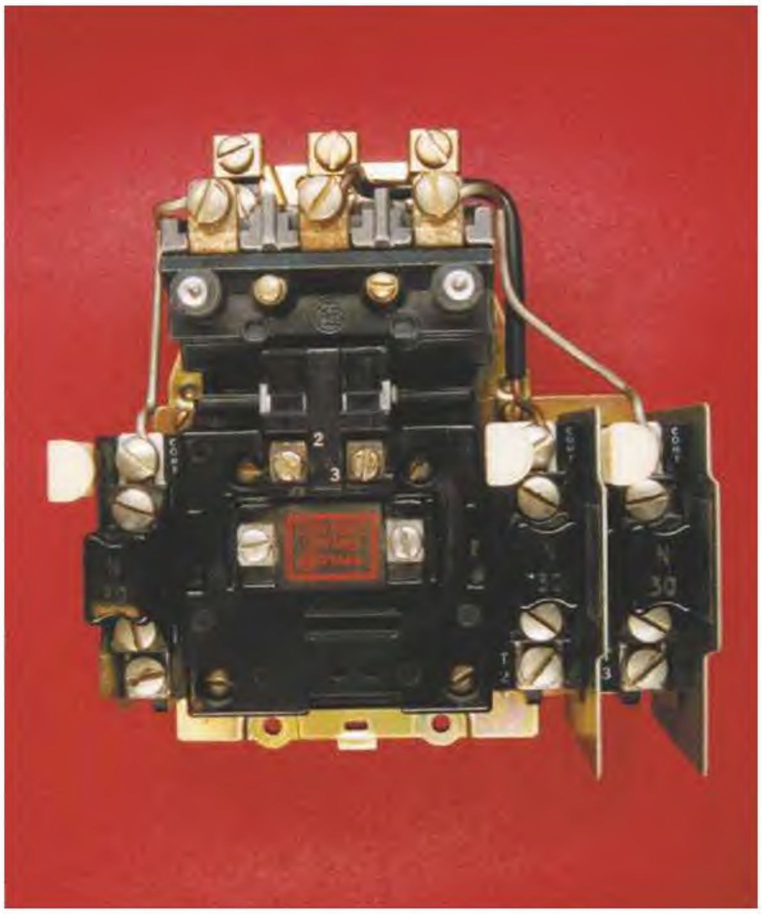


Figure 4–14 Three single overload relays are used to sense the current in each of the three phase lines.

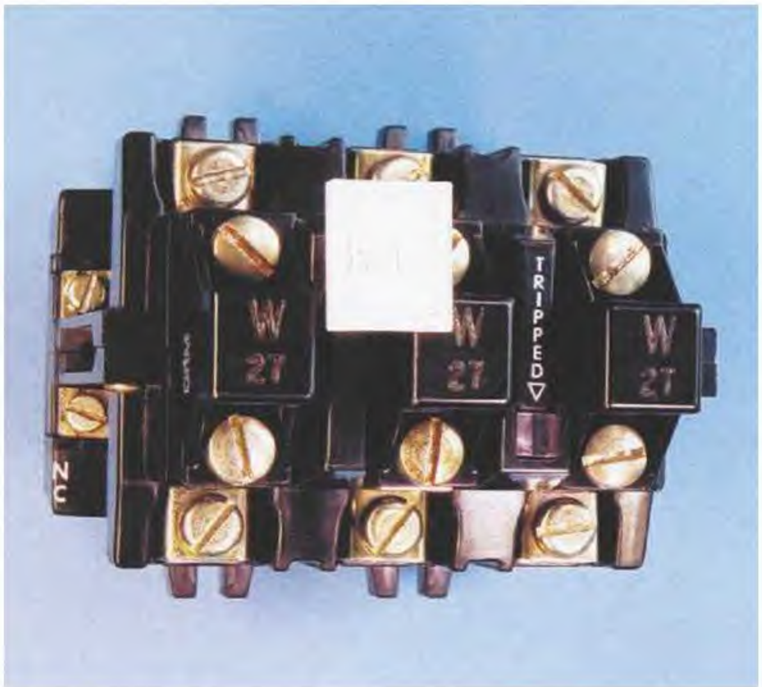


Figure 4–16 Three phase thermal overload relay.

to protect three phase motors. Although there is only one set of normally closed contacts, if an overload occurs on any one of the three heaters, it causes the contacts to open and disconnect the coil of the motor starter (Figure 4–17).

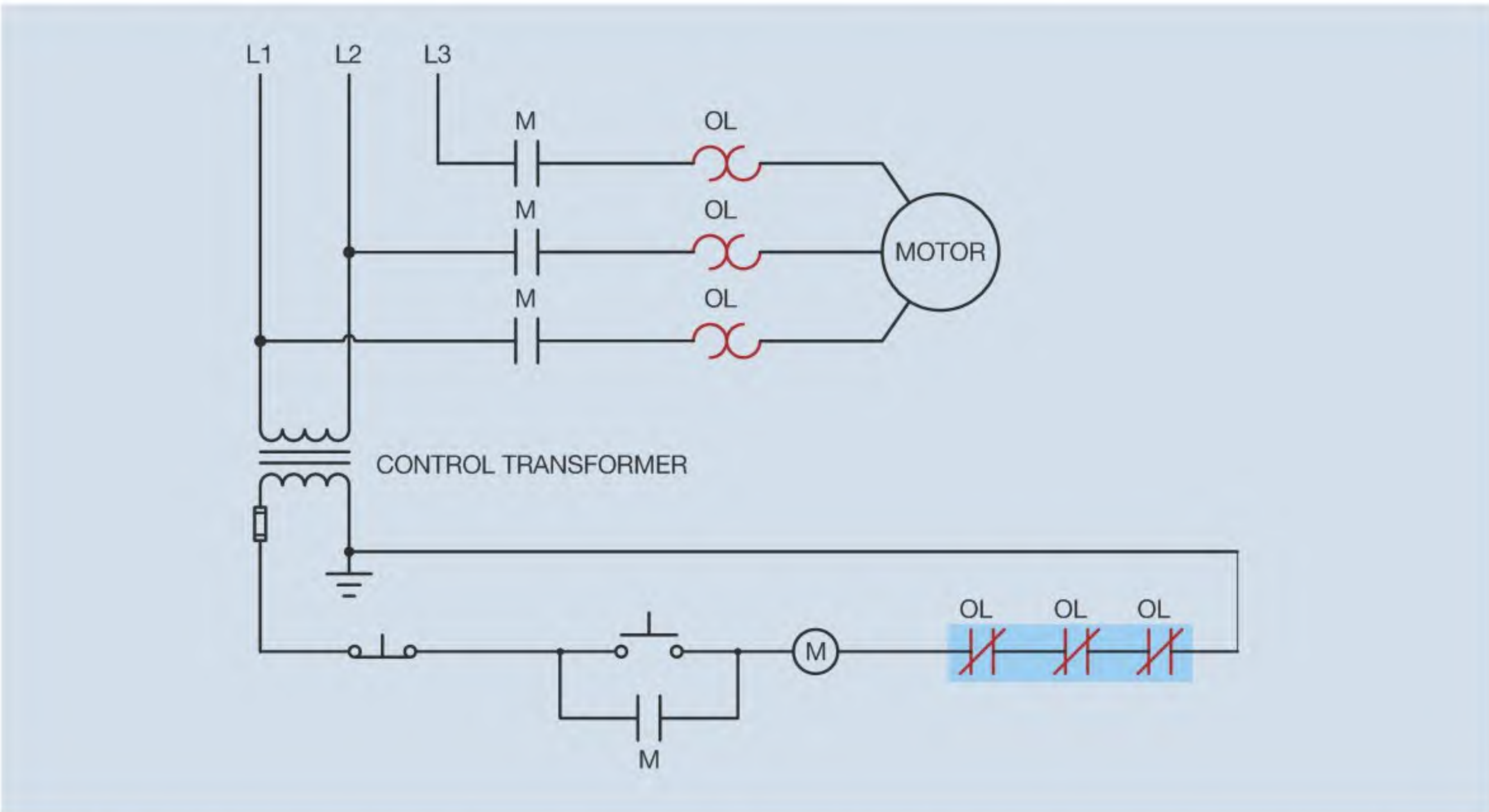


Figure 4–15 When three single overload relays are employed to protect a three phase motor, all normally closed overload contacts are connected in series.

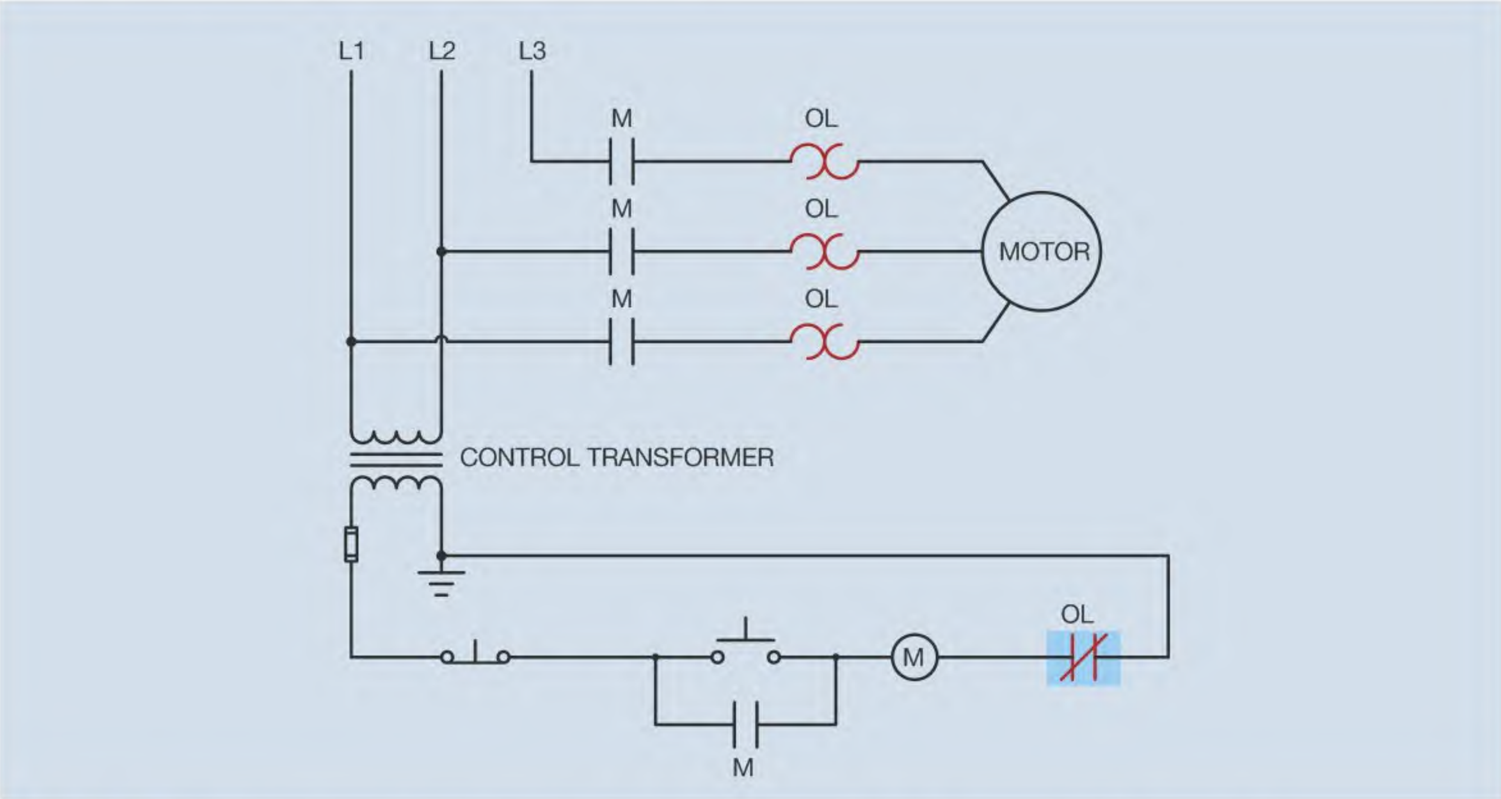


Figure 4–17 A three phase overload relay contains three heaters but only one set of normally closed contacts.

Magnetic Overload Relays

Magnetic type overload relays operate by sensing the strength of the magnetic field produced by the current flow to the motor. The greatest difference between magnetic type and thermal type overload relays is that magnetic types are *not* sensitive to ambient temperature. Magnetic type overload relays are generally used in areas that exhibit extreme changes in ambient temperature. Magnetic overload relays can be divided into two major types: electronic and **dashpot**.

Electronic Overload Relays

Electronic overload relays employ a current transformer to sense the motor current. The conductor that supplies power to the motor passes through the core of a toroid transformer (Figure 4–18). As current

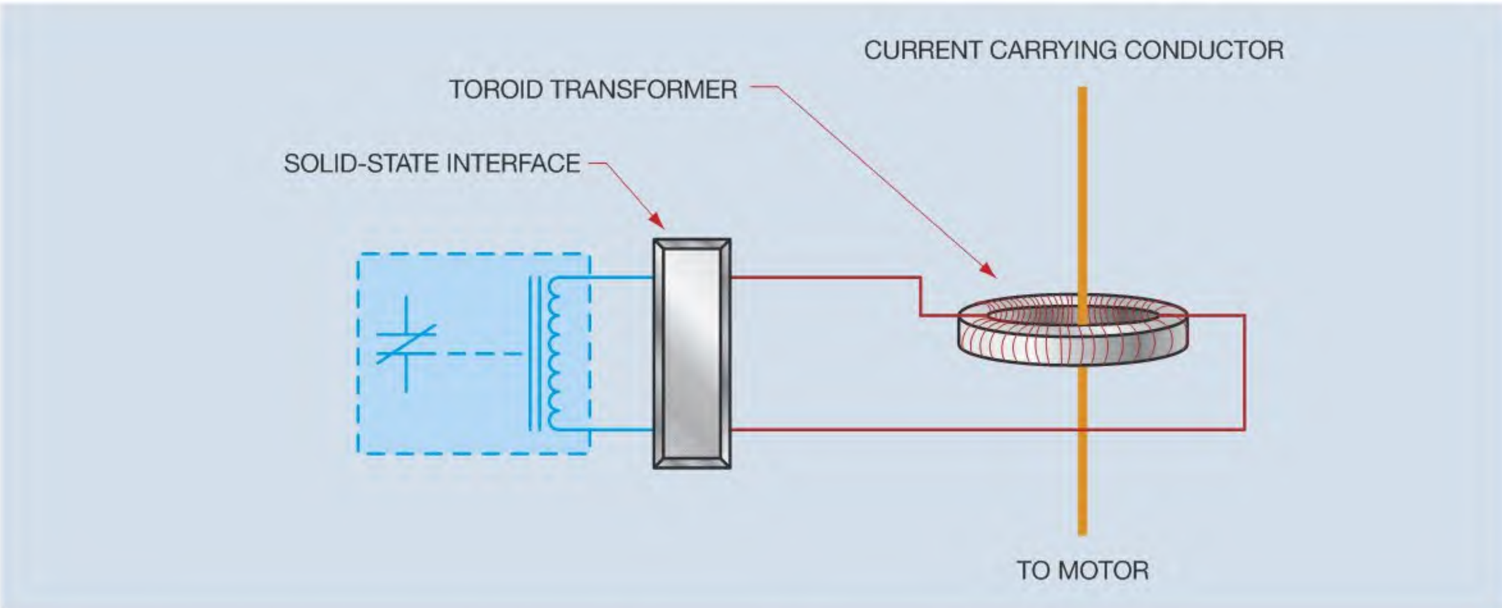


Figure 4–18 Electronic overloads sense motor current by measuring the strength of a magnetic field.

Courtesy Schneider Electric USA, Inc.

Figure 4–19 Three phase electronic overload relay.

flows through the conductor, the alternating magnetic field around the conductor induces a voltage into the toroid transformer. The amount of induced voltage is proportional to the amount of current flowing through the conductor. The same basic principle of operation is employed by most clamp-on type ammeters. The voltage induced into the toroid transformer is connected to an electronic interface that provides the time delay necessary to permit the motor to start. Many electronic type overload relays are programmable and can be set for the amount of full load motor current, maximum and minimum voltage levels, percent of overload, and other factors. A three phase electronic overload relay is shown in Figure 4–19.

Dashpot Overload Relays

Dashpot overload relays receive their name from the method used to accomplish the time delay that permits the motor to start. A dashpot timer is used to provide this time delay. A dashpot timer is basically a container, a piston, and a shaft (Figure 4–20). The piston is placed inside the container and the container is filled with a special type of oil called *dashpot oil* (Figure 4–21). Dashpot oil maintains a constant viscosity over a wide range of temperatures. The type and viscosity of oil used is one of the factors that determine the amount of time delay for the timer. The other factor is setting the opening of the orifices in the piston (Figure 4–22). Orifices permit the oil to flow through the piston as it rises through the oil. The opening of the orifices can be set by adjusting a sliding valve on the piston.

Figure 4–20 A dashpot timer is a container, piston, and shaft.

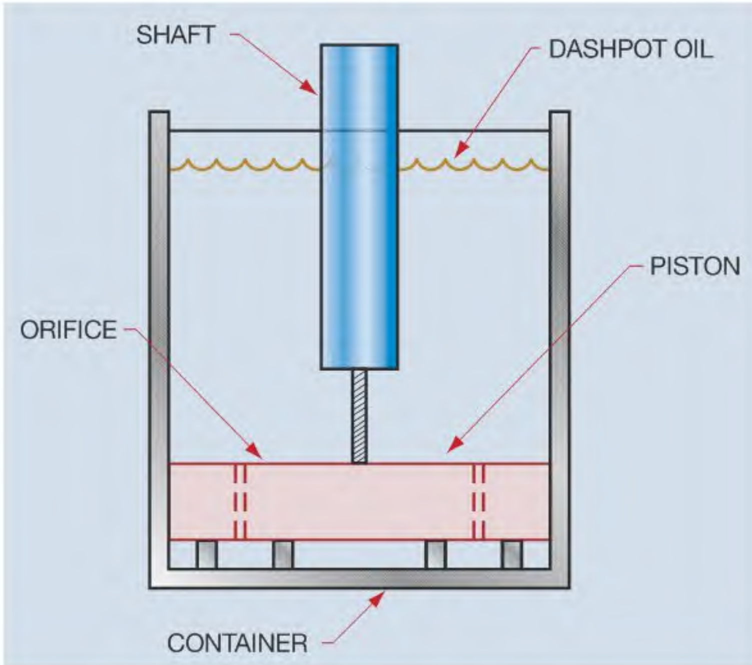


Figure 4–21 Basic construction of a dashpot timer.

Figure 4–22 Setting the opening of the orifices affects the tide delay of the dashpot timer.

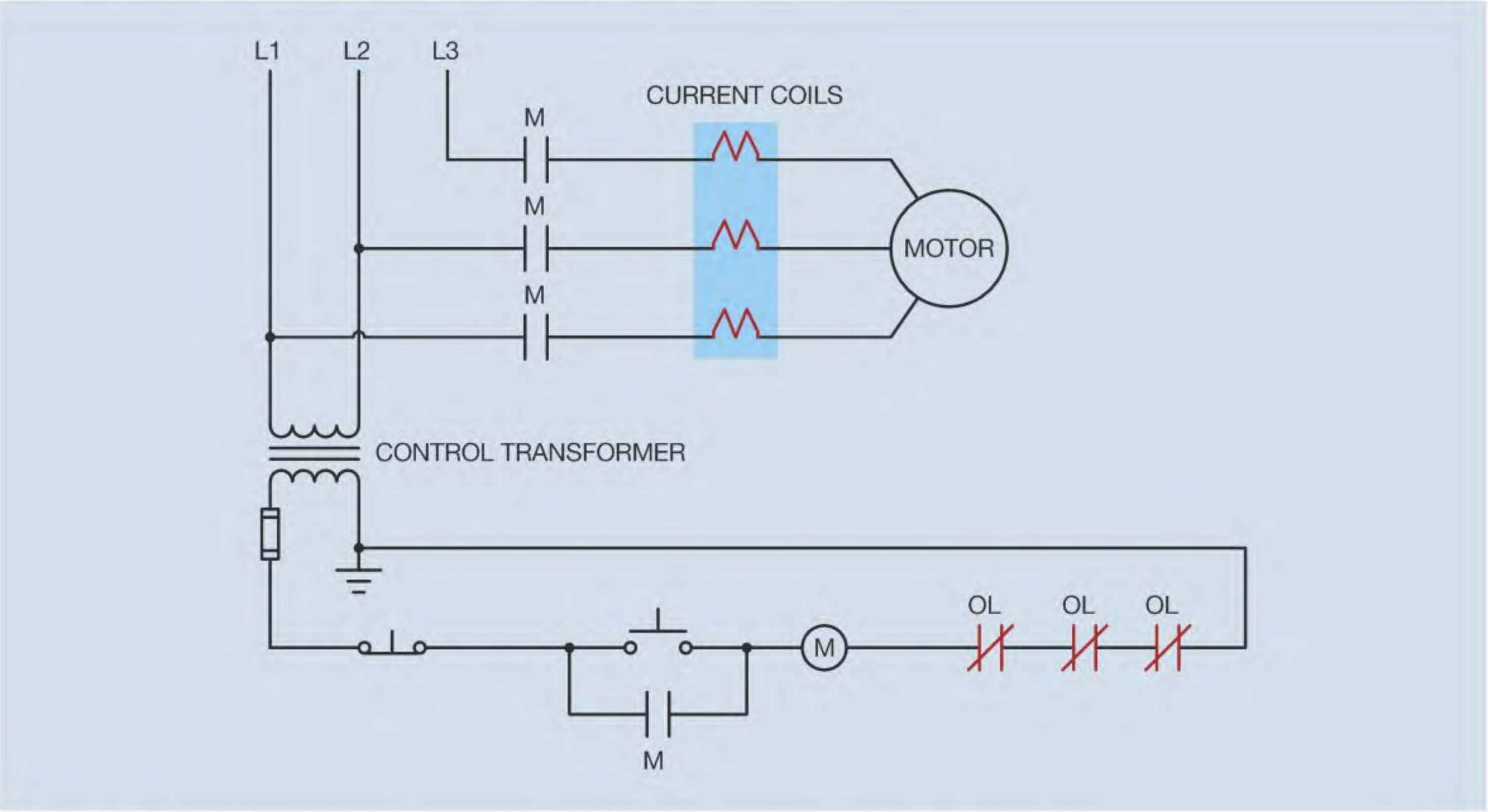


Figure 4–23 Dashpot overload relays contain current coils connected in series with the motor.

The dashpot overload relay contains a coil that is connected in series with the motor (Figure 4–23). As current flows through the coil, a magnetic field is developed around the coil. The strength of the magnetic field is proportional to the motor current. This magnetic field draws the shaft of the dashpot timer into the coil. The shaft's movement is retarded by the fact that the piston must displace the oil in the container. If the motor is operating normally, the motor current drops to a safe level before the shaft is drawn far enough into the coil to open the normally closed contact (Figure 4–24). If the motor is overloaded, however, the magnetic field will be strong enough to continue drawing the shaft into the coil until it opens the overload contact. When power is disconnected from the motor, the magnetic field collapses and the piston returns to the bottom of the container. Check valves permit the piston to return to the bottom of the container almost immediately when motor current ceases.

Dashpot overloads generally provide some method that permits the relay to be adjusted for different full load current values. To make this adjustment, the shaft is connected to a threaded rod (Figure 4–25). This permits the shaft to be lengthened or shortened inside the coil—the greater the length of the shaft the less current required to draw the shaft into the coil far enough to open the contacts. A nameplate on the coil lists the different current settings for a particular overload relay (Figure 4–26). The adjustment is made by moving the

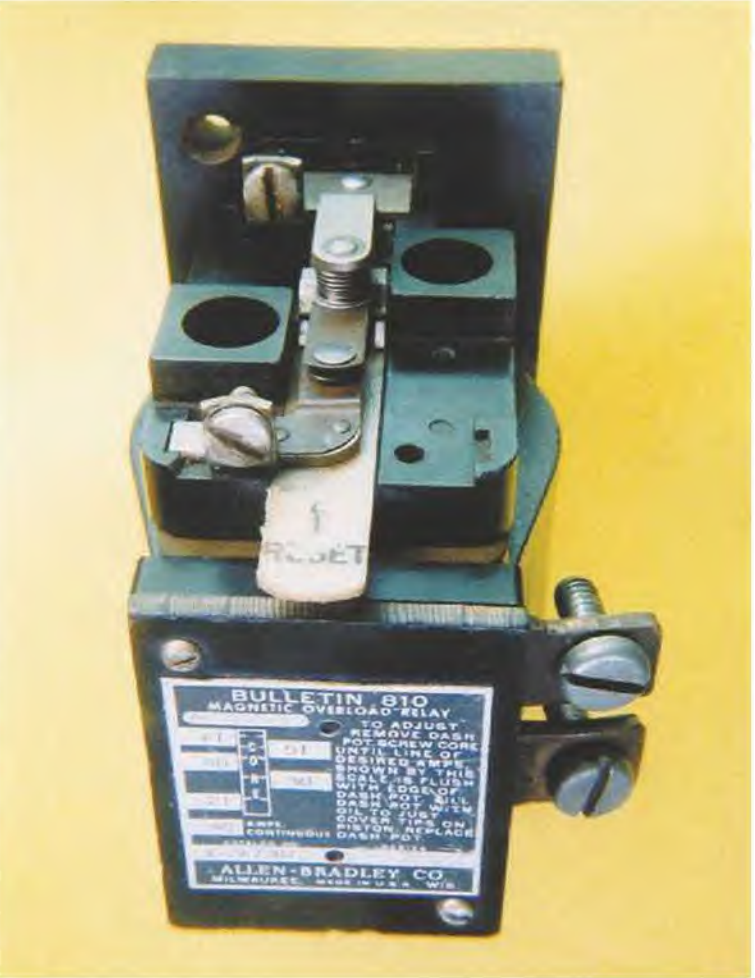


Figure 4–24 Normally closed contact of a dashpot timer.

Figure 4–25 The length of the shaft can be adjusted for different values of current.

Figure 4–27 The line on the shaft that represents the desired amount of current is set flush with the top of the dashpot container.

Figure 4–26 The nameplate lists different current settings.

shaft until the line on the shaft that represents the desired current is flush with the top of the dashpot container (Figure 4–27). A dashpot overload relay is shown in Figure 4–28.

Courtesy EC&M Company, LLC

Figure 4–28 Dashpot overload relay.

Overload Contacts

Although all overload relays contain a set of normally closed contacts, some manufacturers also add a set of normally open contacts as well. These two sets of contacts are either in the form of a single pole double throw switch or as two separate contacts. The single pole double throw switch arrangement contains a common terminal (C), a normally closed terminal (NC), and a normally open terminal (NO). There are several reasons for adding the normally open set of contacts. The starter shown in Figure 4–29 uses the normally closed section to disconnect the motor starter in the event of an overload, and the normally open section to turn on a light to indicate that the overload has tripped.

Another common use for the normally open set of contacts on an overload relay is to provide an input signal to a programmable logic controller (PLC). If the overload trips, the normally closed set of contacts opens and disconnects the starter coil from the line. The normally open set of contacts closes and provides

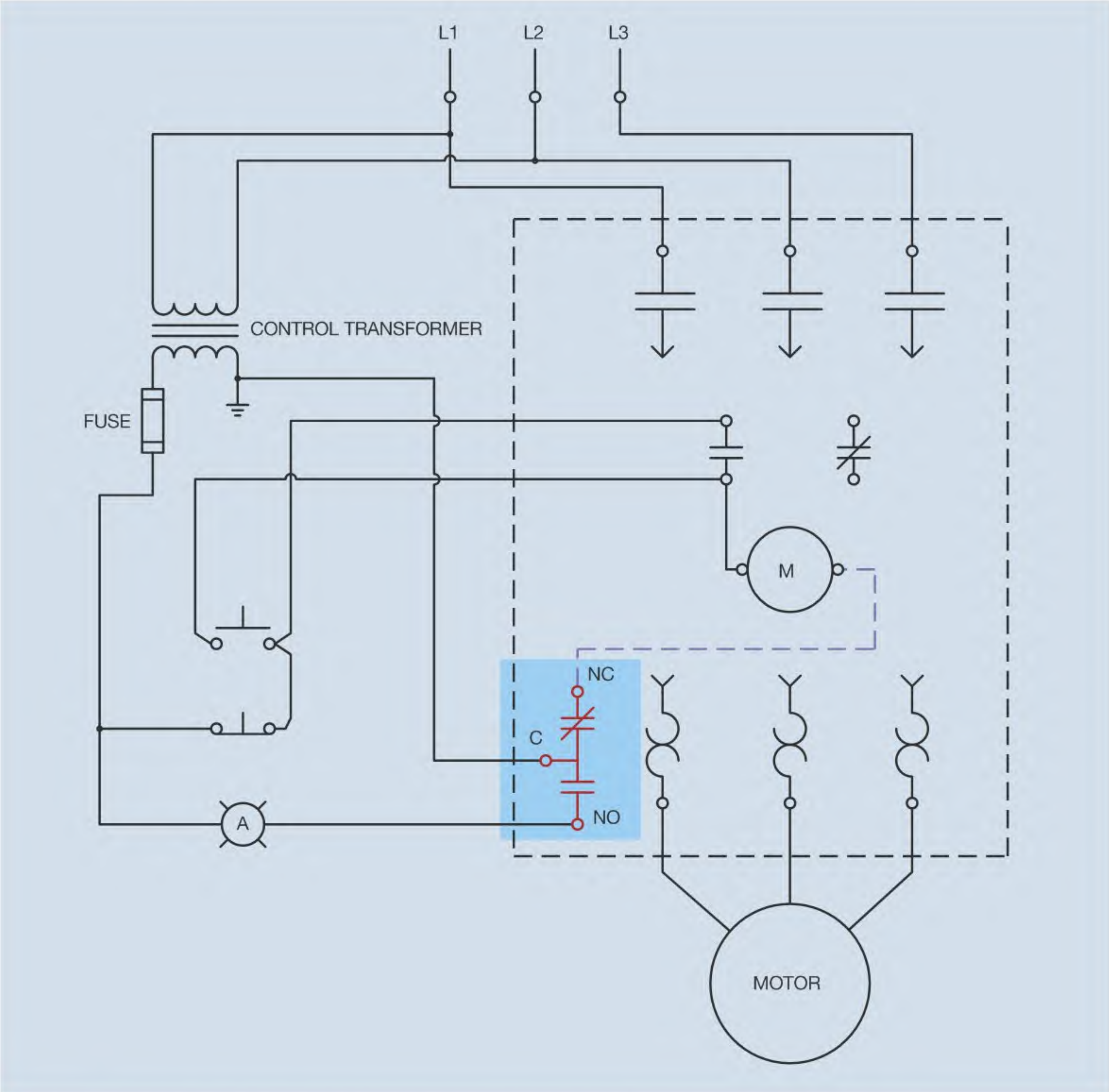


Figure 4–29 The overload relay contains a single pole double throw set of contacts.

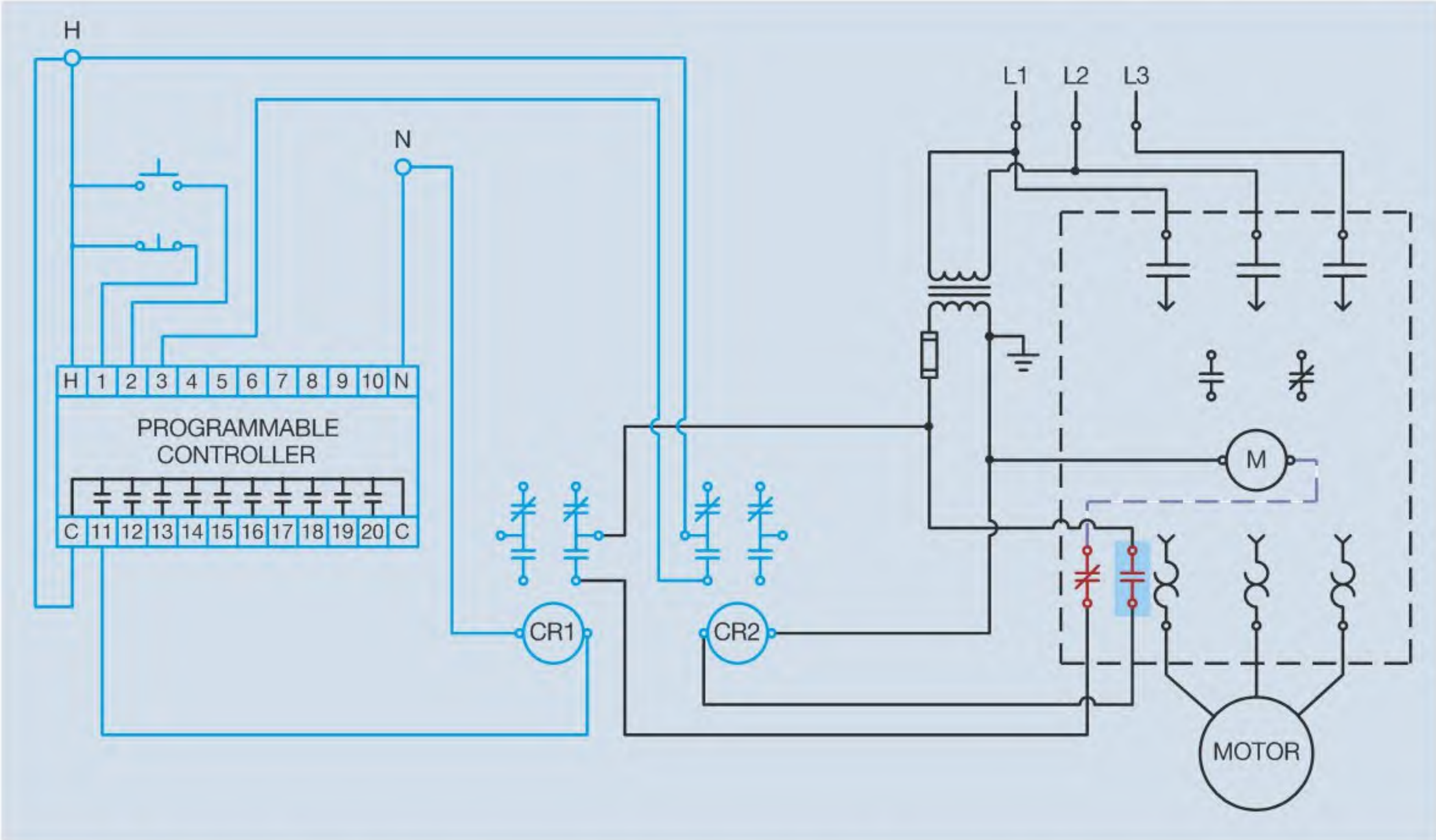


Figure 4–30 The normally open overload contact provides a signal to the input of a programmable logic controller.

a signal to the input of the PLC (Figure 4–30). Notice that two interposing relays, CR1 and CR2, are used to separate the programmable logic controller and the motor starter. This separation is often done for safety reasons. The control relays prevent more than one source of power from entering the starter or programmable controller. Note that the starter and programmable controller each have a separate power source. If the power was disconnected from the starter, for example, it could cause an injury if the power from the programmable controller was connected to any part of the starter.

Protecting Large Horsepower Motors

Large horsepower motors often have current draws of several hundred amperes, making the sizing of overload heaters difficult. When this is the case, it is common practice to use current transformers to reduce the amount of current to the overload heaters (Figure 4–31). The current transformers shown in Figure 4–31 have ratios of 150:5. This ratio means that when 150 amperes of current flows through the primary, which is the line connected to the motor, the transformer secondary produces a current of 5 amperes when the secondary terminals are shorted together. The secondaries of the current transformers are connected to the overload heaters to provide protection for the motor (Figure 4–32). Assume that the motor connected to the current transformers in Figure 4–32 has a full load current of 136 amperes. A simple calculation reveals that current transformers with a

Figure 4–31 Current transformers reduce overload current.

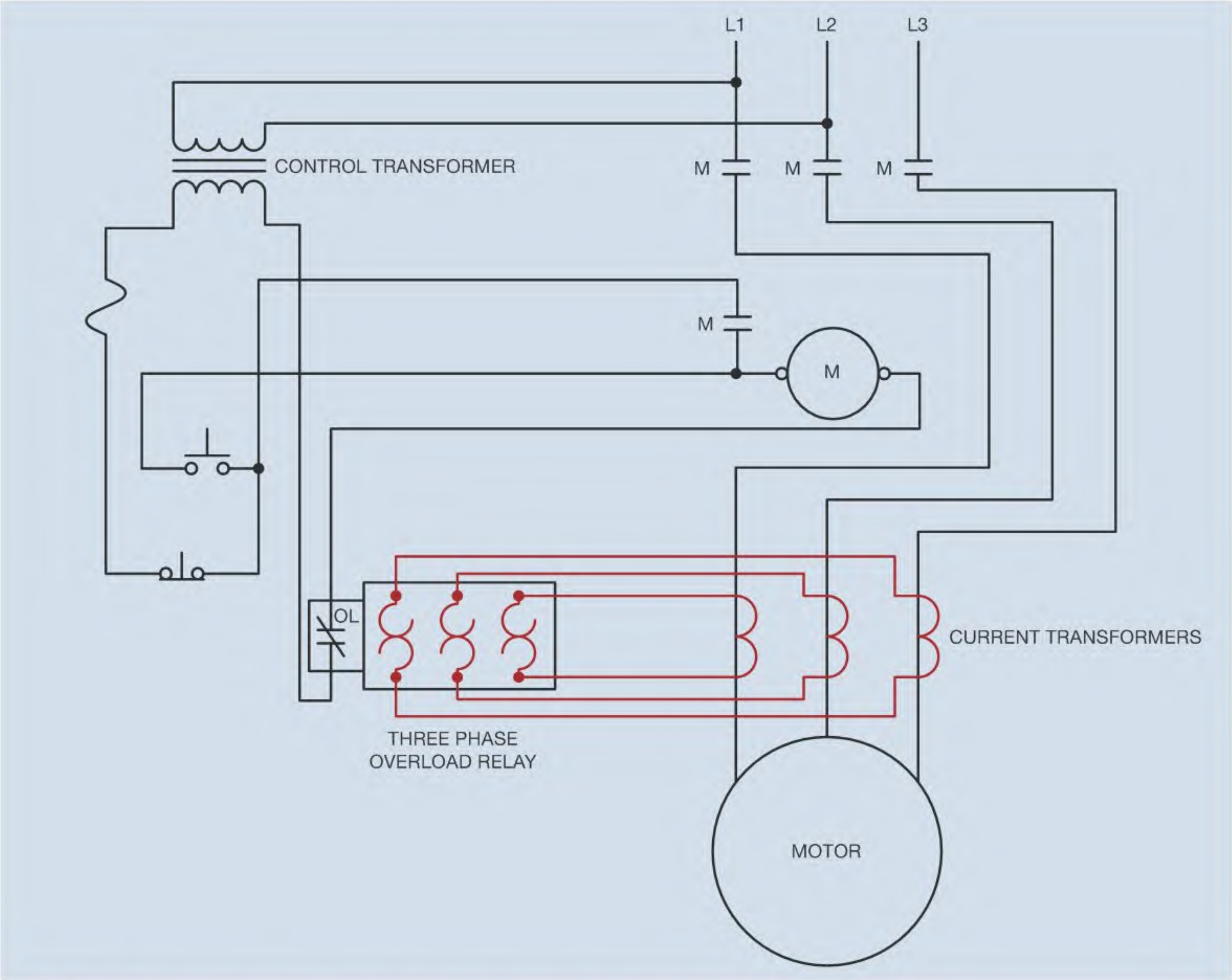


Figure 4–32 Current transformers reduce the current to the overload heaters.

ratio of 150:5 would produce a secondary current of 4.533 amperes when 136 amperes flow through the primary.

$$\frac{150}{5} = \frac{136}{X}$$

$$150X = 680$$

$$X = \frac{680}{150}$$

$$X = 4.533$$

The overload heaters would actually be sized for a motor with a full load current of 4.533 amperes. The typical overload heater chart shown in Figure 4–7 indicates that a XX31 heater would be used if the overload is sized at 115 percent of motor full load current and a XX32 heater would be used if the overload is sized at 125 percent of motor full load current.

Large size starters often contain current transformers as an integral part of the starter. The size 6 starter illustrated in Figure 4–33 contains current transformers

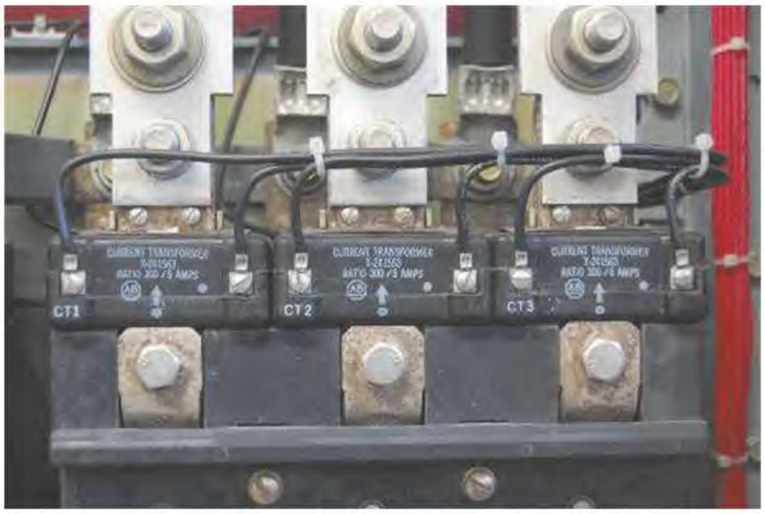


Figure 4–33 Large starters are often provided with current transformers.

with a ratio of 300:5 on each of the input connections. The secondary or outputs of these transformers are connected directly to the overload heater elements.

Review Questions

1. What are the two basic types of overload relays?
2. What is the major difference in characteristics between thermal type and magnetic type overload relays?
3. What are the two major types of thermal overload relays?
4. What type of thermal overload relay can generally be set for manual or automatic operation?
5. Why is it necessary to permit a solder melting type of overload relay to cool for 2 to 3 minutes after it has tripped?
6. All overload relays are divided into two sections. What are these two sections?
7. What device is used to sense the amount of motor current in an electronic overload relay?
8. What two factors determine the time setting for a dashpot timer?
9. How many overload sensors are required by the *National Electrical Code*® to protect a direct current motor?
10. A large motor has a full load current rating of 425 amperes. Current transformers with a ratio of 600:5 are used to reduce the current to the overload heaters. What should be the full load current rating of the overload heaters?

Chapter 5

RELAYS, CONTACTORS, AND MOTOR STARTERS

Objectives

After studying this chapter the student will be able to:

- Discuss the operation of magnetic type relay devices.
- Explain the difference between relays, contactors, and motor starters.
- Connect a relay in a circuit.
- Identify the pins of 8 and 11 pin relays.
- Discuss the differences between DC and AC type relays and contactors.
- Discuss difference between NEMA- and IEC-rated starters.

Relays and **contactors** are electromechanical switches. They operate on the **solenoid** principle. A coil of wire is connected to an electric current. The magnetic field developed by the current is concentrated in an iron pole piece. The electromagnet attracts a metal armature. Contacts are connected to the metal armature. When the coil is energized, the contacts open or close. There are two basic methods of constructing a relay or contactor. The clapper type uses one movable contact to make connection with a stationary contact. The bridge type uses a movable contact to make connection between two stationary contacts.

Relays

Relays are electromechanical switches that contain auxiliary contacts. Auxiliary contacts are small and are intended to be used for control applications. As a general rule, they are not intended to control large amounts of current. Current ratings for most relays can vary from 1 to 10 amperes depending on the manufacturer and type of relay. A clapper type relay is illustrated in Figure 5–1. When the

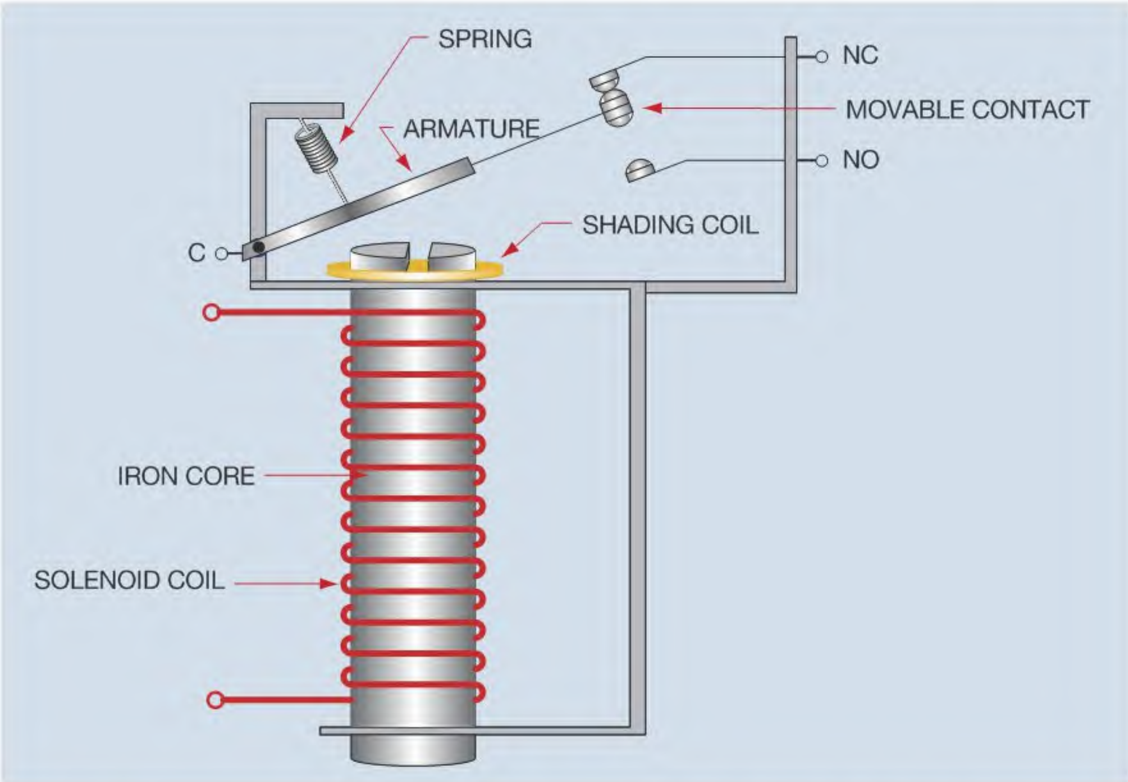


Figure 5–1 A magnetic relay is basically a solenoid with movable contacts attached.

coil is energized, the armature is attracted to the iron core inside the coil. This attraction causes the movable contact to break away from one stationary contact and make connection with another. The common terminal is connected to the armature, which is the movable part of the relay. The movable contact is attached to the armature. The two stationary contacts form the normally closed and normally open contacts. A spring returns the armature to the normally closed position when power is removed from the coil. The shading coil is necessary to prevent the contacts from chattering. All solenoids that operate on alternating current must have a shading coil. Relays that operate on direct current do not require them. A clapper type relay is shown in Figure 5–2.

Bridge Type Relay

A bridge type relay operates by drawing a piece of metal or plunger inside a coil, Figure 5–3. The plunger is connected to a bar that contains movable contacts. The movable contacts are mounted on springs and are insulated from the bar. The plunger and bar assembly are called the armature because they are the moving part of the relay. Bridge contacts receive their name because when the solenoid coil is energized and the plunger is drawn inside the coil, the movable contacts bridge across the two stationary contacts. Bridge contacts can control more voltage than clapper types because they break connection at two places instead of one. When power is removed from the coil, the force of gravity or a spring returns the movable contacts to their original position. A relay with bridge type contacts is shown in Figure 5–4.

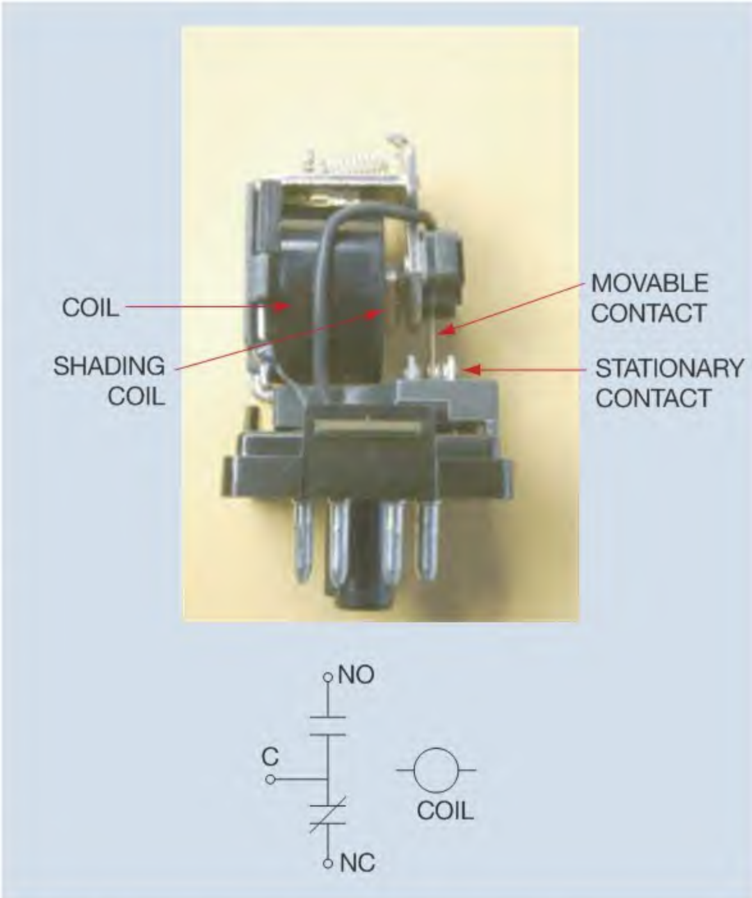


Figure 5–2 Single pole double throw clapper type relay.

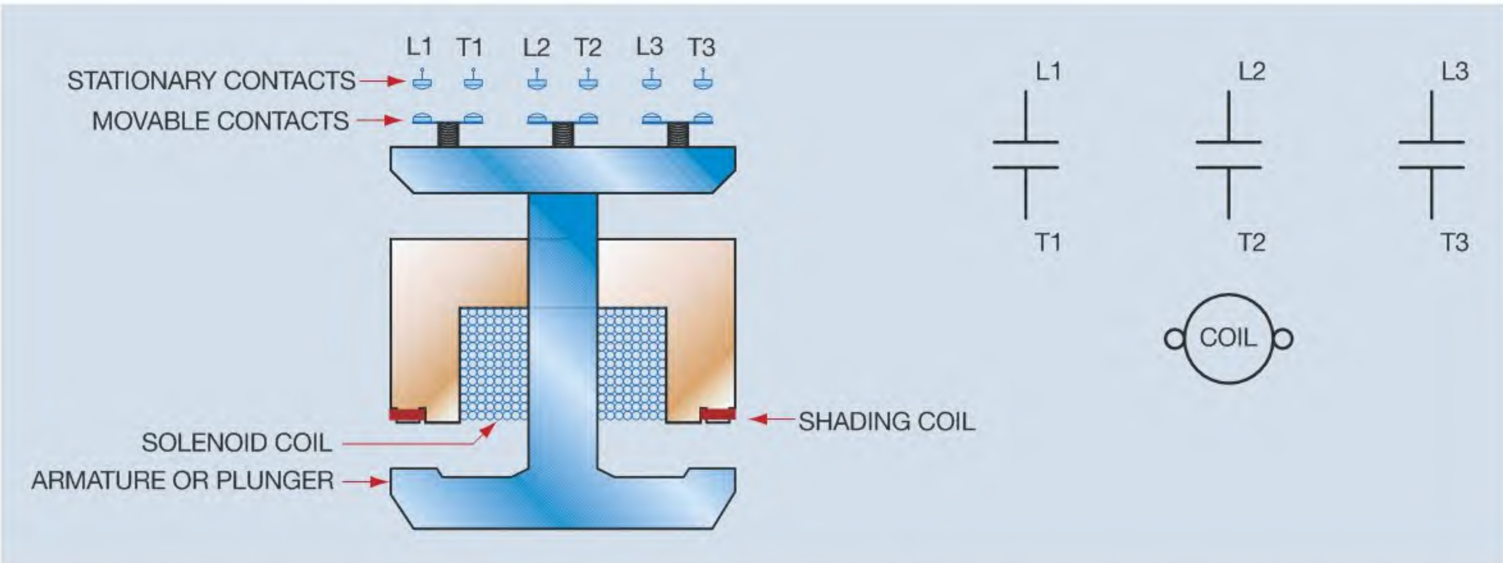


Figure 5–3 Bridge type contacts use one movable and two stationary contacts. They can control higher voltages because they break connection in two places instead of one.

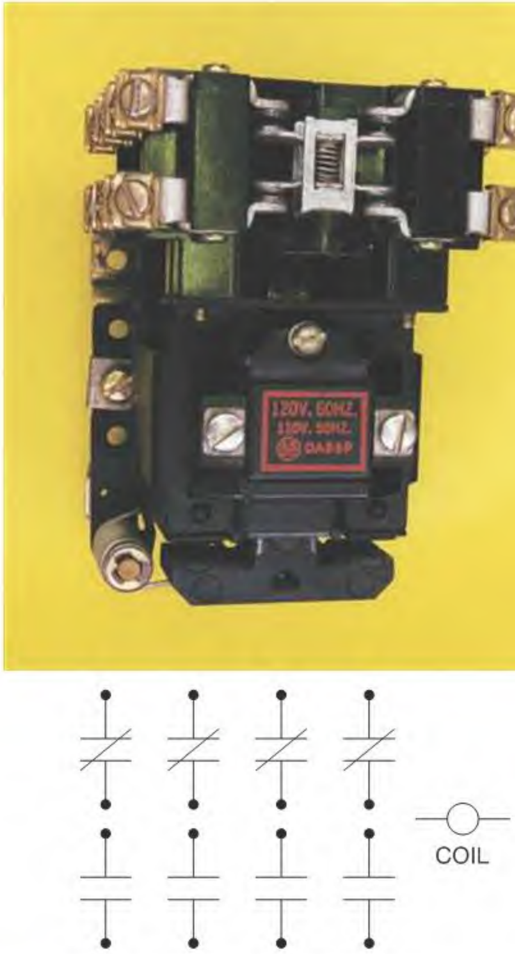


Figure 5–4 A relay with bridge type contacts.

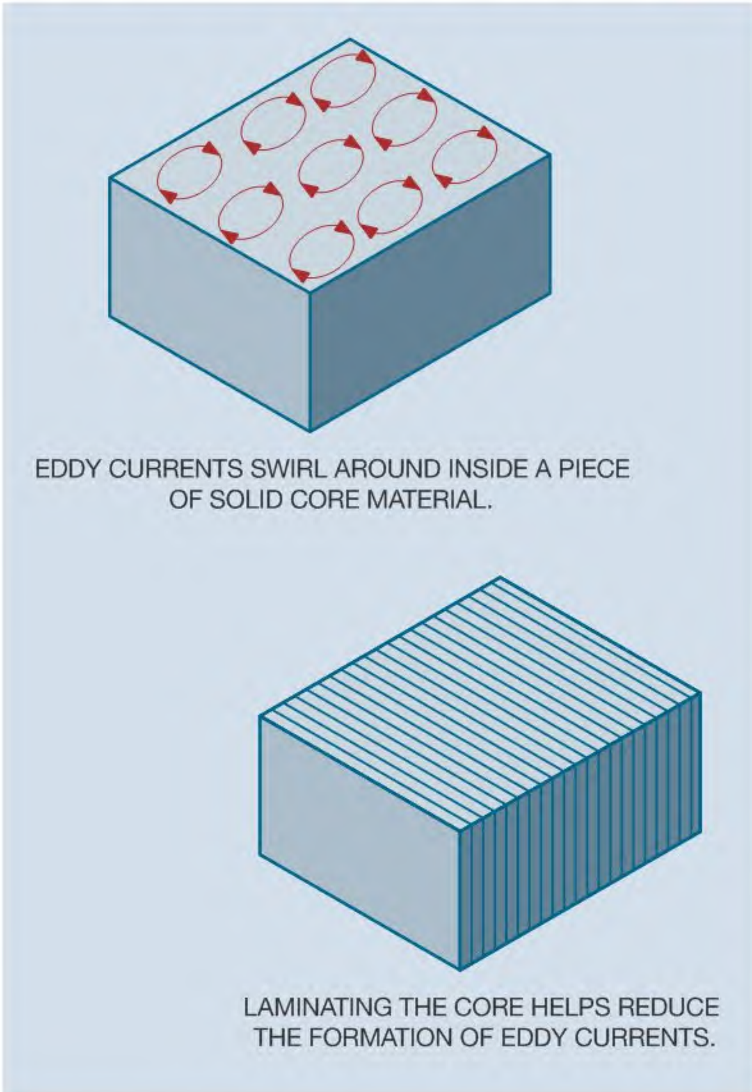


Figure 5–5 Eddy currents are induced into the metal core and produce power loss in the form of heat.

Electromagnet Construction

The construction of the electromagnetic part of a relay or contactor greatly depends on whether it is to be operated by direct or alternating current. Relays and contactors that are operated by direct current generally contain solid core materials, while those intended for use with alternating current contain laminated cores. The main reason is the core losses associated with alternating current caused by the continuous changing of the electromagnetic field.

Core Losses

This continuous change of both amplitude and polarity of the magnetic field causes currents to be induced into the metal core material. These currents are called **eddy currents** because they are similar to eddies (swirling currents) found in rivers. Eddy currents tend to swirl around inside the core material producing heat (Figure 5–5). Laminated cores are constructed with thin sheets of metal stacked together. A thin layer of oxide forms between the laminations. This oxide is an insulator and helps reduce the formation of eddy currents.

Another type of core loss associated with alternating current devices is called **hysteresis loss**. Hysteresis loss is caused by the molecules inside magnetic materials changing direction. Magnetic materials such as iron or soft steel contain magnetic domains or magnetic molecules. In an unmagnetized piece of material, these magnetic domains are not aligned in any particular order (Figure 5–6). If the metal becomes magnetized, the magnetic molecules or domains align themselves in an orderly fashion (Figure 5–7). If the polarity of the magnetic field is reversed, the molecules realign themselves to the new polarity (Figure 5–8). Although the domains realign to correspond to a change of polarity, they resist the realignment. The power required to cause them to change polarity is a power loss in the form of heat. Hysteresis loss is often referred to as **molecular friction** because the molecules are

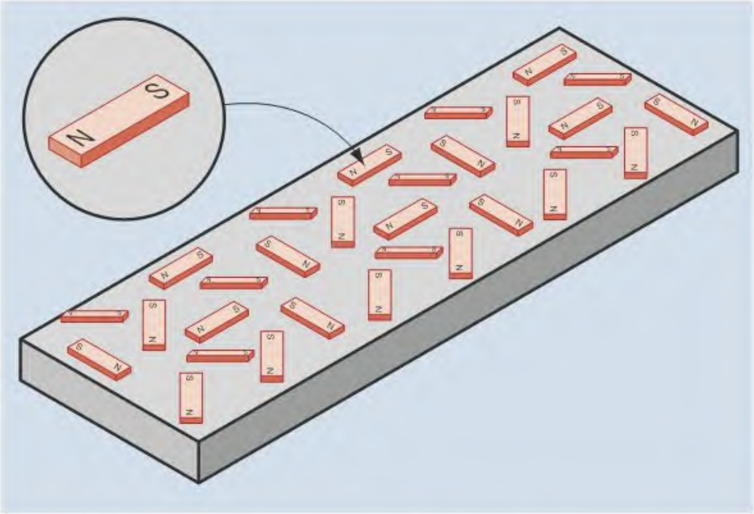


Figure 5–6 In a piece of unmagnetized metal, the molecules are in disarray.

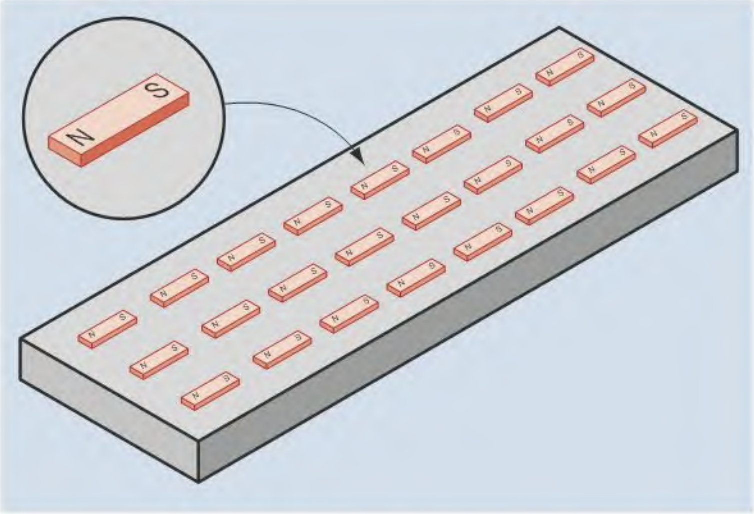


Figure 5–7 In a piece of magnetized material, the magnetic molecules are aligned.

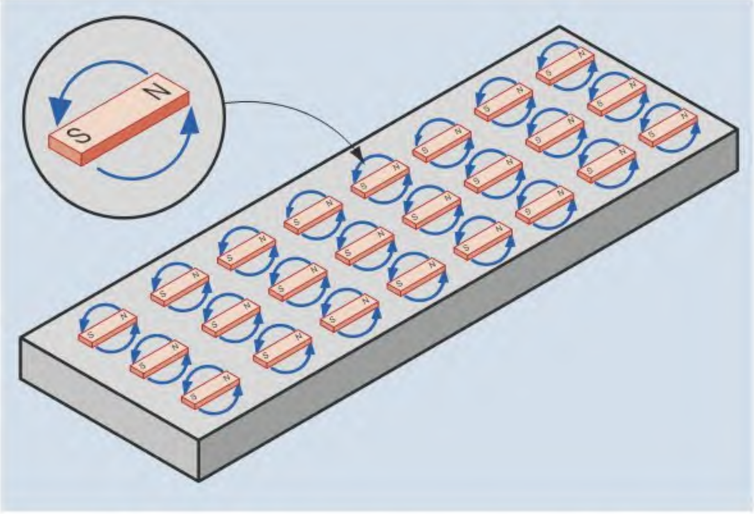


Figure 5–8 When the magnetic polarity changes, all the molecules change position.

continually changing direction in an alternating current field. Hysteresis loss is proportional to the frequency. At low frequencies such as 60 Hz, it is generally so small that it is of little concern.

Shading Coils

As mentioned previously, all solenoid-type devices that operate on alternating current contain shading coils to prevent chatter. The current in an AC circuit is continually increasing from zero to a maximum value in one direction, returning to zero, and then increasing to a maximum value in the opposite direction (Figure 5–9). Because the current is continually falling to zero, the solenoid spring or gravity would continually try to drop out the armature when the magnetic field collapses. Shading coils provide a time delay for the magnetic field to prevent this from happening. As current increases from zero, magnetic lines of flux concentrate in the metal pole piece (Figure 5–10). This increasing magnetic field cuts the shading coil and induces a voltage into it. Because the shading coil or loop is a piece of heavy copper, it has a very low resistance. A very small induced voltage can cause a large amount of current to flow in the loop. The current flow in the shading coil causes a magnetic field to be developed around the shading coil also. This magnetic field acts in opposition to the magnetic field in the pole piece and causes it to bend away from the shading coil (Figure 5–11). As long as the AC current is changing in amplitude, a voltage will be induced in the shading loop.

When the current reaches its maximum or peak value, the magnetic field is no longer changing and no voltage is induced in the shading coil. Because the shading coil

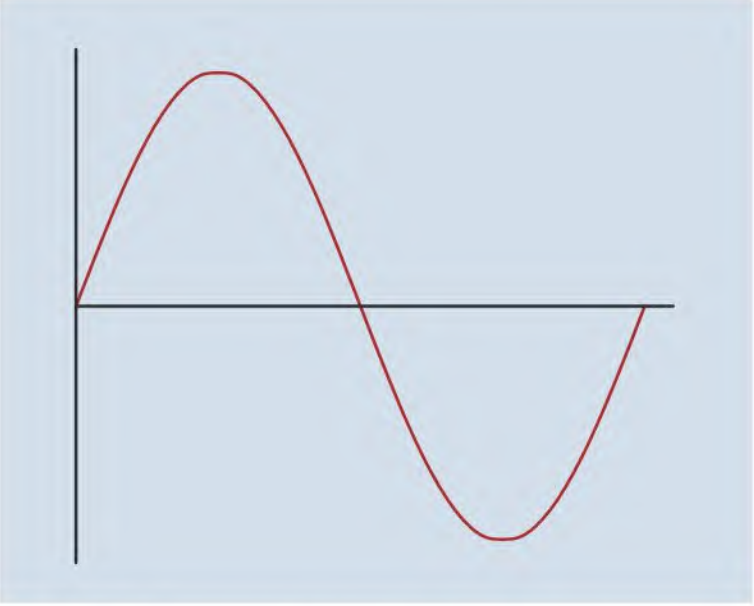


Figure 5–9 The current in an AC circuit continually changes amplitude and direction.

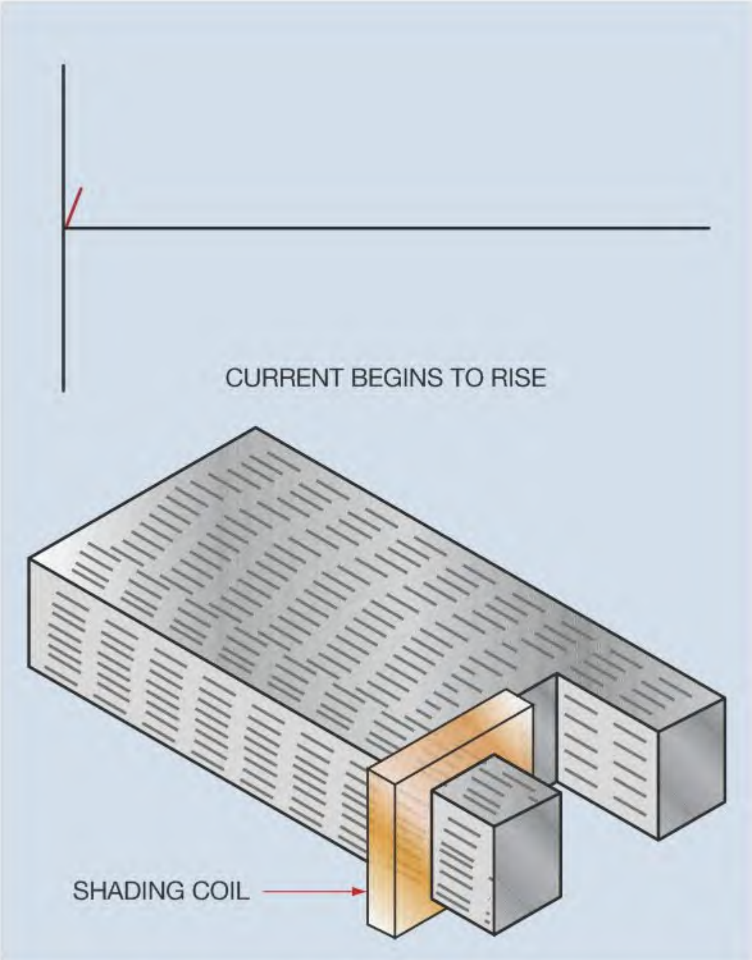


Figure 5–10 As current begins to rise, a magnetic field is concentrated in the pole piece.

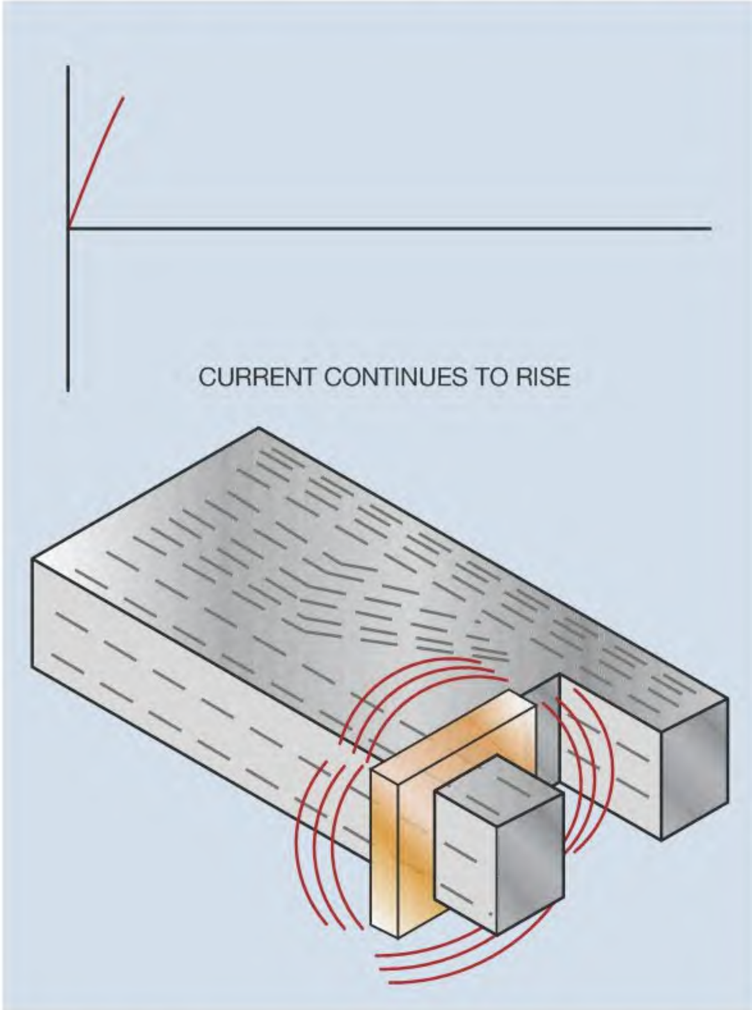


Figure 5–11 The magnetic field of the shading coil causes the magnetic field of the pole piece to bend away and concentrate in the unshaded portion of the pole piece.

has no current flow, there is no magnetic field to oppose the magnetic field of the pole piece (Figure 5–12).

When the current begins to decrease, the magnetic field of the pole piece begins to collapse. The collapsing magnetic field again induces a voltage into the shading coil. Because the collapsing magnetic field is moving in the opposite direction, the voltage induced in the shading coil causes current to flow in the opposite direction producing a magnetic field of the opposite polarity around the shading coil. The magnetic field of the shading coil now tries to maintain the collapsing magnetic field of the pole piece (Figure 5–13). This collapse causes the magnetic flux lines of the pole piece to concentrate in the shaded part of the pole piece. The shading coil provides a continuous magnetic field to the pole piece, preventing the armature from dropping out. A laminated pole piece with shading coils is shown in Figure 5–14.

Control Relay Types

Control relays can be obtained in a variety of styles and types (Figure 5–15). Most have multiple sets of contacts and some are constructed in such a manner that their contacts can be set as either normally open or normally closed. This flexibility can be a great advantage. When a control circuit is being constructed, one relay may require three normally open contacts and one normally closed, while another may need two normally open and two normally closed contacts.

Relays that are designed to plug into 8 or 11 pin tube or relay sockets are very popular for many applications (Figure 5–16). These sockets are often referred to as tube sockets because they were originally used for making connection to vacuum tubes. Relays of this type are relatively inexpensive and replacement is fast and simple in the event of failure. Because the relays plug into a socket, the wiring is connected to the socket, not the relay. Replacement is a matter of removing the defective relay and plugging in a new one. Both 8 and 11 pin tube or relay sockets are shown in Figure 5–17. Both 8 and 11 pin relays can be obtained with different coil voltages. Coil voltages of 12 VDC, 24 VDC, 24 VAC, and 120 VAC are common. Their contact ratings generally range from 5 to 10 amperes depending on

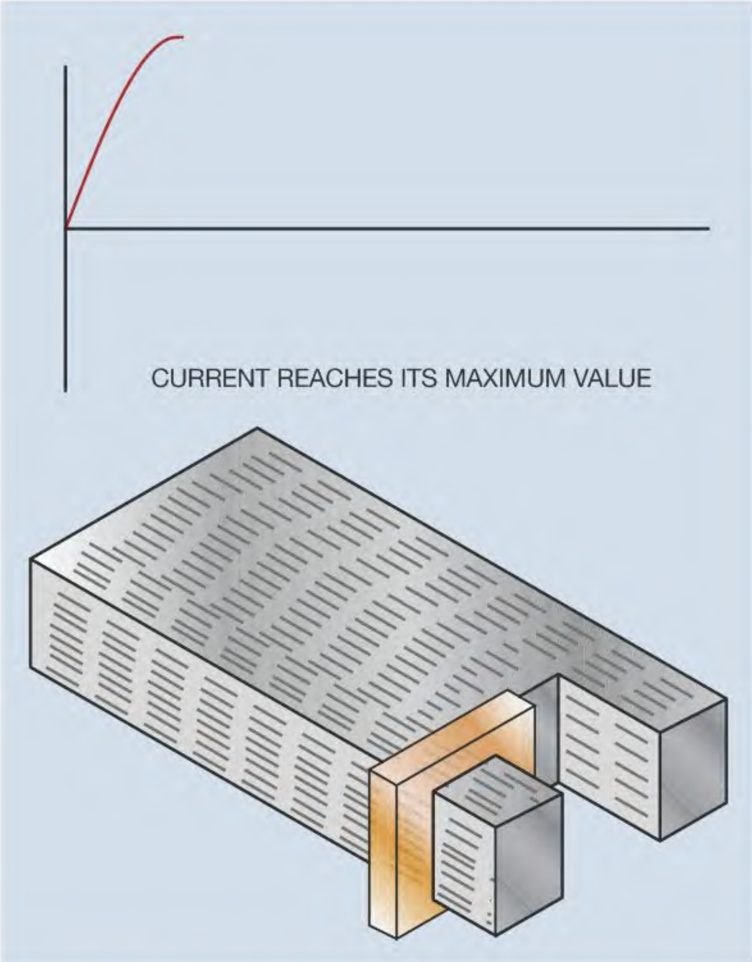


Figure 5–12 When the current reaches its maximum value, the magnetic field is no longer changing and the shading coil offers no resistance to the magnetic field of the pole piece.

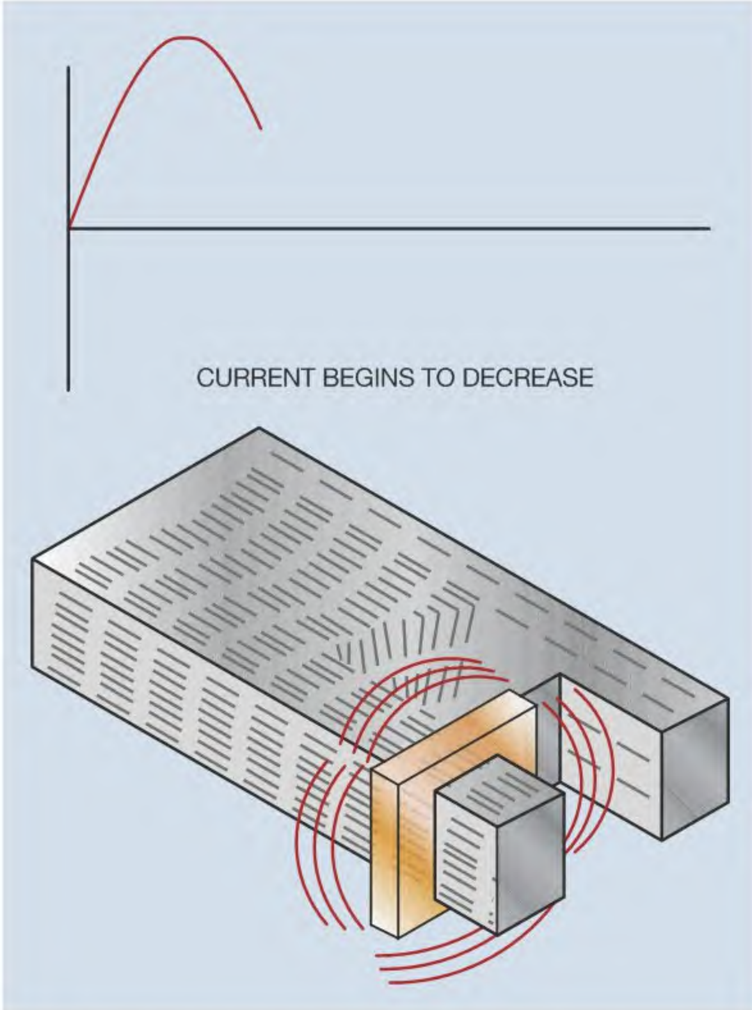


Figure 5–13 As current decreases, the collapsing magnetic field again induces a voltage into the shading coil. The shading coil now aids the magnetic field of the pole piece and flux lines are concentrated in the shaded section of the pole piece.

relay type and manufacturer. The connection diagram for 8 and 11 pin relays is shown in Figure 5–18. The pin numbers for 8 and 11 pin relays can be determined by holding the relay with the bottom facing you. Hold the relay so that the key is facing down. The pins are numbered as shown in Figure 5–18. The 11 pin relay contains three separate single pole double throw contacts. Pins 1 and 4, 6 and 5, and 11 and 8 are normally closed contacts. Pins 1 and 3, 6 and 7, and 11 and 9 are normally open contacts. The coil is connected to pins 2 and 10.

The 8 pin relay contains two separate single pole double throw contacts. Pins 1 and 4, and 8 and 5 are normally closed. Pins 1 and 3, and 8 and 6 are normally open. The coil is connected across pins 2 and 7.

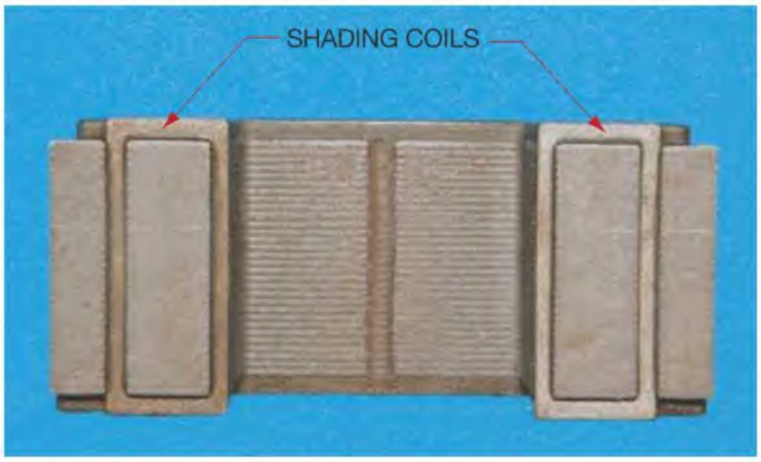


Figure 5–14 Laminated pole piece with shading coils.

Solid-State Relays

Another type of relay that is found in many applications is the solid-state relay. Solid-state relays employ the use of **solid-state devices** to connect the load to the line instead of mechanical contacts. Solid-state relays that are intended to connect alternating current loads to the line use a device called a **triac**. The triac is bidirectional device, which means it permits current to flow through it in either direction. A couple of methods are used to control when the triac turns on or off. One method employs a small relay device that controls the gate of the triac (Figure 5–19). The relay can be controlled by a low voltage source. When energized, the relay contact closes and supplies power to the gate of the triac, which connects the load to the line. Another common method for controlling the operation of a solid-state relay is called *optoisolation*, or optical isolation. This method is used by many programmable logic controllers to communicate with the output device. Optoisolation is achieved by using the light from a light-emitting diode (LED) to energize a photo triac (Figure 5–20). The arrows pointing away from the diode symbol indicate that it emits light when energized. The arrows pointing toward the triac symbol indicate that it must receive light to turn on. Optical isolation is very popular with electronic devices such as computers and programmable logic controllers because there are no moving contacts to wear and the load side of the relay is electrically isolated from the control side. This isolation prevents any electrical noise generated on the load side from being transferred to the control side.

Solid-state relays can also be obtained that control loads connected to direct current circuits (Figure 5–21).

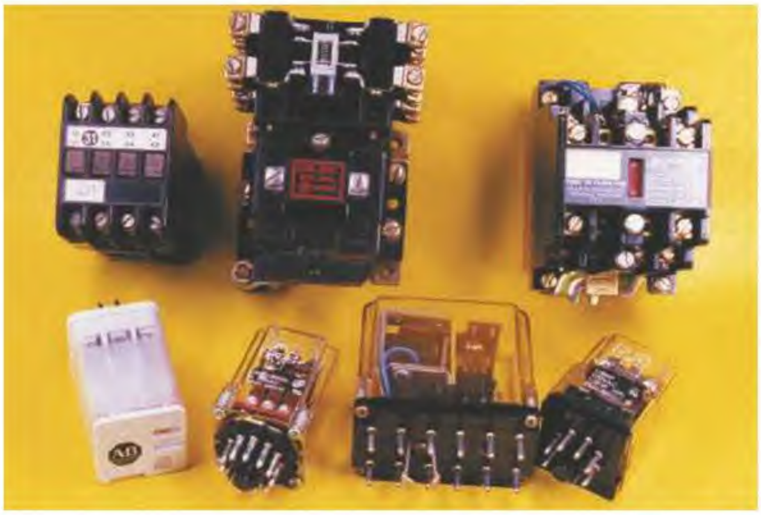


Figure 5–15 Control relays can be obtained in a variety of case styles.

Figure 5–16 Relays designed to plug into 8 and 11 pin tube sockets.

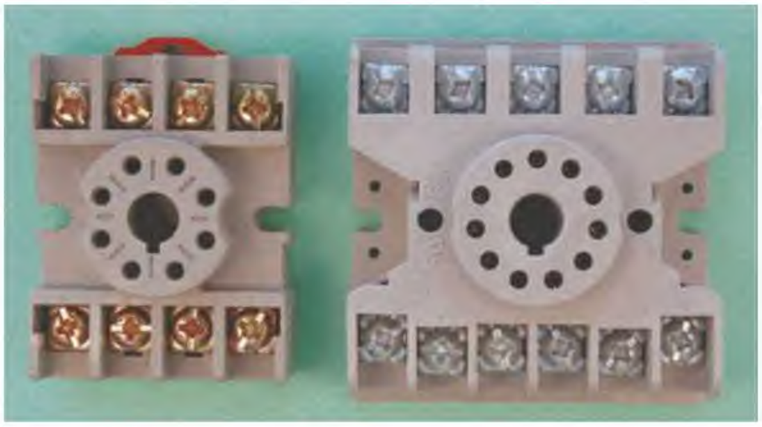


Figure 5–17 8 and 11 pin sockets.

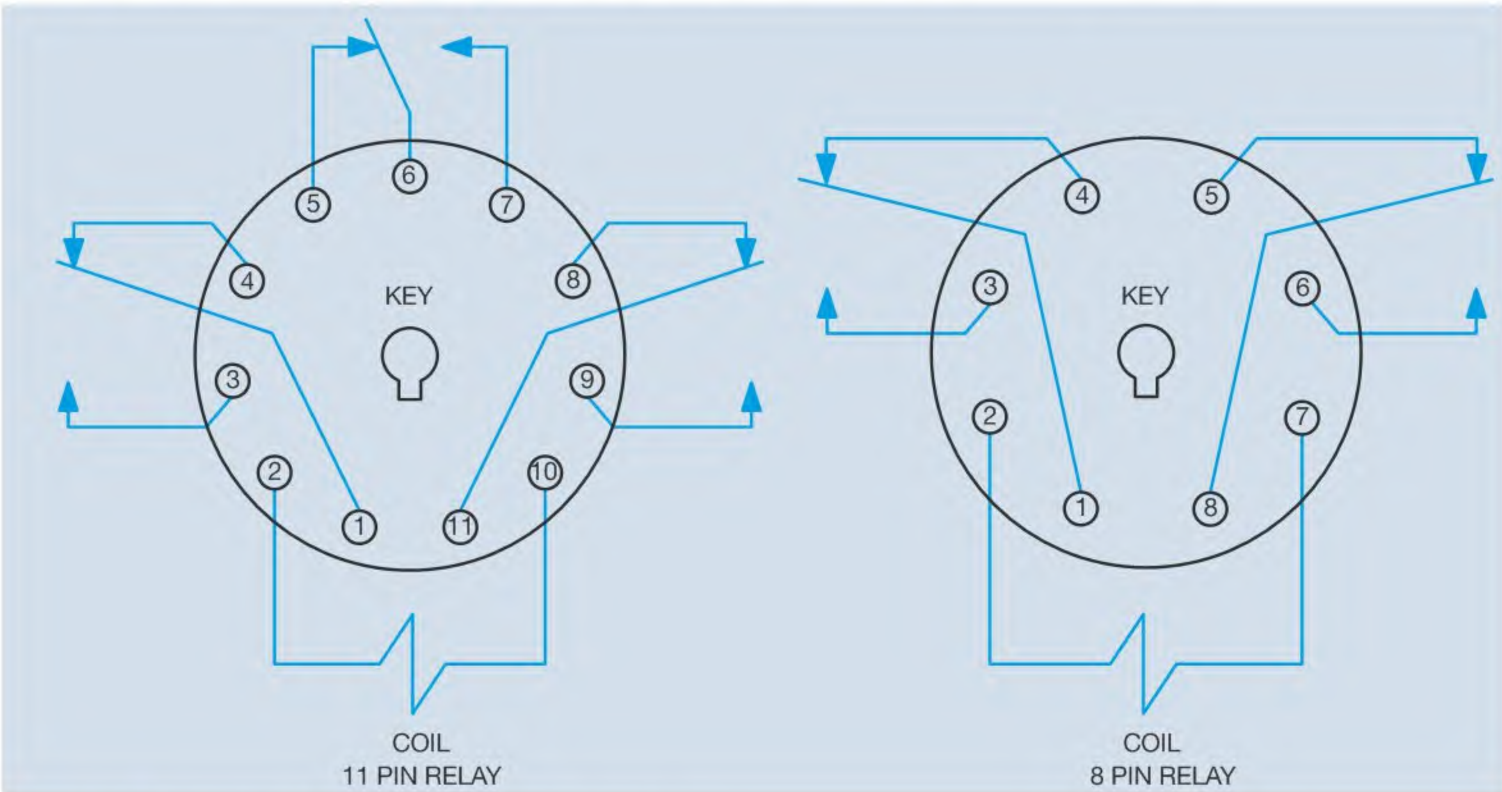


Figure 5–18 Connection diagrams for 8 and 11 pin relays.

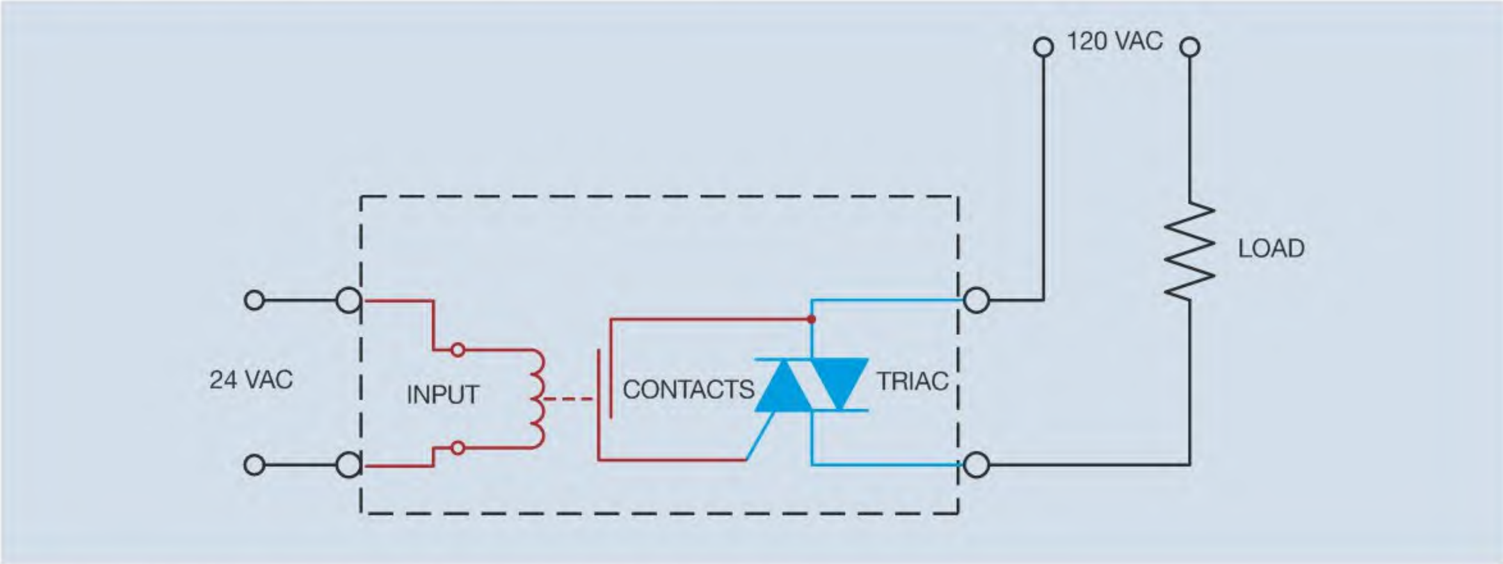


Figure 5–19 Solid-state relay using a relay to control the action of a triac.

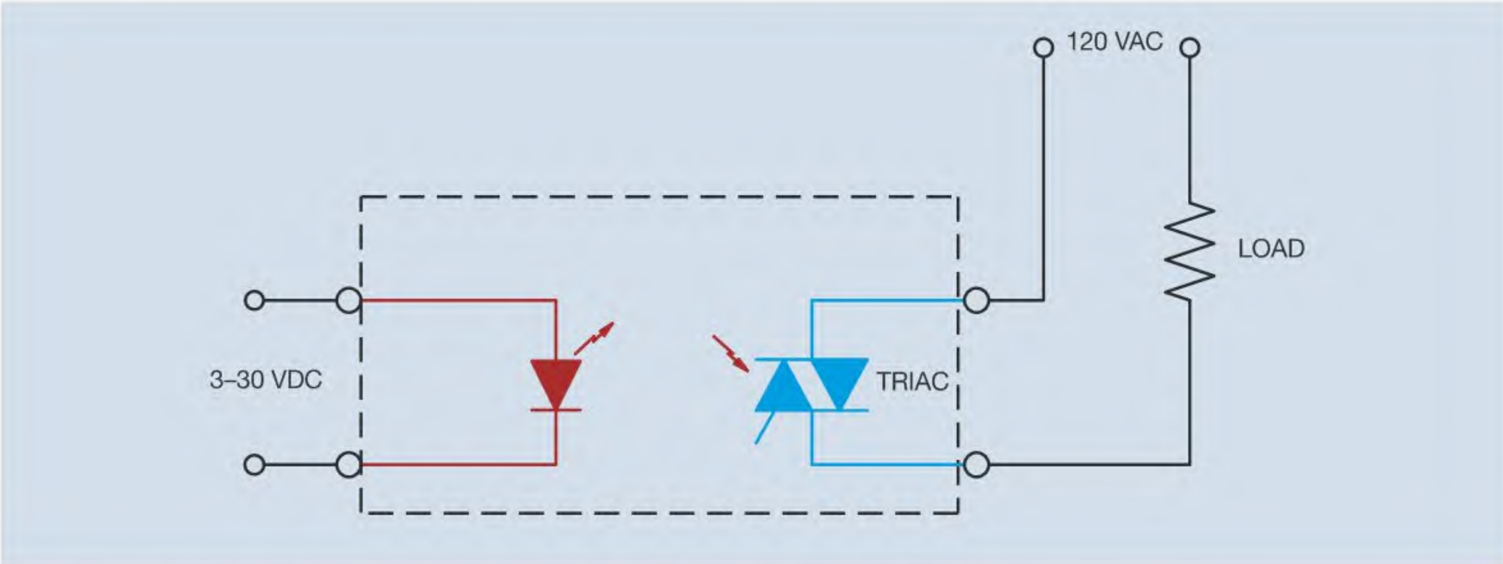


Figure 5–20 Solid-state relay using optical isolation to control the action of a triac.

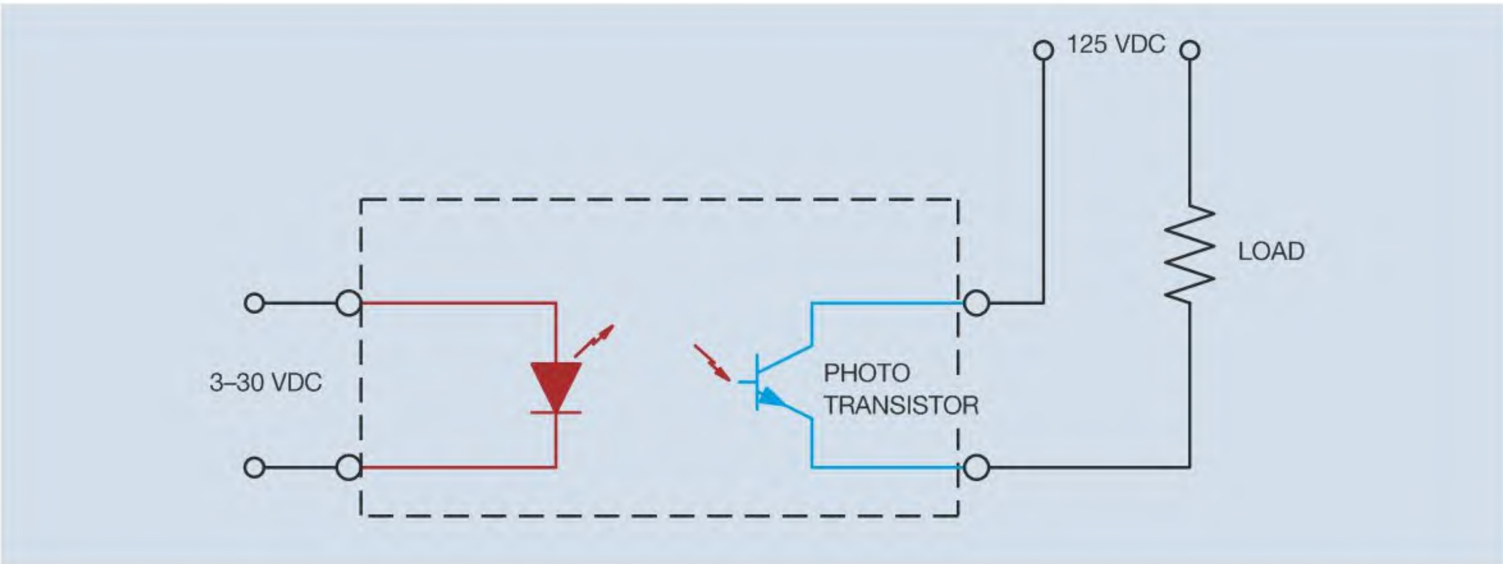


Figure 5–21 A solid-state relay that controls a DC load uses a transistor instead of a triac to connect the load to the line.

Figure 5–22 An 8 pin integrated circuit containing two low power solid-state relays.

These relays use a **transistor** to connect the load to the line instead of a triac.

Solid-state relays can be obtained in a variety of case styles and ratings. Some have voltage ratings that range from about 3 to 30 volts and can control only a small amount of current, while others can control hundreds of volts and several amperes. The 8 pin IC (integrated circuit) shown in Figure 5–22 contains two solid-state relays that are intended for low power applications. The solid-state relay shown in Figure 5–23 is rated to control a load of 8 amperes connected to a 240 volt AC circuit. For this solid-state relay to be capable of controlling that amount of power, it must be mounted on a heat sink to increase its ability to dissipate heat. Although this relay is rated 240 volts, it can control devices at a lower voltage also.

Contactors

Contactors are very similar to relays in that they are electromechanical devices. Contactors can be obtained with coils designed for use on higher voltages than most relays. Most relay coils are intended to operate on voltages that range from 5 to 120 volts AC or DC. Contactors can be obtained with coils that have voltage ranges from 24 volts to 600 volts. Although these higher voltage coils

Figure 5–23 Solid-state relay that can control 8 amperes at 240 volts.

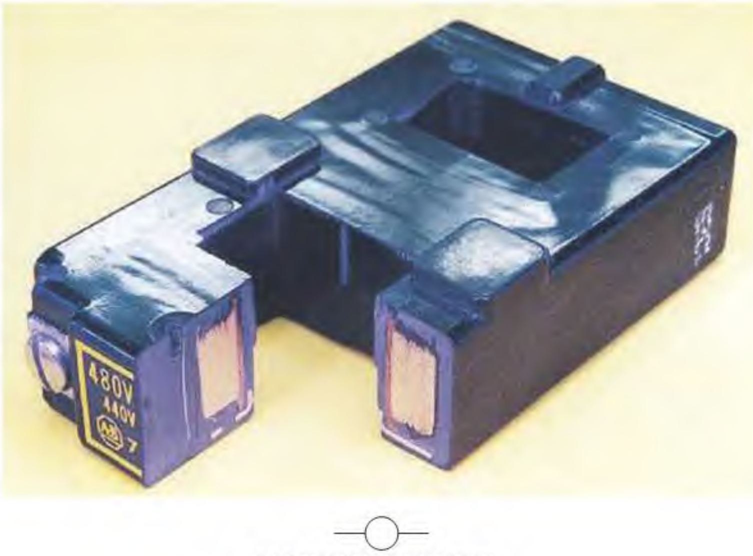


Figure 5–24 Magnetic coil cut away to show insulated copper wire wound on a spool and protected by a molding.

can be obtained, for safety reasons, most contactors operate on voltages that generally do not exceed 120 volts. Contactors can be made to operate on different control circuit voltages by changing the coil. Manufacturers make coils to interchange with specific types of contactors. Most contain many turns of wire and are mounted in some type of molded case that can be replaced by dissembling the contactor (Figure 5–24).

It should be noted that NEMA standards require the magnetic switch device to operate properly on voltages that range from 85 percent to 110 percent of the rated coil voltage. Voltages can vary from one part of the country to another, as well as the variation of voltage that often occurs inside a plant. If coil voltage is excessive, it draws too much current causing the insulation to overheat and eventually burn out. Excessive voltage also causes the armature to slam into the stationary pole pieces with a force that can cause rapid wear of the pole pieces and shorten the life to the contactor. Another effect of too much voltage is the wear caused by the movable contacts slamming into the stationary contacts causing excessive contact bounce. Contact bounce can produce arcing that creates more heat and more wear on the contacts.

Insufficient coil voltage can produce as much, if not more, damage than excessive voltage. If the coil voltage is too low, the coil will have less current flow causing the magnetic circuit to be weaker than normal. The armature may pick up, but not completely seal against, the stationary pole pieces. This forms too much of an air gap and the coil current does not drop to its sealed value, causing excessive coil current, overheating, and coil burn out. A weak magnetic circuit can cause the movable contacts to touch the stationary contacts and provide a connection, but not have the necessary force to permit the contact springs to provide proper contact pressure. This lack of pressure can cause arcing and possible welding of the contacts. Without proper contact pressure, high currents produce excessive heat and greatly shorten the life of the contacts.

Load Contacts

The greatest difference between relays and contactors is that contactors are equipped with contacts intended to connect high current loads to the power line (Figure 5–25). These large contacts are called *load* contacts. Depending on size, load contacts can be rated to control several hundred amperes. Most will contain some type of arcing chamber to help extinguish the arc that is produced when heavy current loads are disconnected from the power line. Arcing chambers can be seen in Figure 5–25.

Other contacts may contain arc chutes that lengthen the path of the arc to help extinguish it. When the contacts open, the established arc rises because of the heat the arc produces (Figure 5–26). The horn of the arc chute pulls the arc farther and farther apart until it can no longer sustain itself. Another device that operates on a similar principle is the **blowout coil.** Blowout coils are connected in series with the load (Figure 5–27). When the contact opens, the arc is attracted to the magnetic field and rises at a rapid rate. This same basic action causes the armature of a direct current motor to turn. Because the arc is actually a flow or current, a magnetic field exists around the arc. The arc's magnetic field is

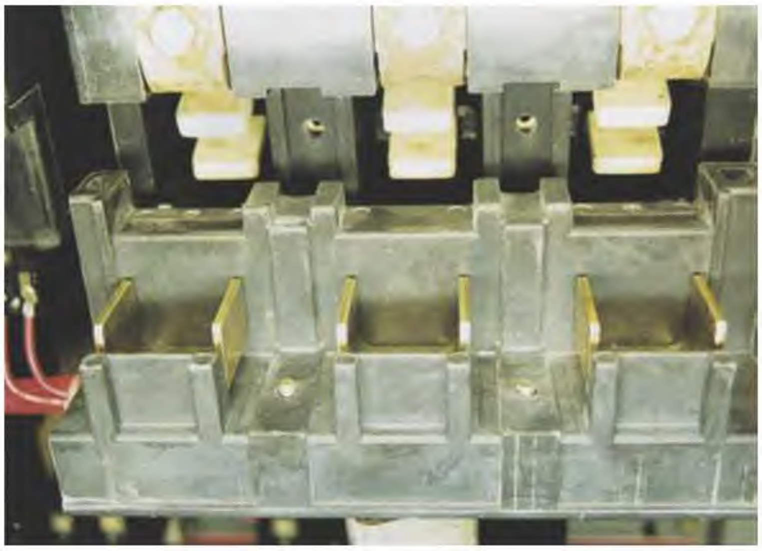


Figure 5–25 Contactors contain load contacts designed to connect high current loads to the power line.

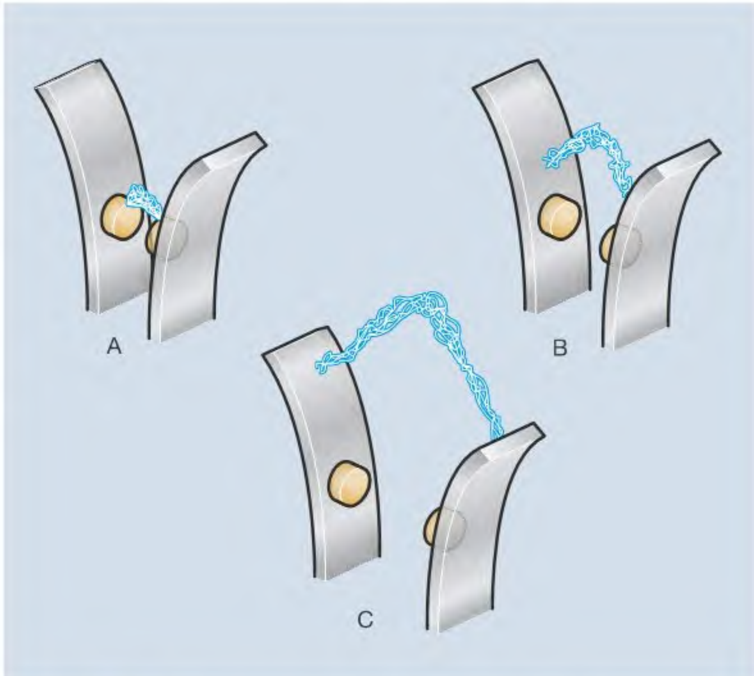


Figure 5–26 The arc rises between the arc chutes because of heat.

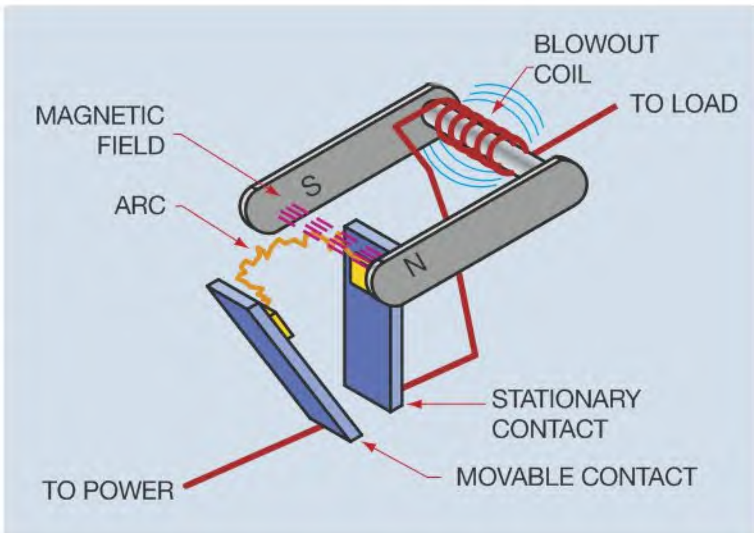


Figure 5–27 Magnetic blowout coils are connected in series with the load to establish a magnetic field.

attracted to the magnetic field produced by the blowout coil causing it to move upward. The arc is extinguished at a faster rate than is possible with an arc chute that depends on heat to draw the arc upward. Blowout coils are sometimes used on contactors that control large amounts of alternating current, but they are most often employed with contactors that control direct current loads. Alternating current turns off each half cycle when the waveform passes through zero, which helps to extinguish arcs in alternating current circuit. Direct current, however, does not turn off at periodic intervals. Once a DC arc is established, it is much more difficult to extinguish. Blowout coils are an effective means of extinguishing these arcs. A contactor with a blowout coil is shown in Figure 5–28.

Most contactors contain auxiliary contacts as well as load contacts. The auxiliary contacts can be used in the control circuit if required. The circuit shown in Figure 5–29 uses a three pole contactor to connect a bank of three phase heaters to the power line. Note that a normally open auxiliary contact is used to control an amber pilot light that indicates that the heaters are turned on, and a normally closed contact controls a red pilot light that indicates that the heaters are turned off. A thermostat controls the action of HR contactor coil. In the normal de-energized state, the normally closed HR auxiliary contact provides power to the red pilot light. When the thermostat contact closes, coil HR energizes and all HR contacts change position. The three load contacts close and connect the heaters to the line. The normally closed HR auxiliary contact opens and turns off the red pilot light, and the normally open HR auxiliary contact closes and turns on the amber pilot light. A size 1 contactor with auxiliary contacts is shown in Figure 5–30.

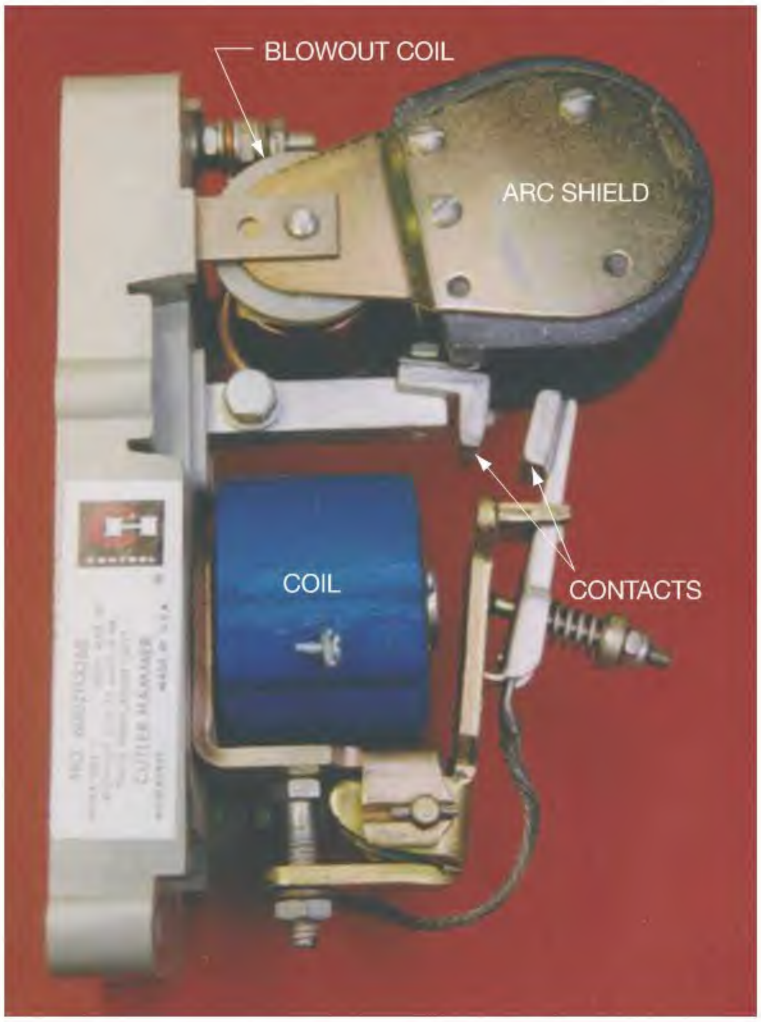


Figure 5–28 Clapper type contactor with blowout coil.

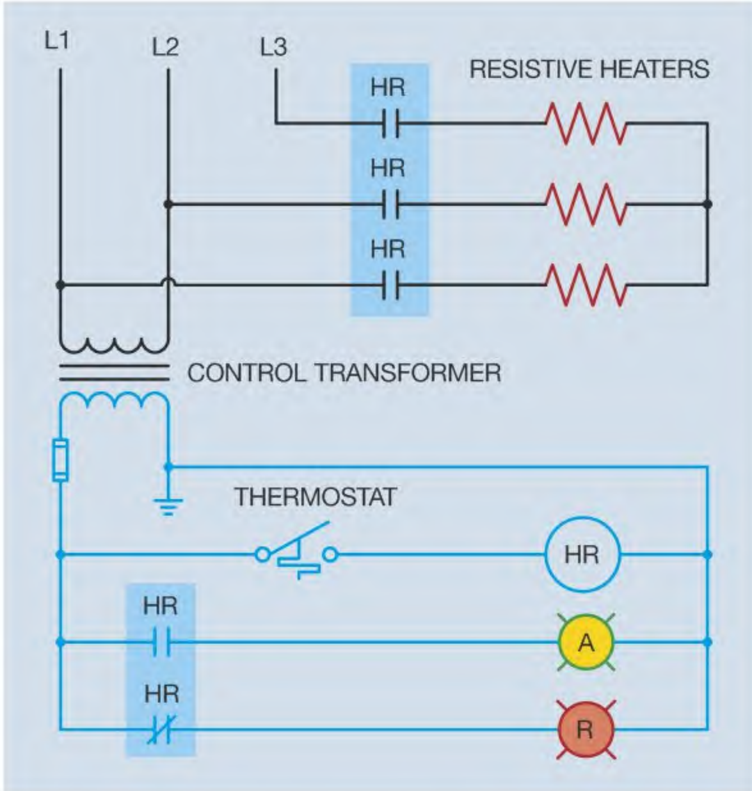


Figure 5–29 The contactor contains both load and auxiliary contacts.

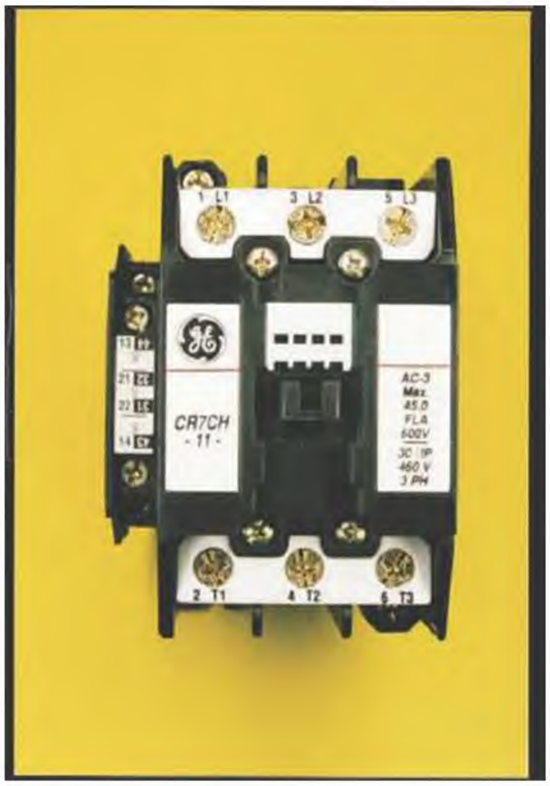


Figure 5–30 Size 1 contactor with auxiliary contacts.

Vacuum Contactors

Vacuum contactors enclose their load contacts in a sealed vacuum chamber. A metal bellows connected to the movable contact permits it to move without breaking the seal (Figure 5–31). Sealing contacts inside a vacuum chamber permits them to switch higher voltages with a relative narrow space between the contacts without establishing an arc. Vacuum contactors are generally employed for controlling devices connected to medium voltage. Medium voltage is generally considered to be in a range from 1 kV to 35 kV.

An electric arc is established when the voltage is high enough to ionize the air molecules between stationary and movable contacts. Medium voltage contactors are generally large because they must provide enough distance between the contacts to break the arc path. Some medium voltage contactors use arc suppressers, arc shields, and oil immersion to quench or prevent an arc. Vacuum contactors operate on the principle that if there is no air surrounding the contact, there is no ionization path for the establishment of an arc. Vacuum contactors are generally smaller in size than other types of medium voltage contactors. A three phase motor starter with vacuum contacts is shown in Figure 5–32. A reversing starter with vacuum contacts is shown in Figure 5–33.

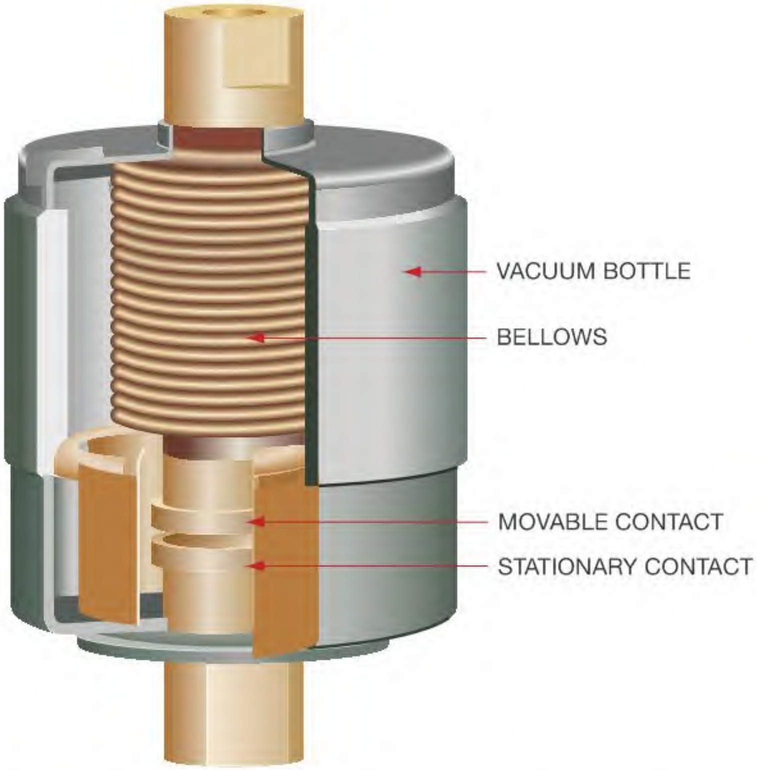


Figure 5–31 Vacuum contacts are sealed inside a vacuum chamber.

Figure 5–32 Three phase motor starter with vacuum contacts.

Courtesy of Rockwell Automation, Inc.

Figure 5–33 Reversing starter with vacuum contacts.

Mechanically Held Contactors and Relays

Mechanically held contactors and relays are often referred to as **latching** contactors or relays. They employ two electromagnets to operate. One coil is generally called the *latch* coil and the other is called the *unlatch* coil. The latch coil causes the contacts to change position and mechanically hold in position after power is removed from the latch coil. To return the contacts to their normal de-energized position, the unlatch coil must be energized. Power to both coils is momentary. The coils of most mechanically held contactors and relays are intended for momentary use and continuous power often cause burnout.

Unlike common magnetic contactors or relays, the contacts of latching relays and contacts do not return to a normal position if power is interrupted. They should be used only where there is danger of persons or equipment being harmed if power is suddenly restored after a power failure.

Sequence of Operation

Many latching type relays and contactors contain contacts that are used to prevent continuous power being supplied to the coil after it has been energized. These contacts are generally called **coil clearing contacts**. In Figure 5–34, coil L is the latching coil and coil U is the unlatch coil. When the ON push button is pressed, current can flow to coil L, through normally closed contact L to neutral. When the relay changes to the latch position, the normally closed L contact connected in series with L coil opens and disconnects power to L coil. This disconnection prevents further power from being supplied to coil L. At the same time, the open U contact connected in series with coil U closes to permit operation of coil U when the OFF push button is pressed. When coil L energized, it also closed the L load contacts, energizing a bank of lamps. The lamps can be turned off by pressing the OFF push button and energizing coil U. This process causes the relay to return to the normal position. Notice that the coil clearing contacts prevent power from being supplied continuously to the coils of the mechanically held relay.

An 11 pin latching relay is shown in Figure 5–35. The connection diagram for this relay is shown in Figure 5–36.

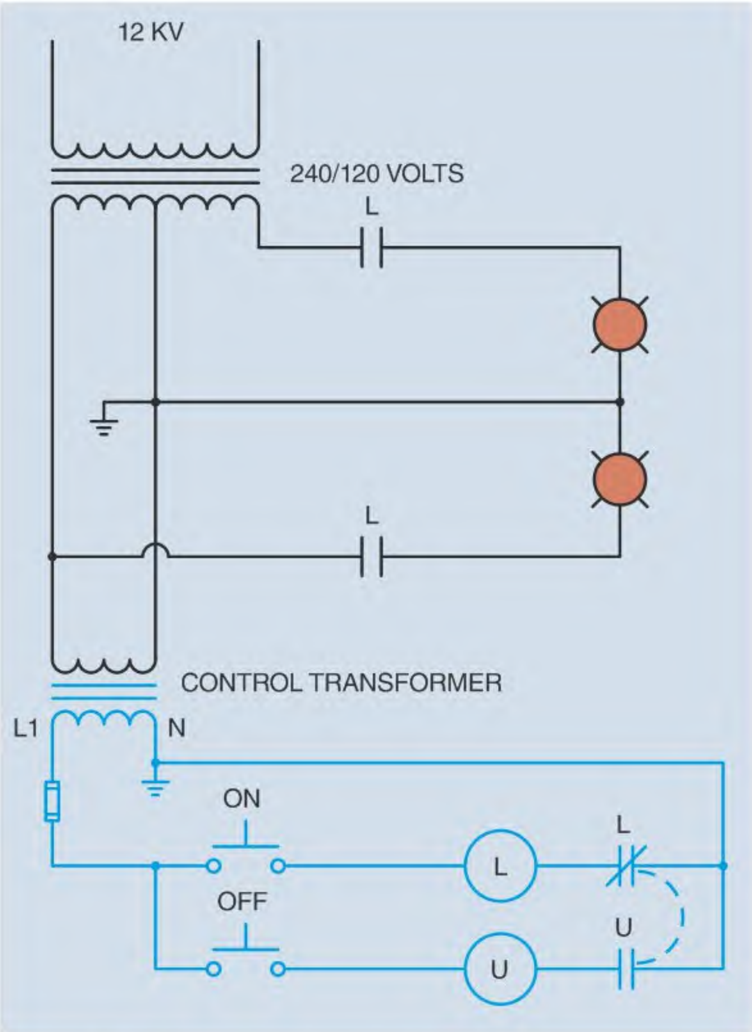


Figure 5–34 Latching type relays and contactors contain a latch and unlatch coil.

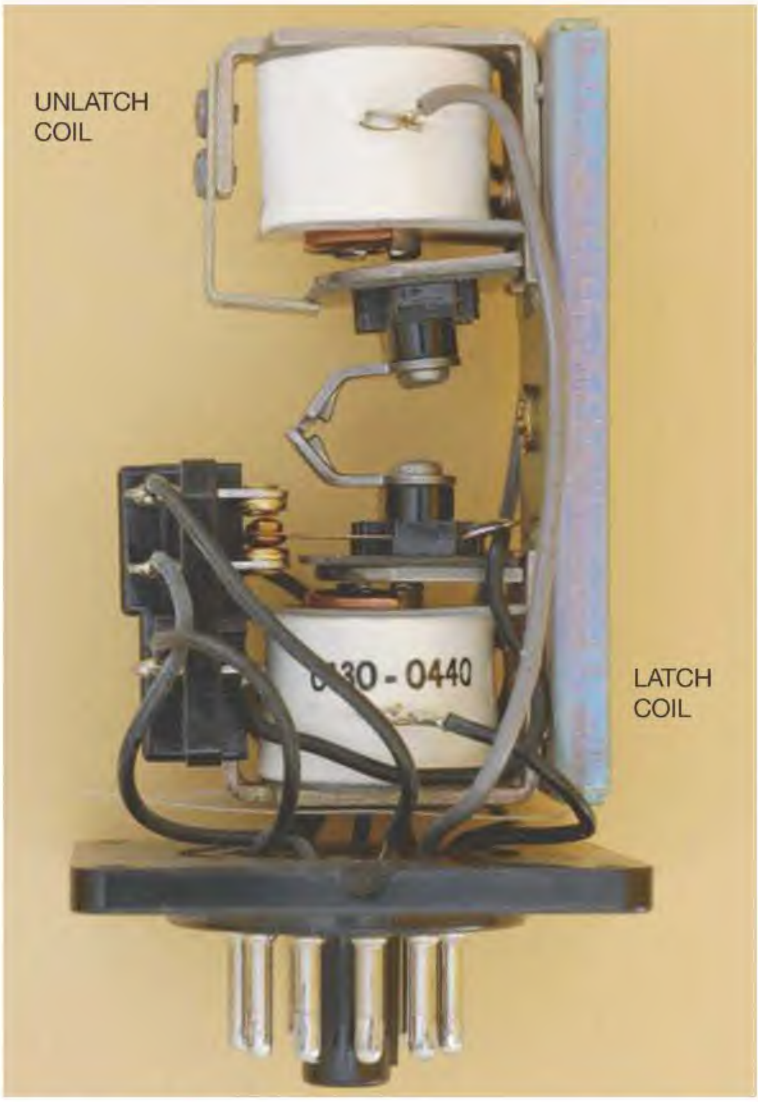


Figure 5–35 An 11 pin latching relay.

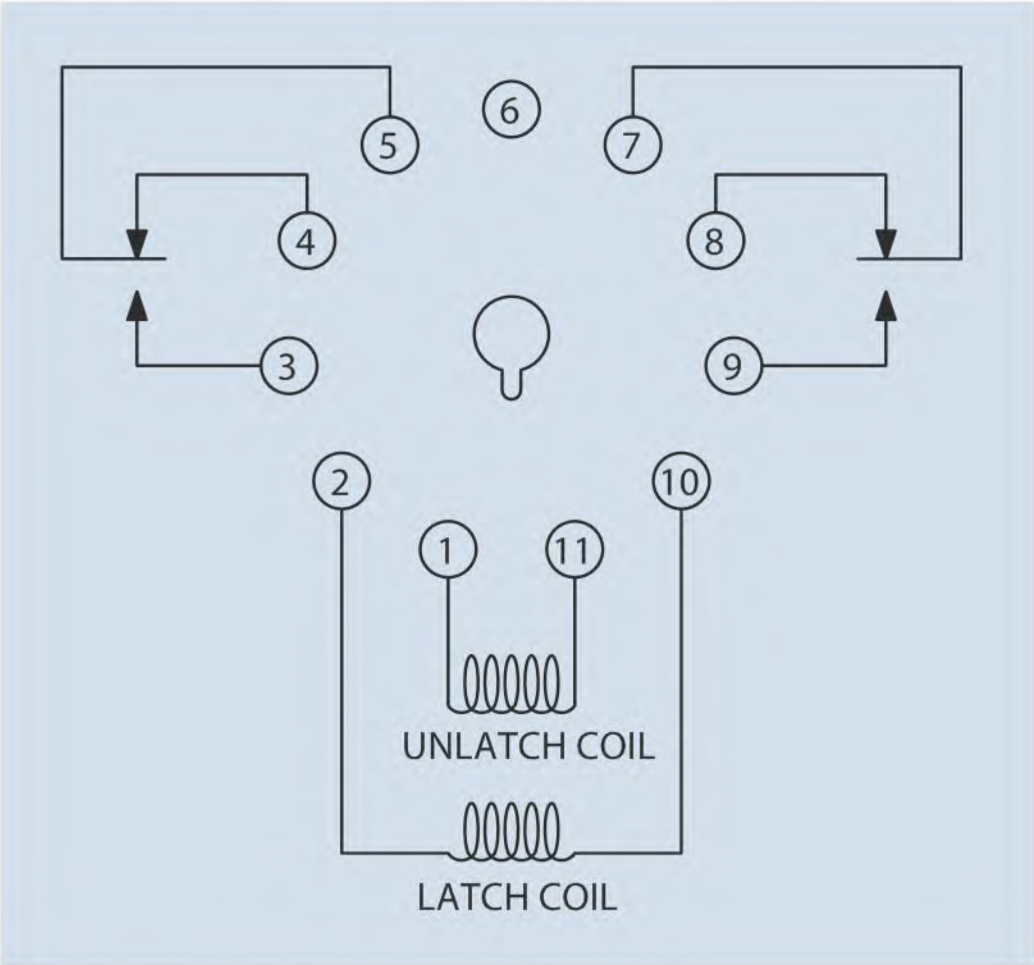


Figure 5–36 Connection diagram for an 11 pin latching relay.

Mercury Relays

Mercury relays employ the use of mercury-wetted contacts instead of mechanical contacts. Mercury relays contain one stationary contact called the electrode. The electrode is located inside the electrode chamber. When the coil is energized, a magnetic sleeve is pulled down inside a pool of liquid mercury, causing the mercury to rise in the chamber and make connection with the stationary electrode (Figure 5–37). The advantage of mercury relays is that each time the relay is used the contact is renewed, eliminating burning and pitting caused by an arc when connection is made or broken. The disadvantage of mercury relays is that they contain mercury. Mercury is a toxic substance that has been shown to cause damage to the nervous system and kidneys. Mercury is banned in some European countries.

Mercury relays must be mounted vertically instead of horizontally. They are available in single-pole, double-pole, and three-pole configurations. A single-pole mercury relay is shown in Figure 5–38.

Motor Starters

Motor starters are contactors with the addition of an overload relay (Figure 5–39). Because they are intended to control the operation of motors, motor starters are rated in horsepower. Magnetic motor starters are available in different sizes. The size starter required is determined by the horsepower and voltage of the motor it is intended to control. Two standards are used to determine the size starter needed—NEMA and IEC. Figure 5–40 shows the NEMA-size starters needed for normal starting duty. The capacity of the starter is determined by the size of its load or power contacts and the wire cross-sectional area that can be connected to the starter. The size of the load contacts is reduced when the voltage is doubled because the current is halved for the same power rating ($P = E \times I$).

The number of **poles** refers to the load contacts and does not include the number of control or auxiliary contacts. Three pole starters are used to control

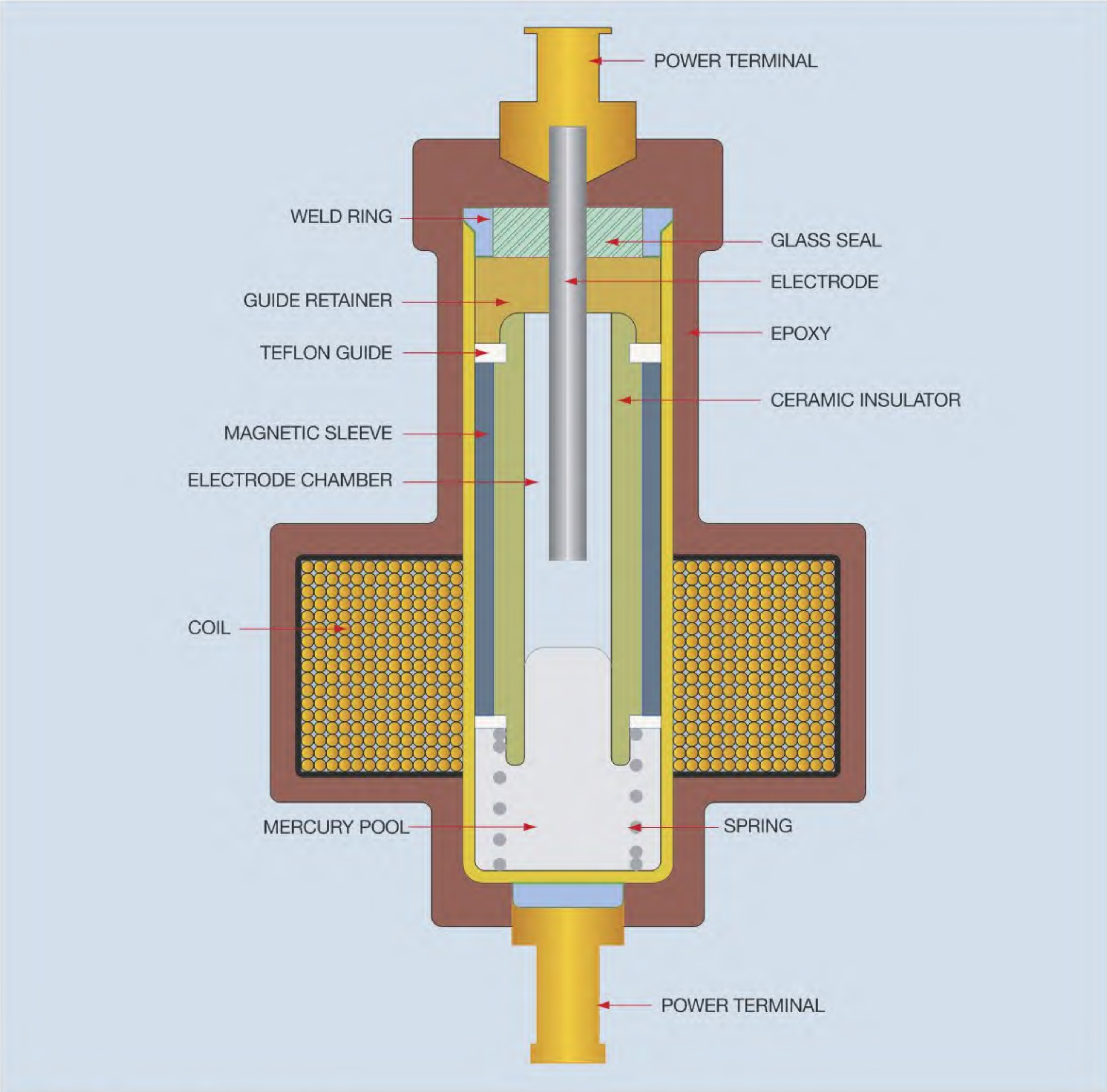


Figure 5–37 Diagram of a mercury relay.

three phase motors, and two pole starters are used for single phase motors.

NEMA and IEC

The IEC establishes standards and ratings for different types of equipment just as NEMA does. The IEC, however, is more widely used throughout Europe than in the United States. Many equipment manufacturers are now beginning to specify IEC standards for their products produced in the United States. The main reason is that much of the equipment produced in the United States is also marketed in Europe. Many European companies will not purchase equipment that is not designed with IEC standard equipment.

Although the IEC uses some of the same ratings as similar NEMA-rated equipment, there is often a vast difference in the physical characteristics of the two. Two sets of load contacts are shown in

Figure 5–38 Single-pole mercury relay.

Courtesy Schneider Electric USA, Inc.

Figure 5–39 A motor starter is a contactor combined with an overload relay. Reproduced by permission of International Rectifier.

Figure 5–41. The load contacts on the left are employed in a NEMA-rated 00 motor starter. The load contacts on the right are used in an IEC-rated 00 motor starter. Notice that the surface area of the NEMA-rated contacts is much larger than the IEC-rated contacts. This difference permits the NEMA-rated starter to control a much higher current than the IEC starter. In fact, the IEC-rated 00 starter contacts are smaller than the contacts of a small 8 pin control relay (Figure 5–42). Due to the size difference in contacts between NEMA- and IEC-rated starters, many engineers and designers of control systems specify a one to two larger size for IEC-rated equipment than would be necessary for NEMA-rated equipment. A table showing the ratings for IEC starters is shown in Figure 5–43.

Although motor starters are basically a contactor and overload relay mounted together, most contain auxiliary contacts. Many manufacturers make auxiliary contacts that can be added to a starter or contactor (Figure 5–44). Adding auxiliary contacts can often reduce the need for control relays that perform part of the circuit logic. In the circuit shown in Figure 5–45, motor #1 must be started before motors #2 or #3. This is accomplished by placing normally open contacts in series with starter coils M2 and M3. In the circuit shown in Figure 5–45(A), the coil of a control relay has been connected in parallel with motor starter coil M1. In this way, control relay CR will operate in conjunction with motor starter coil M1. The two normally open CR contacts prevent motors 2 and 3 from starting until motor 1 is running. In the circuit shown in Figure 5–45(B), it is assumed that two auxiliary contacts have been added to motor starter M1. The two new auxiliary contacts can replace the two normally open CR contacts, eliminating the need for control relay CR.

CAUTION: By necessity, motor control centers have very low impedance and can produce extremely large fault currents. It is estimated that the typical MCC can deliver enough energy in an arc-fault condition to kill a person 30 feet away. For this reason, many industries now require electricians to wear full protection (flame-retardant clothing, face shield, ear plugs, and hard hat) when opening the door on a combination starter or energizing the unit. When energizing the starter, always stand to the side of the unit and not directly in front of it. In a direct short condition, it is possible for the door to be blown off or open.

		Maximum Horsepower Rating—Nonplugging and Nonjogging Duty	
NEMA Size	**Load Volts**	**Single Phase**	**Poly Phase**
00	115	½	. . .
	200	. . .	1½
	230	1	1½
	380	. . .	1½
	460	. . .	2
	575	. . .	2
0	115	1	. . .
	200	. . .	3
	230	2	3
	380	. . .	5
	460	. . .	5
	575	. . .	5
1	115	2	. . .
	200	. . .	7½
	230	3	7½
	380	. . .	10
	460	. . .	10
	575	. . .	10
*1P	115	3	. . .
	230	5	. . .
2	115	3	. . .
	200	. . .	10
	230	7½	15
	380	. . .	25
	460	. . .	25
	575	. . .	25
3	115	7½	. . .
	200	. . .	25
	230	15	30
	380	. . .	50
	460	. . .	50
	575	. . .	50
4	200	. . .	40
	230	. . .	50
	380	. . .	75
	460	. . .	100
	575	. . .	100
5	200	. . .	75
	230	. . .	100
	380	. . .	150
	460	. . .	200
	575	. . .	200
6	200	. . .	150
	230	. . .	200
	380	. . .	300
	460	. . .	400
	575	. . .	400
7	230	. . .	300
	460	. . .	600
	575	. . .	600
8	230	. . .	450
	460	. . .	900
	575	. . .	900

Tables are taken from NEMA Standards.

*1¾, 10 hp is available.

Figure 5–40 Motor starter sizes and ratings.

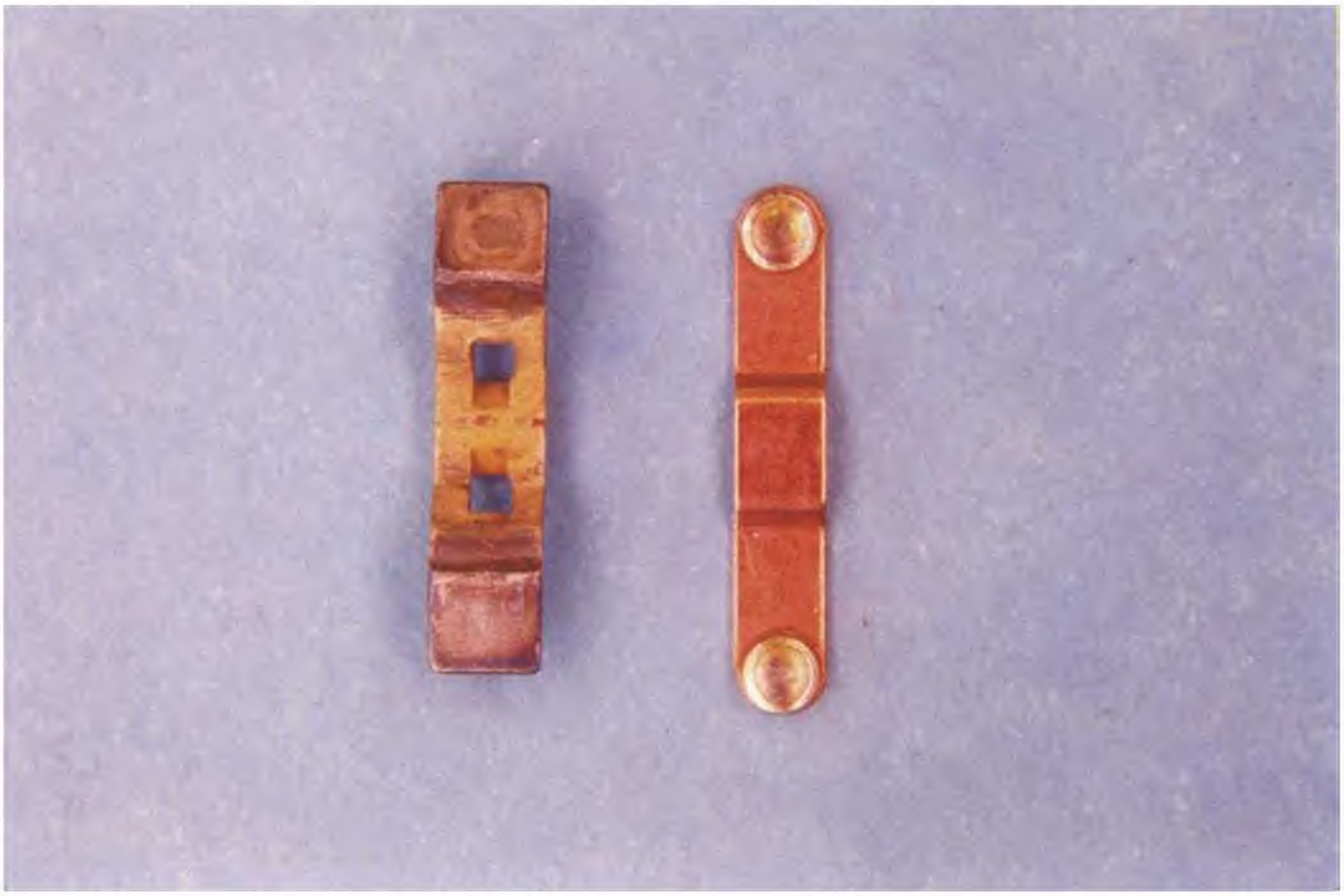


Figure 5–41 The load contacts on the left are NEMA size 00. The load contacts on the right are IEC size 00.

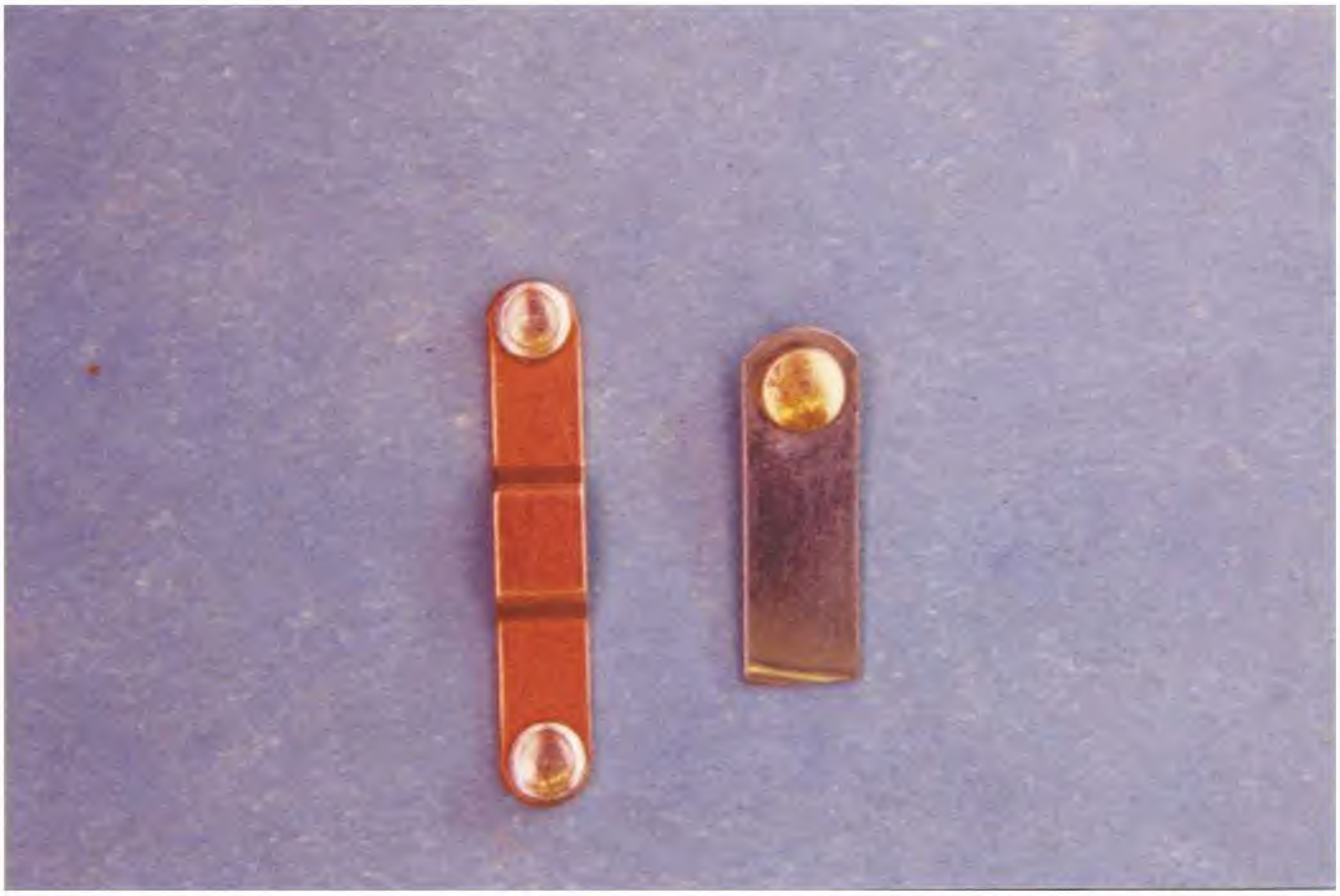


Figure 5–42 The load contacts of an IEC 00 starter shown on the left are smaller than the auxiliary contacts of an 8 pin control relay shown on the right.

IEC MOTOR STARTERS (60 HZ)

SIZE	MAX AMPS	MOTOR VOLTAGE	MAX. HORSEPOWER SINGLE PHASE	MAX. HORSEPOWER THREE PHASE
A	7	115	1/4	
		200		1 1/2
		230	1/2	1 1/2
		460		3
		575		5
B	10	115	1/2	
		200		2
		230	1	2
		460		5
		575		7 1/2
C	12	115	1/2	
		200		3
		230	2	3
		460		7 1/2
		575		10
D	18	115	1	
		200		5
		230	3	5
		460		10
		575		15
E	25	115	2	
		200		5
		230	3	7 1/2
		460		15
		575		20
F	32	115	2	
		200		7 1/2
		230	5	10
		460		20
		575		25
G	37	115	3	
		200		7 1/2
		230	5	10
		460		25
		575		30
H	44	115	3	
		200		10
		230	7 1/2	15
		460		30
		575		40
J	60	115	5	
		200		15
		230	10	20
		460		40
		575		40
K	73	115	5	
		200		20
		230	10	25
		460		50
		575		50
L	85	115	7 1/2	
		200		25
		230	10	30
		460		60
		575		75

SIZE	MAX AMPS	MOTOR VOLTAGE	MAX. HORSEPOWER SINGLE PHASE	MAX. HORSEPOWER THREE PHASE
M	105	115	10	
		200		30
		230	10	40
		460		75
		575		100
N	140	115	10	
		200		40
		230	10	50
		460		100
		575		125
P	170	115		
		200		50
		230		60
		460		125
		575		125
R	200	115		
		200		60
		230		75
		460		150
		575		150
S	300	115		
		200		75
		230		100
		460		200
		575		200
T	420	115		
		200		125
		230		125
		460		250
		575		250
U	520	115		
		200		150
		230		150
		460		350
		575		250
V	550	115		
		200		150
		230		200
		460		400
		575		400
W	700	115		
		200		200
		230		250
		460		500
		575		500
X	810	115		
		200		250
		230		300
		460		600
		575		600
Z	1215	115		
		200		450
		230		450
		460		900
		575		900

Figure 5–43 IEC motor starters rated by size, horsepower, and voltage for 60 Hz circuits.

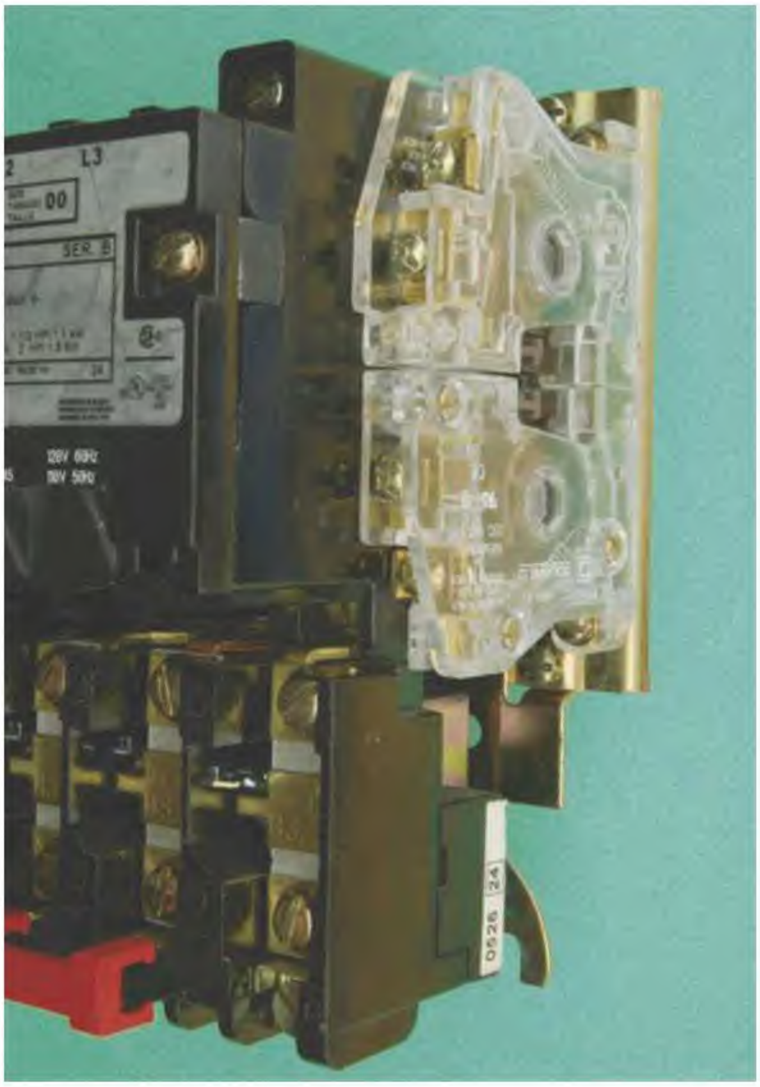


Figure 5–44 Motor starter with additional auxiliary contacts.

Motor Control Centers

Motor starters are often grouped with other devices, such as circuit breakers, fuses, disconnects, and control transformers, and referred to as a combination starter. These components are often contained inside one enclosure (Figure 5–46).

Motor control centers employ the use of combination starters that are mounted in special enclosures designed to plug into central buss bars that supply power for several motors. The enclosure for this type of combination starter is often referred to as a module, cubical, or can (Figure 5–47). They are designed to be inserted into a motor control center (MCC) (Figure 5–48). Connection to individual modules is generally made with terminal strips located inside the module. Most manufacturers provide some means of removing the entire terminal strip without having to remove each individual wire. If a starter should fail, this permits rapid installation of a new starter. The defective starter can then be serviced at a later time.

Current Requirements

When the coil of an alternating current relay or contactor is energized, it will require more current to pull the armature in than to hold it in. The reason is the change of inductive reactance caused by the air gap (Figure 5–49). When the relay is turned off, a large air gap exists between the metal of the stationary pole piece and the armature. This air gap causes a poor

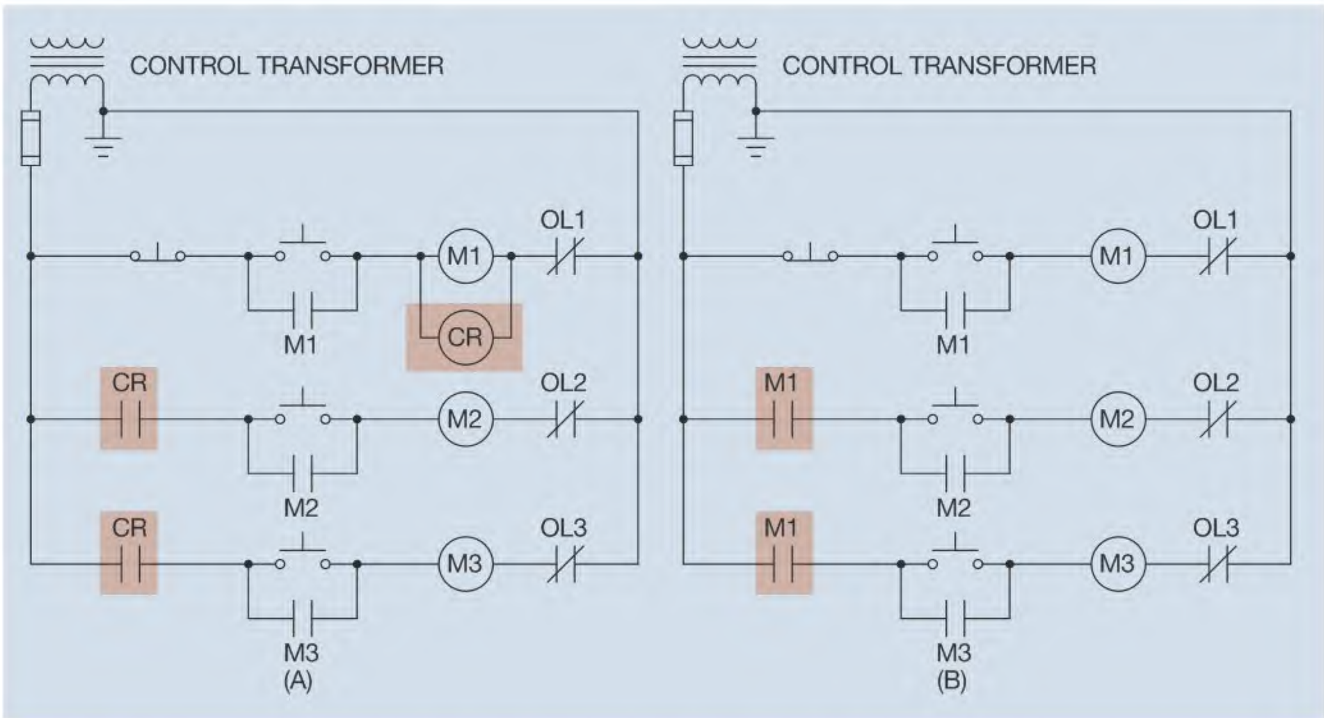


Figure 5–45 Control relays can sometimes be eliminated by adding auxiliary contacts to a motor starter.

Courtesy Schneider Electric USA, Inc.

Figure 5–46 A combination starter with fused disconnect, control transformer, push buttons, and motor starter.

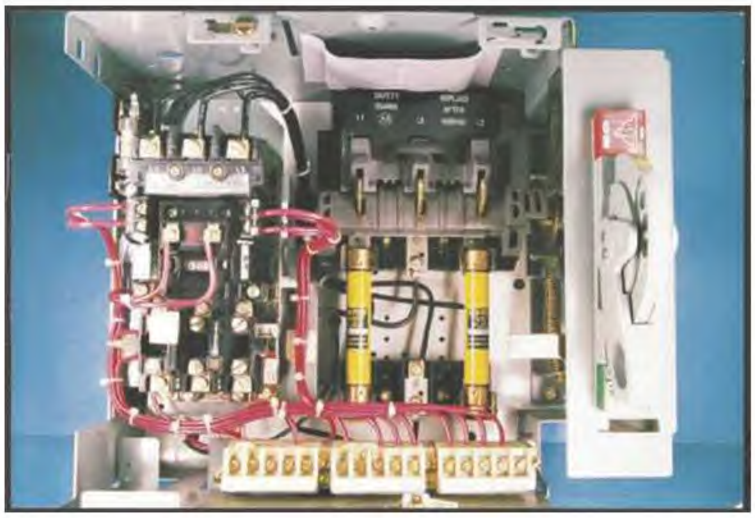


Figure 5–47 Combination starter with fused disconnect intended for use in a motor control center (MCC). Note that only two fuses are used in this module. Delta connected power systems with one phase grounded do not require a fuse in the grounded conductor.

magnetic circuit and the inductive reactance X_L has a low ohmic value. Although the wire used to make the coil does have some resistance, the main current limiting factor of an inductor is inductive reactance. After

Courtesy of Eaton Corporation

Figure 5–48 Motor control center.

the coil is energized and the armature makes contact with the stationary pole piece, there is a very small air gap between the armature and pole piece. This small air gap permits a better magnetic circuit, which increases the inductive reactance causing the current to decrease. If dirt or some other foreign matter should prevent the armature from making a seal with the stationary pole piece, the coil current will remain higher than normal, which can cause overheating and eventual coil burn out.

Direct current relays and contactors depend on the resistance of the wire used to construct the coil to limit current flow. For this reason, the coils of DC relays and contactors exhibit a higher resistance than coils of AC relays. Large direct current contactors are often equipped with two coils instead of one (Figure 5–50). When the contactor is energized, both coils are connected in parallel to produce a strong magnetic field in the pole piece. A strong field is required to provide the attraction needed to attract the armature. Once the armature has been attracted, a much weaker magnetic field can hold the armature in place. When the armature closes, a switch disconnects one of the coils reducing the current to the contactor.

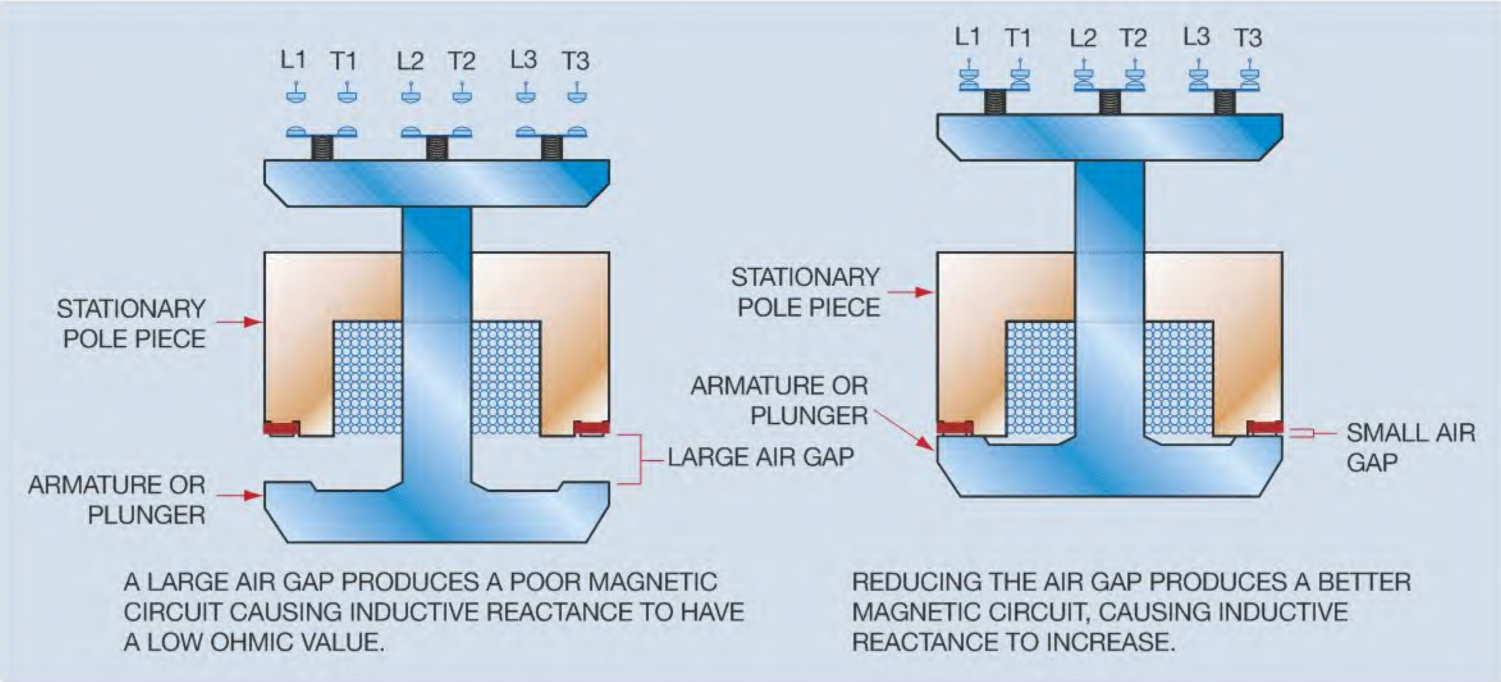


Figure 5–49 The air gap determines the inductive reactance of the solenoid.

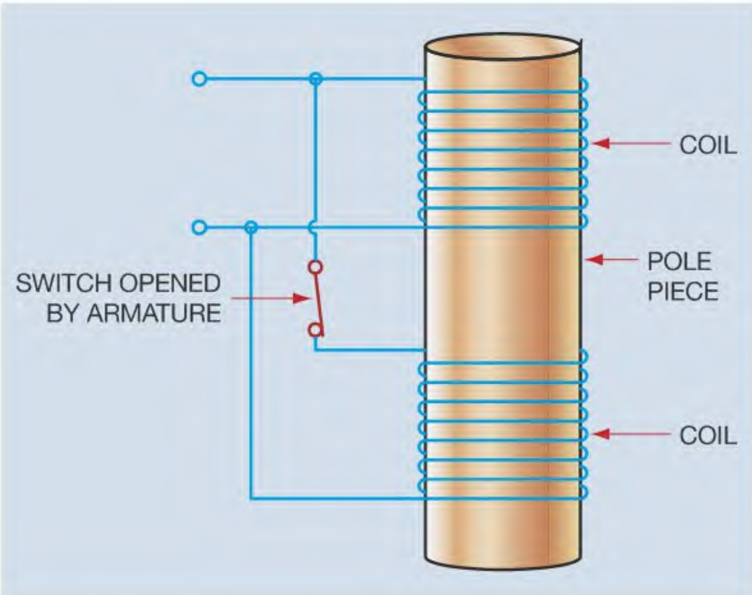


Figure 5–50 Direct current contactors often contain two coils.

Review Questions

1. Explain the difference between clapper type contacts and bridge type contacts.
2. What is the advantage of bridge type contacts over clapper type contacts?
3. Explain the difference between auxiliary contacts and load contacts.
4. What type of electronic device is used to connect the load to the line in a solid-state relay used to control an alternating current load?
5. What is optoisolation and what is its main advantage?
6. What pin numbers are connected to the coil of an 8 pin control relay?
7. An 11 pin control relay contains three sets of single pole double throw contacts. List the pin numbers by pairs that can be used as normally open contacts.
8. What is the purpose of the shading coil?
9. Refer to the circuit shown in Figure 5–29. Is the thermostat contact normally open, normally closed, normally closed held open, or normally open held closed?
10. What is the difference between a motor starter and a contactor?
11. A 150-horsepower motor is to be installed on a 480-volt three phase line. What is the minimum size NEMA starter that should be used for this installation?
12. What is the minimum size IEC starter rated for the motor described in question 11?
13. When energizing or de-energizing a combination starter what safety precaution should always be taken?
14. What is the purpose of coil clearing contacts?
15. Refer to the circuit shown in Figure 5–29. In this circuit, the HR contactor is equipped with five contacts. Three are load contacts and two are auxiliary contacts. From looking at the schematic diagram, how is it possible to identify which contacts are the load contacts and which are the auxiliary contacts?

Chapter 6

THE CONTROL TRANSFORMER

Objectives

After studying this chapter the student will be able to:

- Discuss the use of control transformers in a control circuit.
- Connect a control transformer for operation on a 240- or 480-volt system.

Most industrial motors operate on voltages that range from 240 to 480 volts. Magnetic control systems, however, generally operate on 120 volts. A control transformer is used to step the 240 or 480 volts down to 120 volts to operate the control system. There is really nothing special about a control transformer except that most of them are made with two primary windings and one secondary winding. Each primary winding is rated at 240 volts and the secondary winding is rated at 120 volts. This means there is a turns ratio of 2:1 (2 to 1) between each primary winding and the secondary winding. For example, assume that each primary winding contains 200 turns of wire and the secondary winding contains 100 turns. There are two turns of wire in each primary winding for every one turn of wire in the secondary.

One of the primary windings of the control transformer is labeled H1 and H2. The other primary winding is labeled H3 and H4. The secondary winding is labeled X1 and X2. If the transformer is to be used to step 240 volts down to 120 volts, the two primary windings are connected parallel to each other as shown in Figure 6–1. Notice that in Figure 6–1 the H1 and H3 leads are connected together, and the H2 and H4 leads are connected together. Because the voltage applied to each primary winding is same, the effect is the same as having only one primary winding with 200 turns of wire in it. This means that when the transformer is connected in this manner, the turns ratio is 2:1. When 240 volts are connected to the primary winding, the secondary voltage is 120 volts.

If the transformer is to be used to step 480 volts down to 120 volts, the primary windings are connected in series, as shown in Figure 6–2. With the windings connected in series, the primary winding now has a total of 400 turns of wire, which makes a turns ratio of 4:1. When 480 volts are connected to the primary winding, the secondary winding has an output of 120 volts.

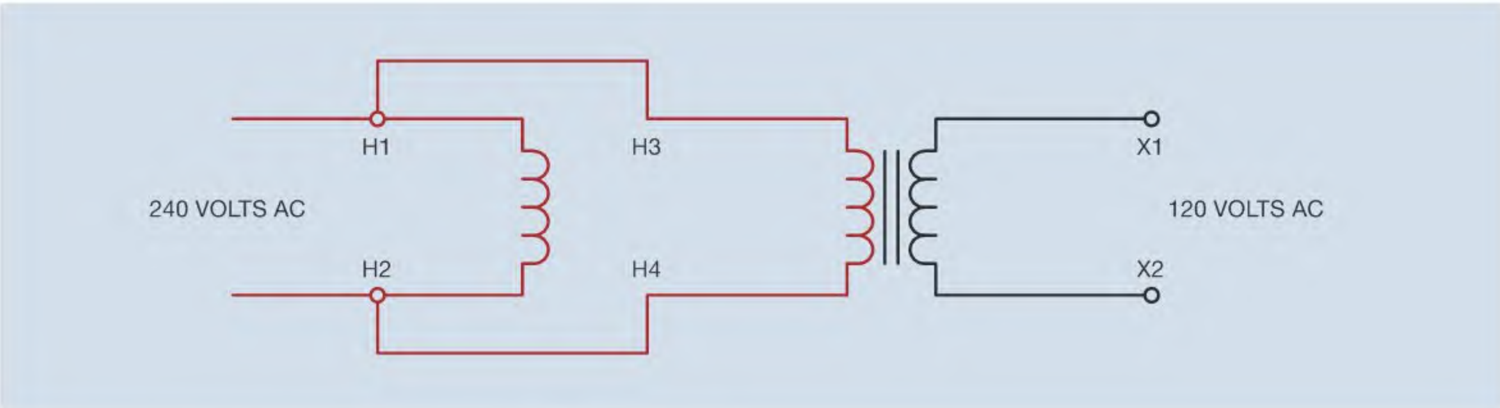


Figure 6–1 Primaries connected in parallel for 240-volt operation.

Control transformers generally have screw terminals connected to the primary and secondary leads. The H2 and H3 leads are crossed to make connection of the primary winding easier, Figure 6–3. For example, if the transformer is to be connected for 240-volt operation, the two primary windings must be connected parallel to each other as shown in Figure 6–1. This connection can be made on the transformer by using one metal link to connect leads H1 and H3, and another metal link to connect H2 and H4 (Figure 6–4).

If the transformer is to be used for 480-volt operation, the primary windings must be connected in series as shown in Figure 6–2. This connection can be made on the control transformer by using a metal link to connect H2 and H3 as shown in Figure 6–5. A typical control transformer is shown in Figure 6–6.

Multi-Tapped Control Transformers

Some control transformers provide connection to different voltages by providing different taps on the high voltage winding, Figure 6–7.

The transformer in this example can be connected to 208, 277, or 380 volts. The secondary or low voltage winding provides an output of 120 volts. The connection diagram for this transformer is shown in Figure 6–8.

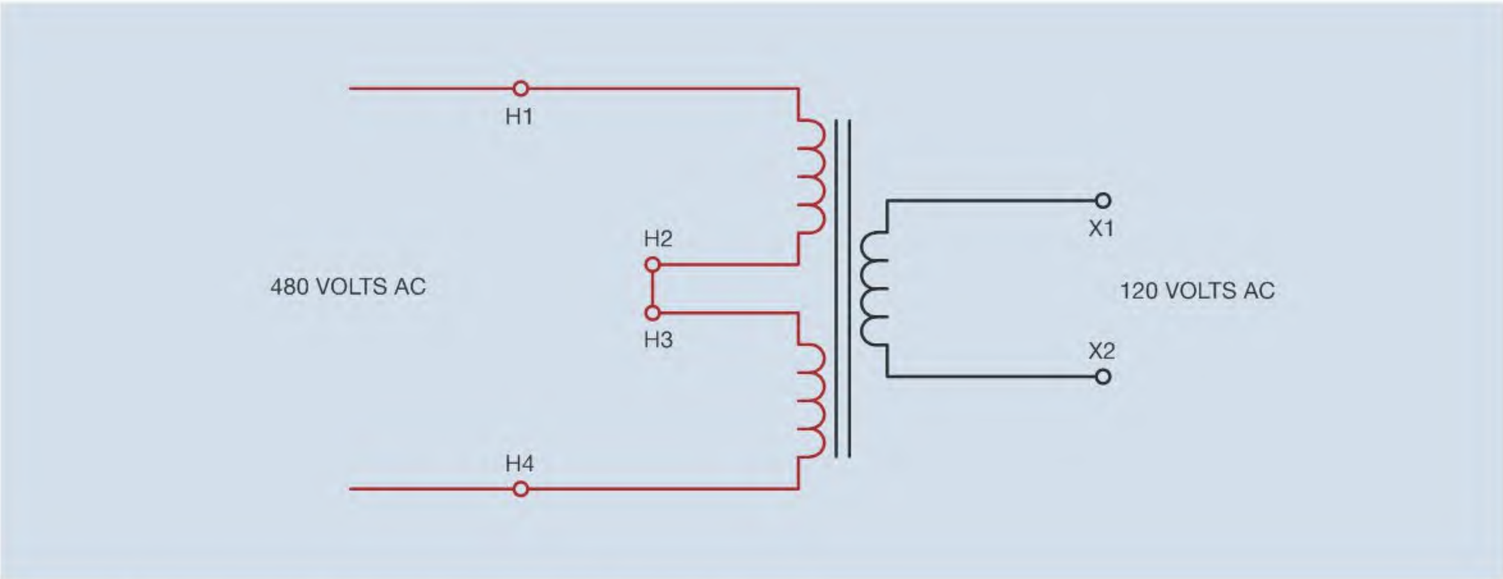


Figure 6–2 Primary windings connected in series for 480-volt operation.

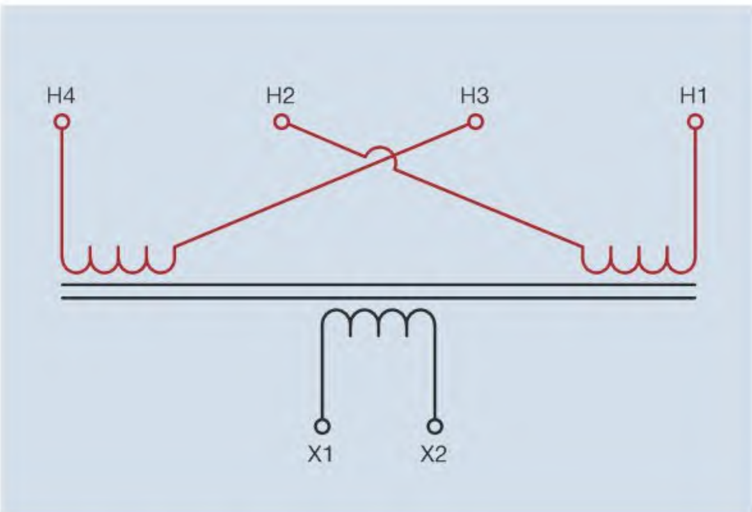


Figure 6–3 Primary leads are crossed.

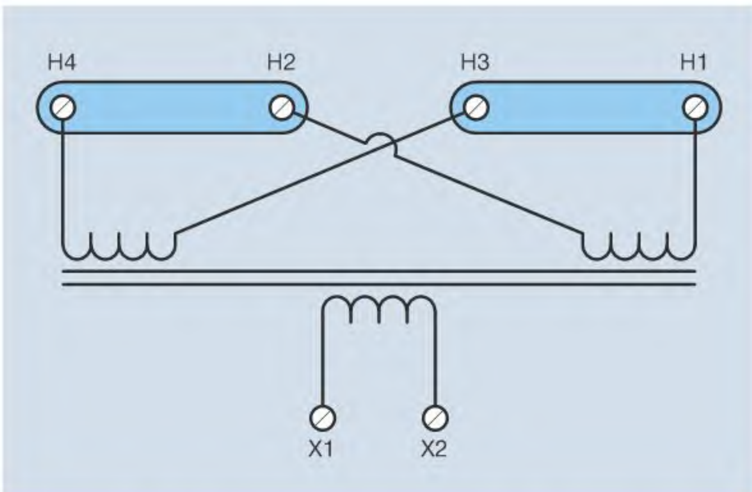


Figure 6–4 Metal links used to make a 240-volt connection.

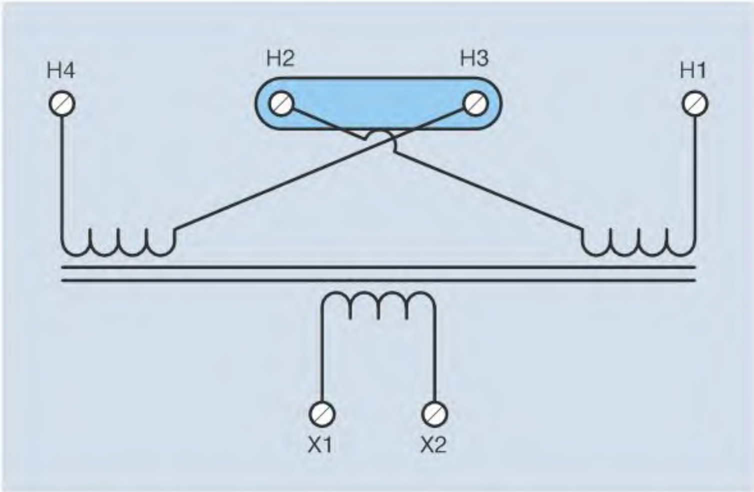


Figure 6–5 Metal link used to make a 480-volt connection.

Figure 6–6 Control transformer.

If the transformer is connected to 208 volts, primary taps H1 and H2 would be used. Taps H3 and H4 are left disconnected. If the transformer is to be connected to 277 volts, taps H1 and H3 would be used. Taps H2 and H4 would be left disconnected. Taps H1 and H4 can be connected to 380 volts, which is a common voltage used in Europe.

Figure 6-7 A multi-tapped control transformer.

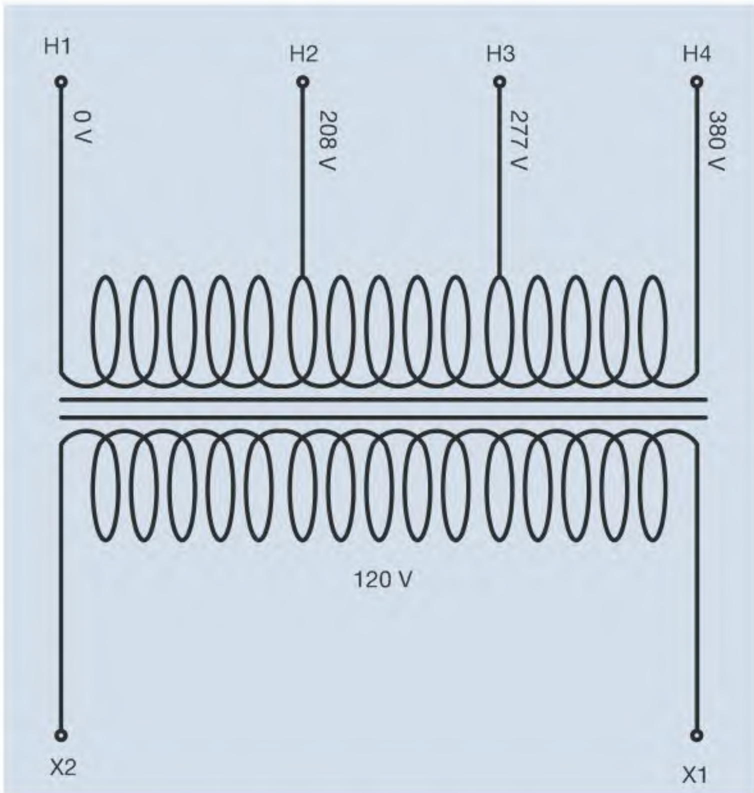


Figure 6-8 Diagram of a multi-tapped control transformer.

Grounded and Floating Control Systems

One side of the secondary winding of a control transformer is often grounded (Figure 6–9). When this is done, the control system is referred to as a **grounded system**. Many industries prefer to ground the control system and it is a very common practice. Some technicians believe that it is an aid when troubleshooting a problem. Grounding one side of the control transformer permits one lead of a voltmeter to be connected to any grounded point and the other voltmeter lead is used to test voltage at various locations throughout the circuit (Figure 6–10).

It is also a common practice to not ground one side of the control transformer. This is generally referred to as a **floating system**. If one voltmeter probe was connected to a grounded point, the meter reading would be erroneous or meaningless because there is not a complete circuit (Figure 6–11). High impedance voltmeters would probably indicate some amount of voltage caused by the capacitance of the ground and induced voltage produced by surrounding magnetic fields. These are generally referred to as **ghost voltages**. A low impedance meter such as a plunger type voltage tester would indicate no voltage. Accurate voltage measurement can be made in a float control system, however, by connecting one voltmeter probe directly to one side of the control transformer (Figure 6–12). Because both grounded and floating control systems are common, both will be illustrated throughout this textbook.

Transformer Fusing

Control transformers are generally protected by fuses or circuit breakers. Protection can be placed on the primary or secondary side of the transformer, and some industries prefer protection in both sides. *NEC® Section 430.72(C)* lists requirements for the protection of transformers employed in motor control circuits. This section basically states that control transformers that have a primary current of less than 2 amperes shall be protected by an overcurrent device set at not more than 500 percent of the rated primary current. This large percentage is necessary because of the high in-rush current associated with transformers. To determine the rated current of the transformer, divide the volt-ampere rating of the transformer by the primary voltage.

The secondary fuse size can be set at a lower percentage of the rated current because the secondary does not experience the high in-rush current of the primary. Because primary and secondary fuse protection is common throughout industry, control circuits presented in this textbook illustrate both.

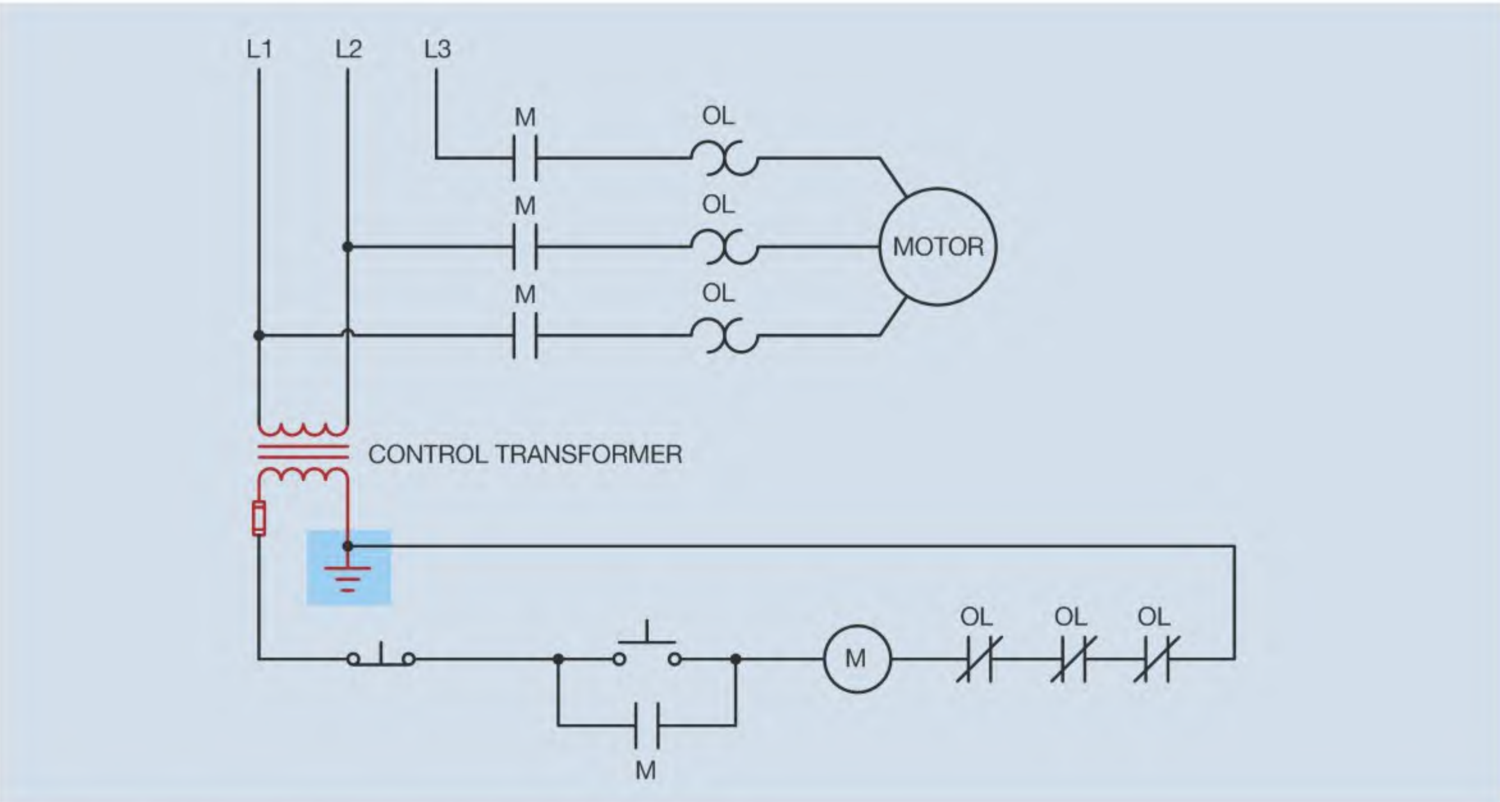


Figure 6–9 One side of the transformer has been grounded.

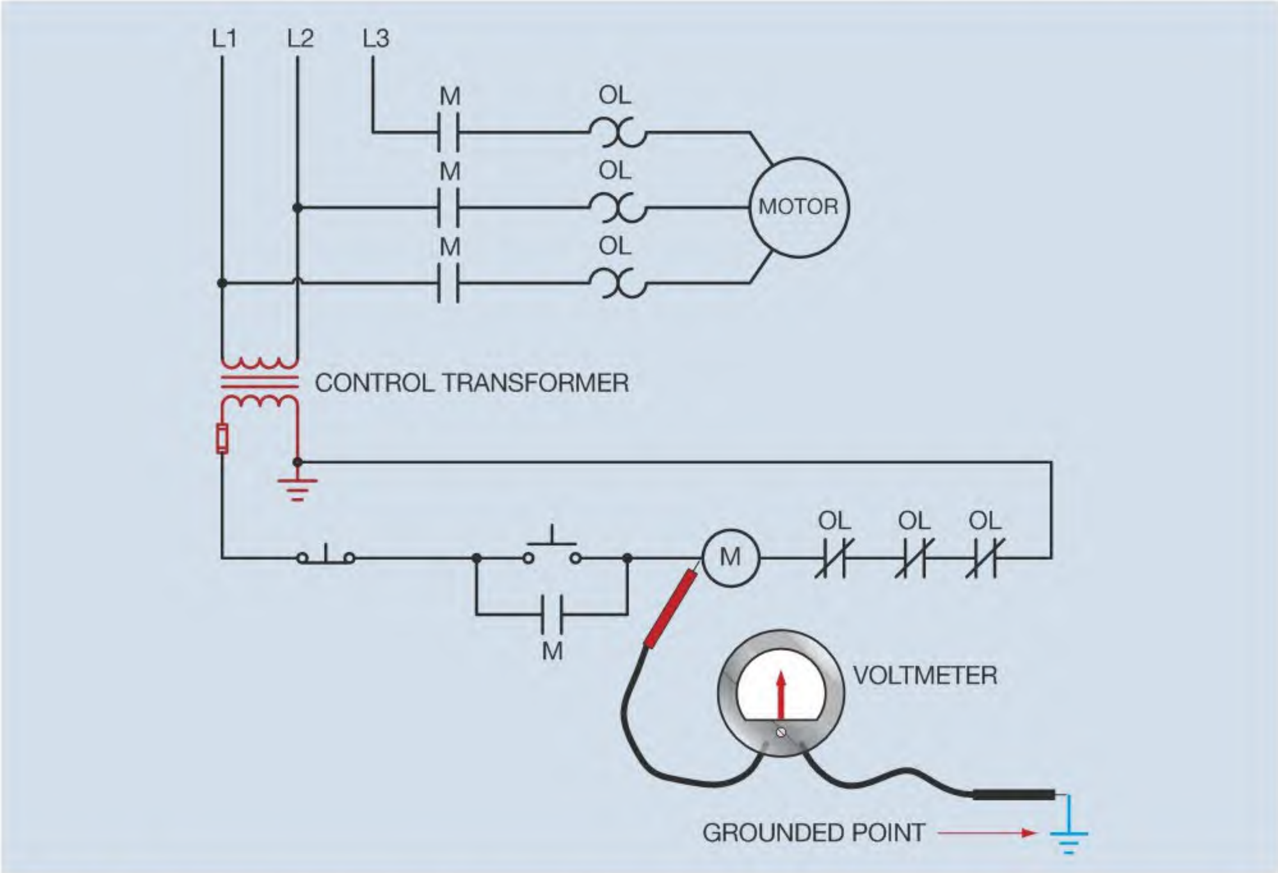


Figure 6–10 Voltage can be measured by connecting one meter probe to any grounded point.

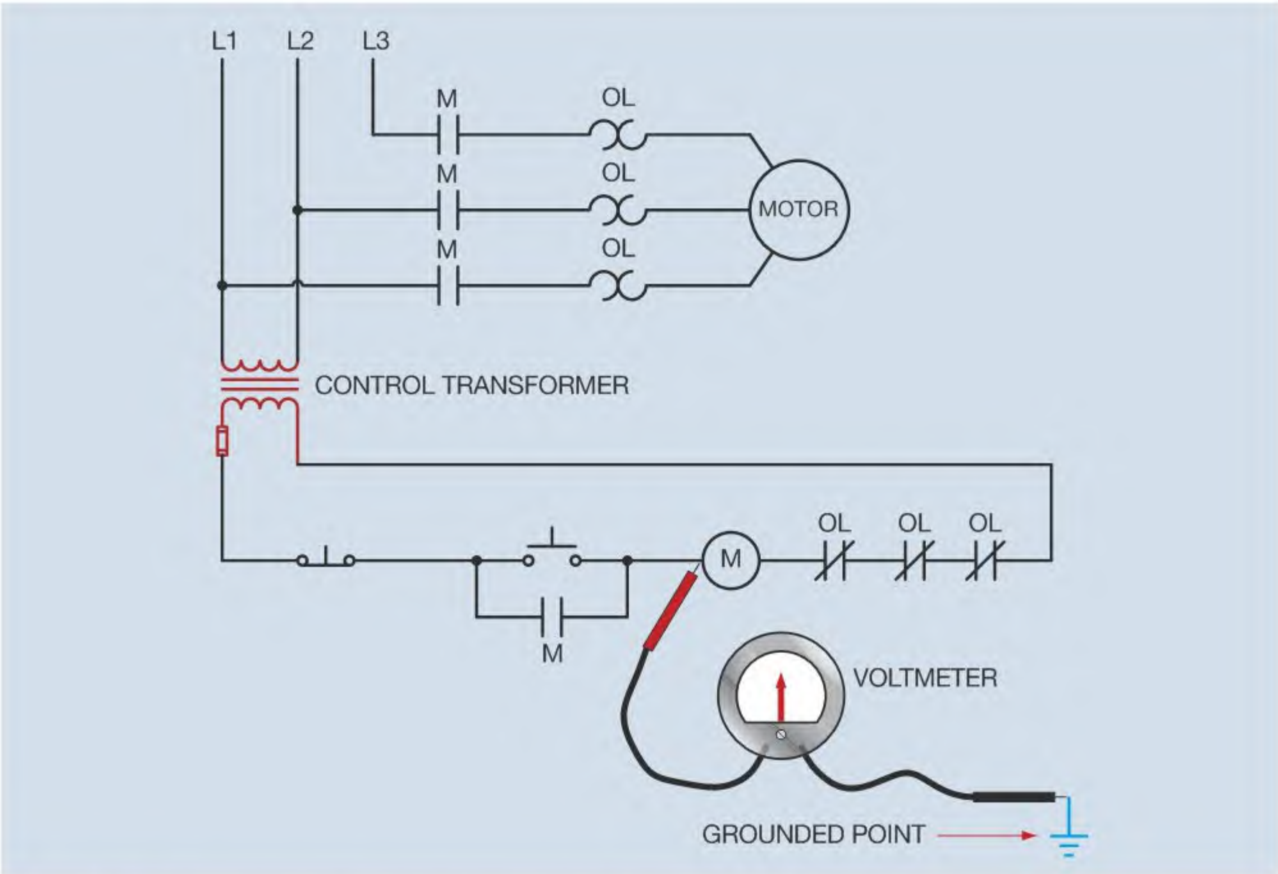


Figure 6–11 Floating control systems do not ground one side of the transformer. Connecting a voltmeter probe to a grounded point would provide meaningless values of voltage because a complete circuit does not exist.

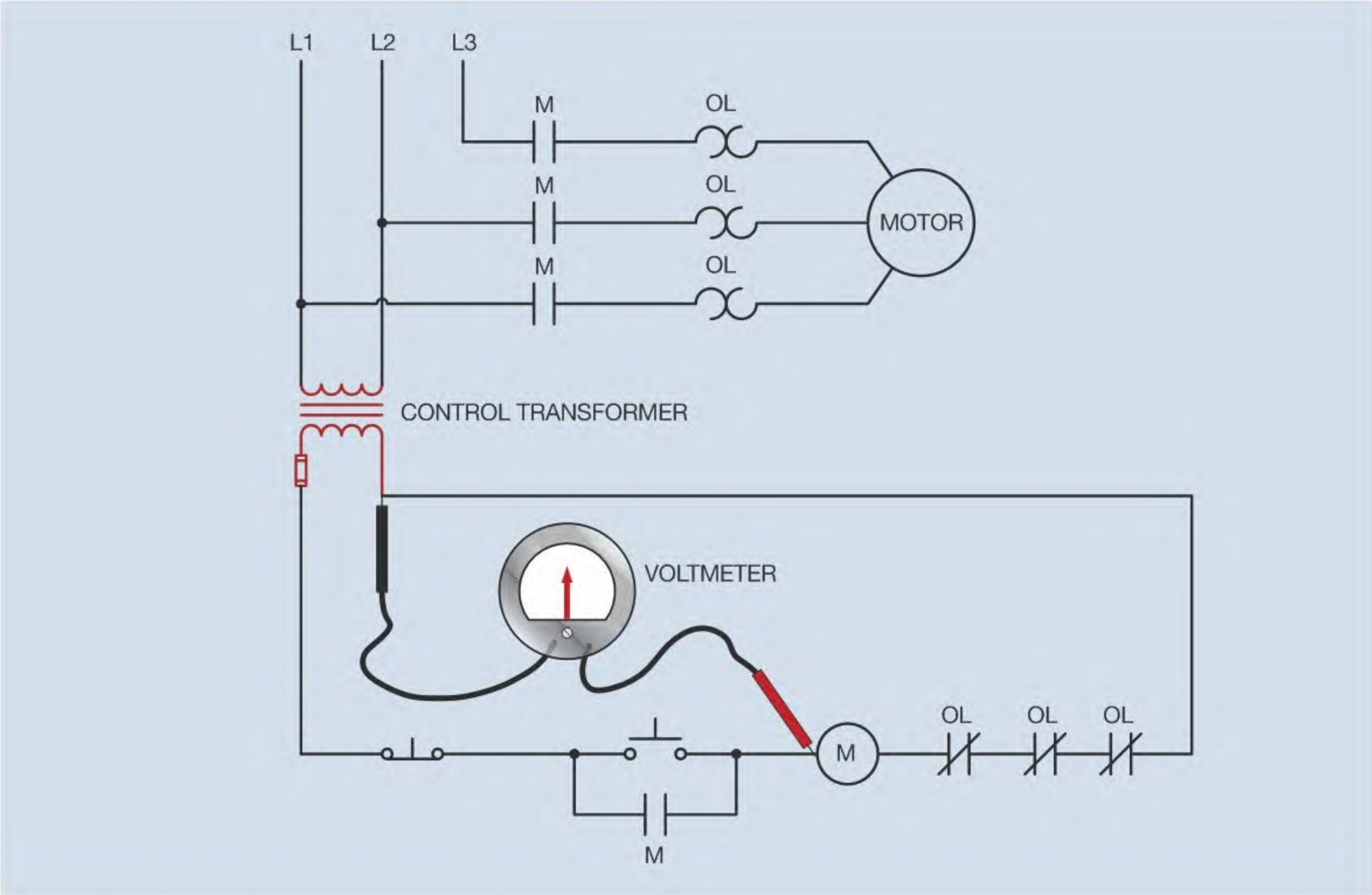


Figure 6–12 One meter probe is connected directly to one side of the control transformer.

EXAMPLE: What is the maximum fuse size permitted to protect the primary winding of a control transformer rated at 300 VA and connected to 240 volts?

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

$$I = \frac{300}{240}$$

$$I = 1.25 \text{ amperes}$$

$$\textit{Fuse size} = 1.25 \times 5 \text{ amperes}$$

$$\textit{Fuse size} = 6.25 \text{ amperes}$$

NEC® Section 240.6 indicates that a standard fuse size is 6 amperes. A 6-ampere fuse would be used.

NEC® Section 430.72(C)(2) states that fuse protection in accordance with 450.3 is permitted also. This section states that primary protection for transformers rated 600 volts or less is determined in *Table 430.3(B)*. The table indicates a rating of 300 percent of the rated current.

The secondary fuse size can also be determined from *NEC® Table 450.3(B)*. The table indicates a rating of 167 percent of the rated secondary current for fuses protecting a transformer secondary with a current of less than 9 amperes. Assuming a control voltage of 120 volts, the rated secondary current of the transformer in the previous example would be 2.5 amperes (300/120). The fuse size would be:

$$2.5 \times 1.67 = 4.175 \text{ amperes}$$

The nearest standard fuse size listed in 240.6 without going over this value is 3 amperes.

Review Questions

1. What is the operating voltage of most magnetic control systems?
2. How many primary windings do control transformers have?
3. How are the primary windings connected when the transformer is to be operated on a 240-volt system?
4. How are the primary windings connected when the transformer is to be operated on a 480-volt system?
5. Why are two of the primary leads crossed on a control transformer?

Section 2

BASIC CONTROL CIRCUITS

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Chapter 7

START–STOP PUSH BUTTON CONTROL

Objectives

After studying this chapter the student will be able to:

- Explain the operation of a START–STOP push button control.
- Place wire numbers on a schematic diagram.
- Place corresponding numbers on control components.
- Draw a wiring diagram from a schematic diagram.
- Define the difference between a schematic or ladder diagram and a wiring diagram.
- Connect a START–STOP push button control circuit.

The START–STOP push button circuit is the basis for many other control circuits. In this chapter you will learn the difference between schematic or ladder diagrams and wiring diagrams, and how to convert a ladder diagram into a wiring diagram. The laboratory exercise section provides instructions in step-by-step order for connecting a START–STOP push button circuit.

Schematics and Wiring Diagrams

Schematic or ladder diagrams show electrical components in their electrical sequence without regard for physical location. Several basic rules apply to how schematics are drawn:

1. **Schematic or ladder diagrams are read like a book, from left to right and from top to bottom.**
2. **Electrical components are always shown in their de-energized or off state.**
3. **Any contact that is marked with the same letter or number as a coil is controlled by that coil regardless of where it is located in the schematic.**
4. **Dashed lines between components indicate that the components are mechanically connected together.**

Wiring diagrams show a pictorial illustration of electrical components with connecting wires. Beginning electricians often prefer wiring diagrams when connecting a circuit because they show precise placement of the wires, but with time electricians discover that it is much easier to troubleshoot circuits and make connections using a schematic diagram.

Circuit Operation

The schematic of a START–STOP push button circuit is shown in Figure 7–1. The operation of the circuit is as follows:

- When the START push button is pressed, current can flow to the coil of M motor starter.
- When M motor starter energizes, all M contacts change position (Figure 7–2).
- The three M load contacts close and connect the motor to the power line.
- The M auxiliary contact connected in parallel with the START button closes. This contact is generally referred to as a **holding contact**, **sealing contact**, or **maintaining contact**, because its function is to maintain or hold a current

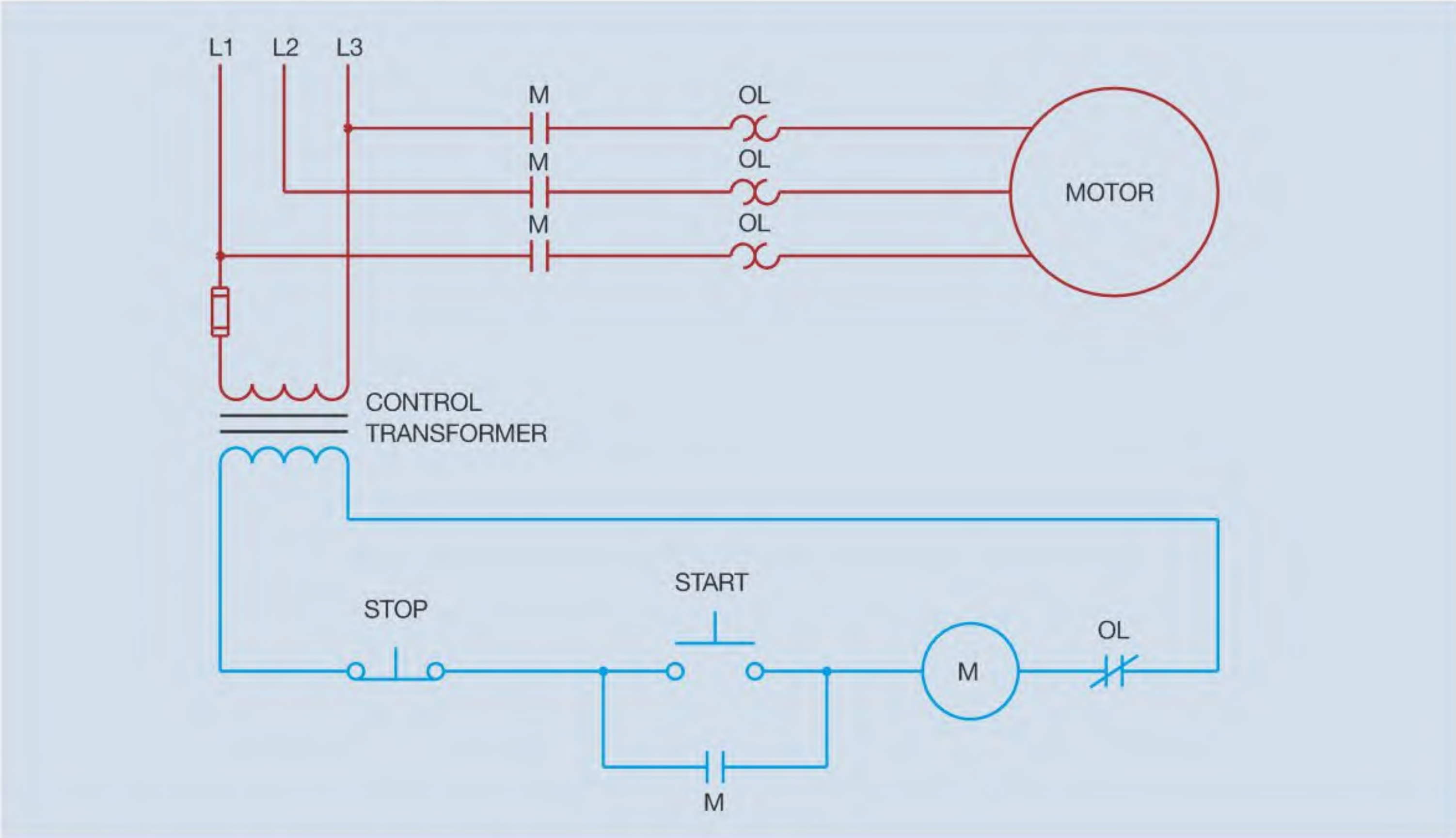


Figure 7–1 Schematic diagram of a basic START–STOP push button control circuit.

path to the coil when the push button is released (Figure 7–3).

- When the STOP button is pressed, current flow to the coil is interrupted and all M contacts return to their original position, (Figure 7–4).
- If an overload should occur, the normally closed overload contact will open. This opening has the same effect as pressing the STOP button.

Converting a Schematic Diagram into a Wiring Diagram

The pictorial representation of the components is shown in Figure 7–5.

To simplify the task of converting the schematic diagram into a wiring diagram, wire numbers are added to the schematic diagram. These numbers are then transferred to the control components shown in Figure 7–5. The rules for numbering a schematic diagram are as follows:

1. A set of numbers can be used only once.
2. Each time you go through a component the number set must change.
3. All components that are connected together have the same number.

To begin the numbering procedure, begin at Line 1 (L1) with the number 1 and place a number 1 beside each component that is connected to L1 (Figure 7–6). The number 2 is placed beside each component connected to L2 (Figure 7–7), and a 3 is placed beside each component connected to L3 (Figure 7–8 on page 106). The number 4 will be placed on the other side of the M load contact that already has a number 1 on one side and on one side of the overload heater (Figure 7–9 on page 107). Number 5 is placed on the other side of the M load contact, which has one side number with a 2 and a 5 will be placed beside the second overload heater. The other side of the M load contact that has been numbered with a 3 will be numbered with a 6, and one side of the third overload heater will be labeled with a 6. Numbers 7, 8, and 9 are placed between the other side of the overload heaters and the motor T leads.

The number 10 will begin at one side of the control transformer secondary and go to one side of the normally closed STOP push button. The number 11 is placed on the other side of the STOP button and on one side of the normally open START push button and normally open M auxiliary contact. A number 12 is placed on the other

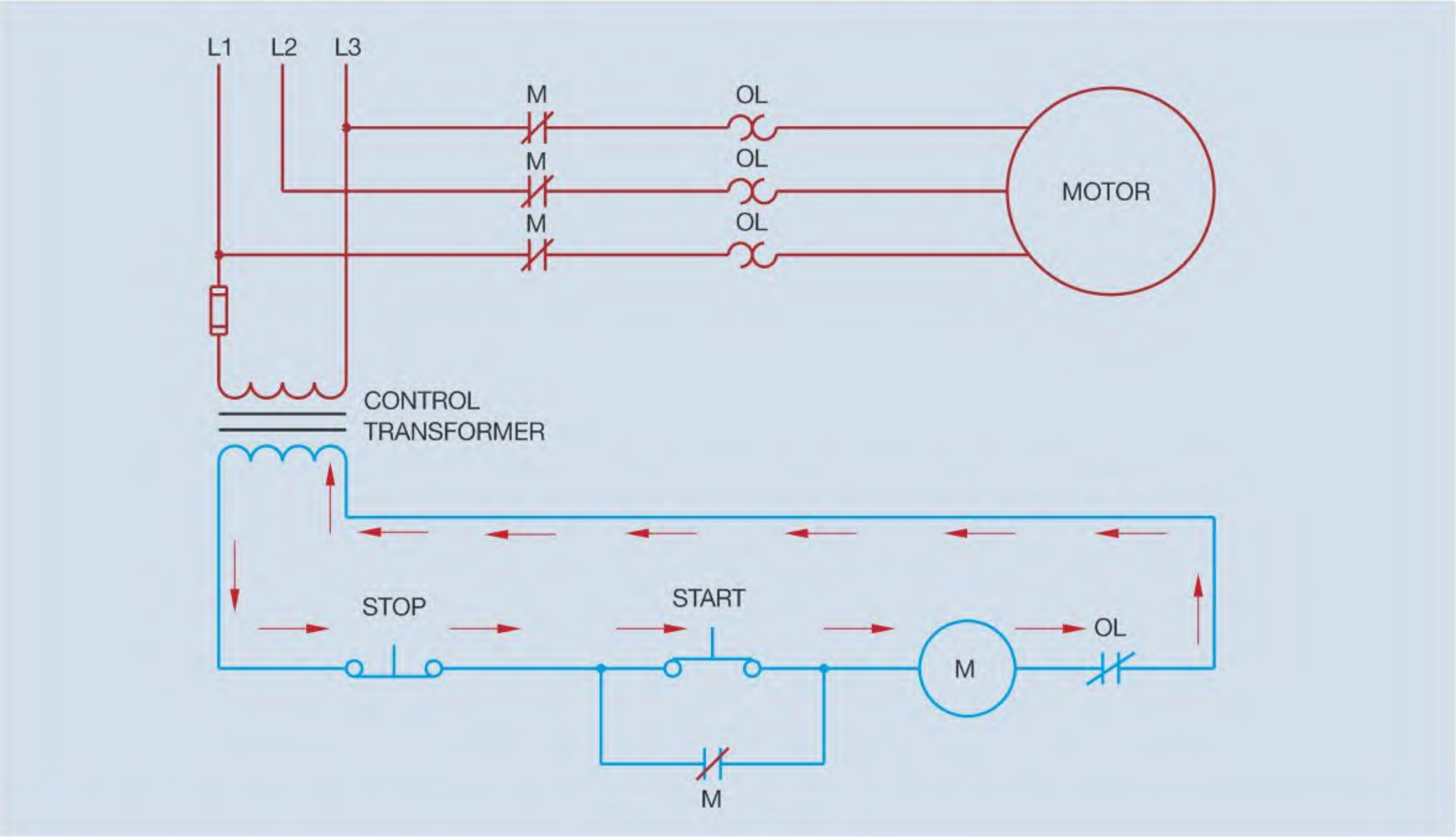


Figure 7–2 When the START button is pressed, current flows through M coil.

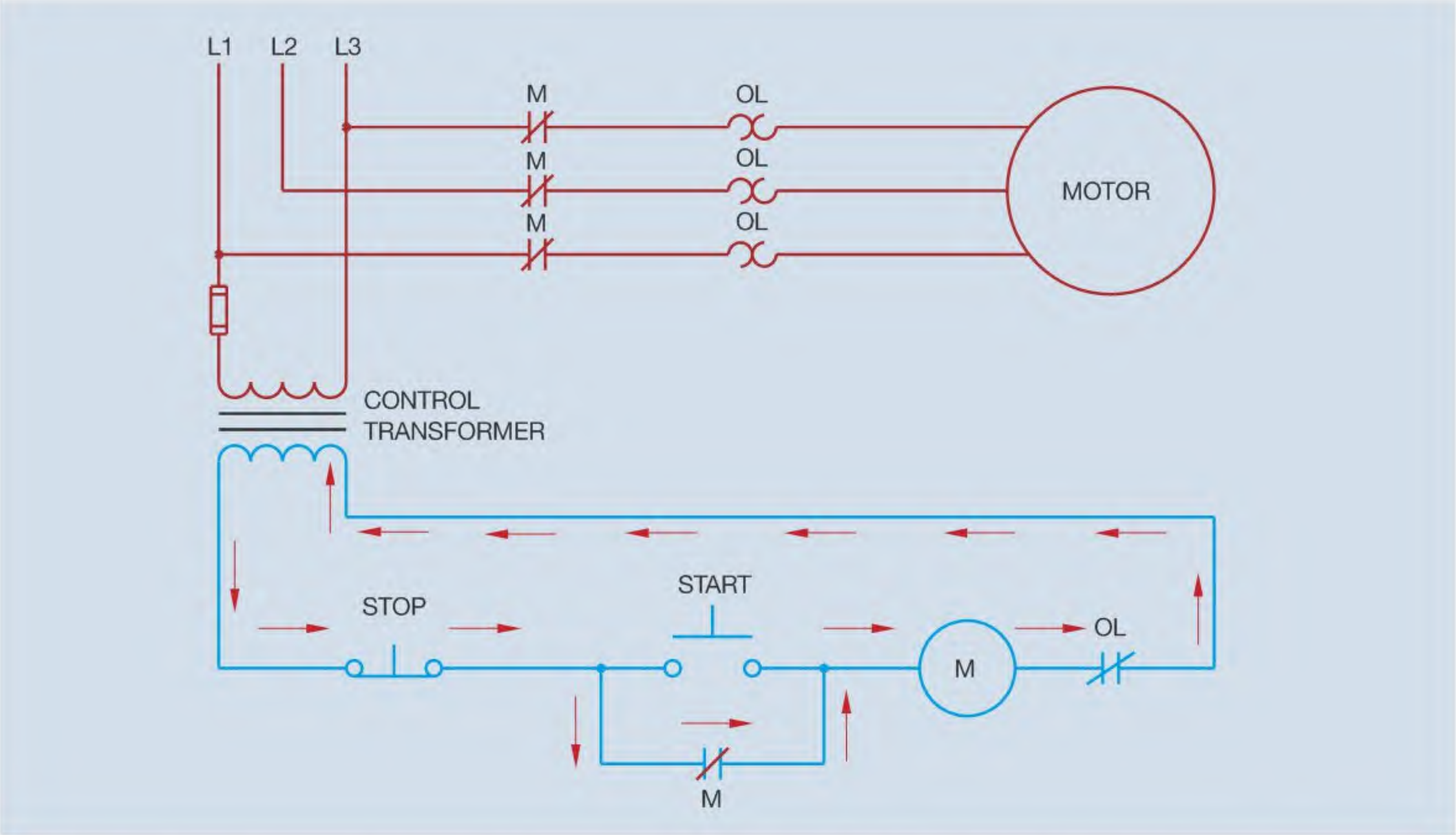


Figure 7–3 The auxiliary contact maintains the current path to the coil after the START button is released.

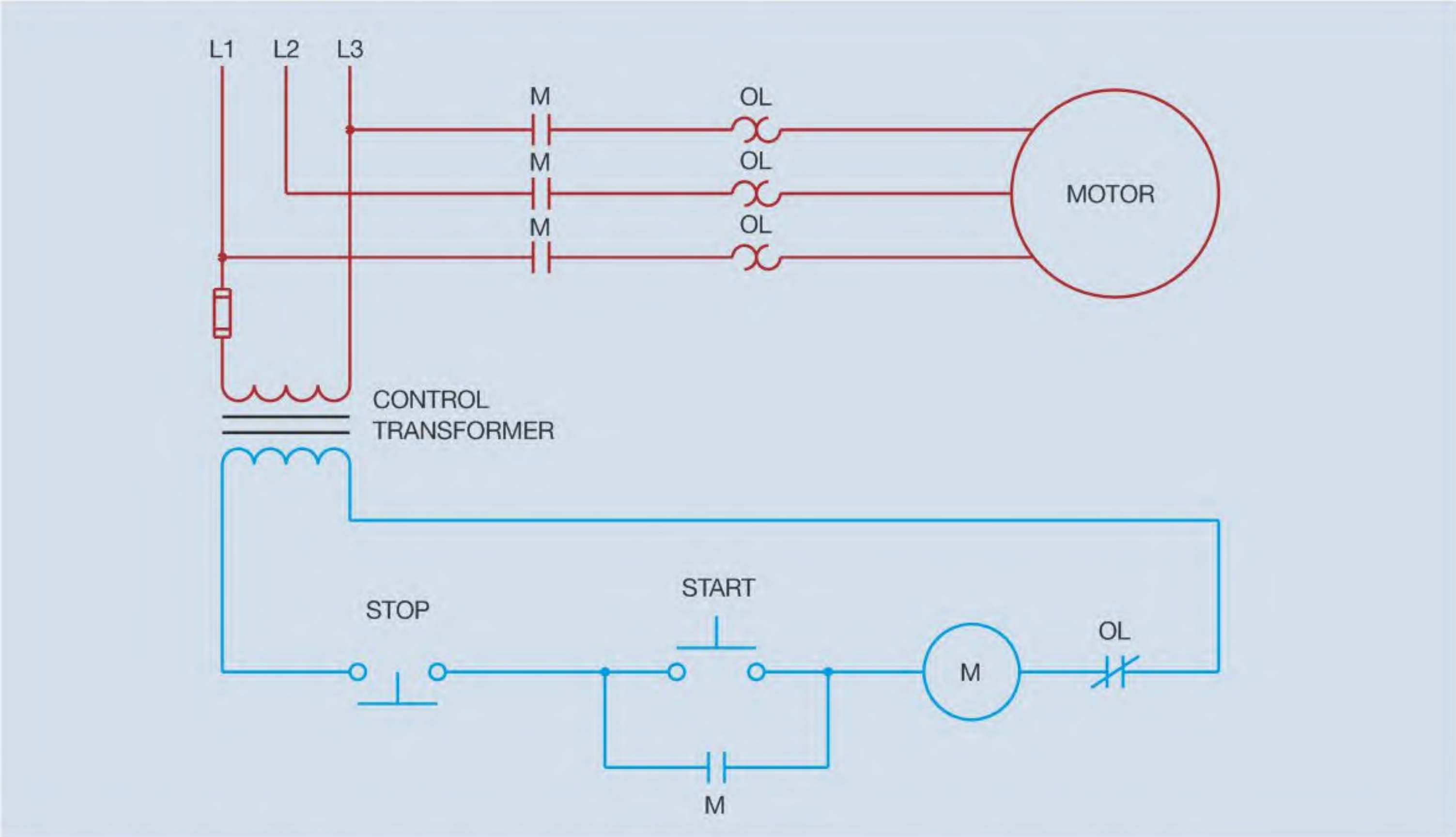


Figure 7–4 Pressing the STOP button de-energizes the coil and all M contacts return to their normal position.

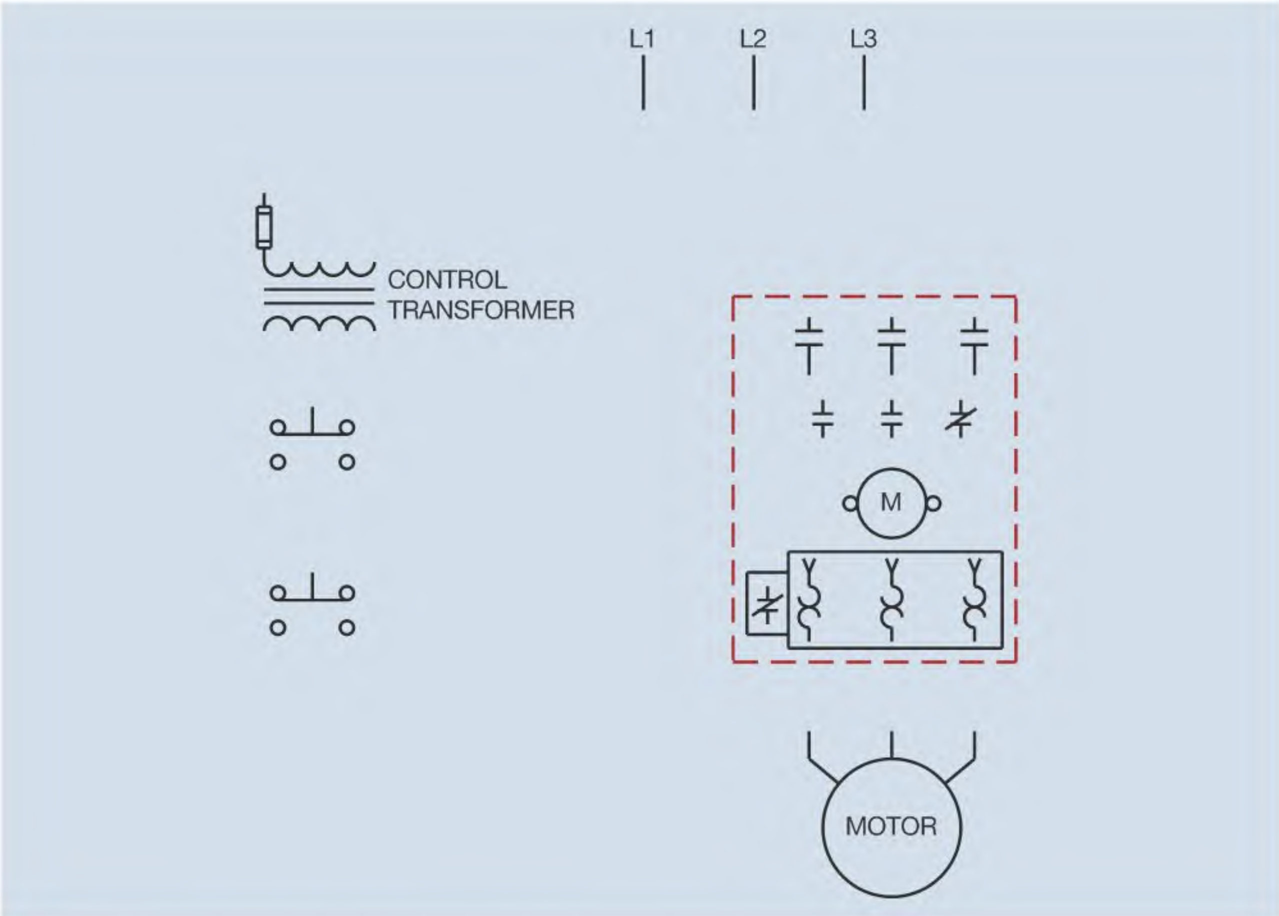


Figure 7–5 Components of the basic START–STOP control circuit.

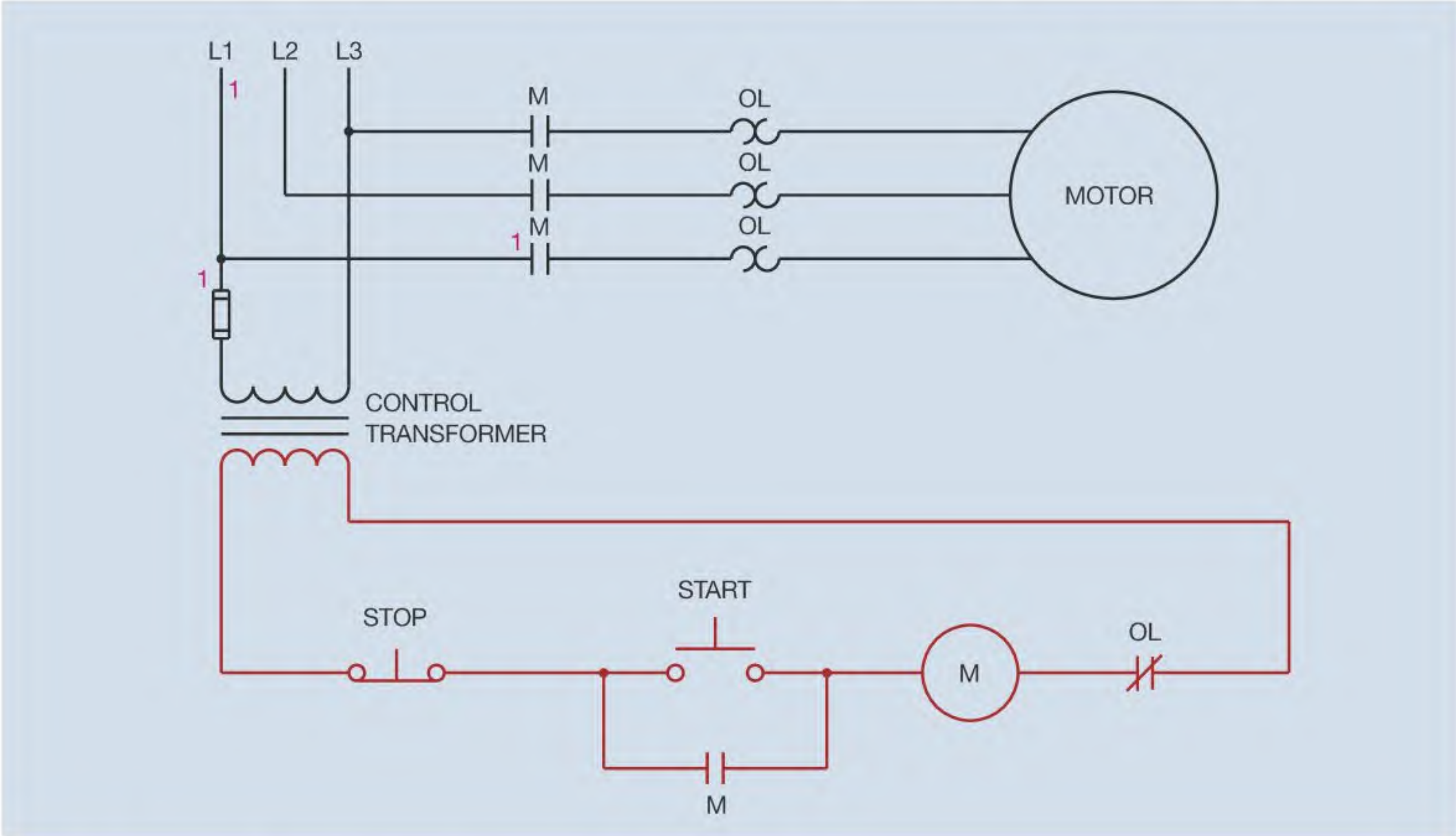


Figure 7–6 The number 1 is placed beside each component connected to Line 1.

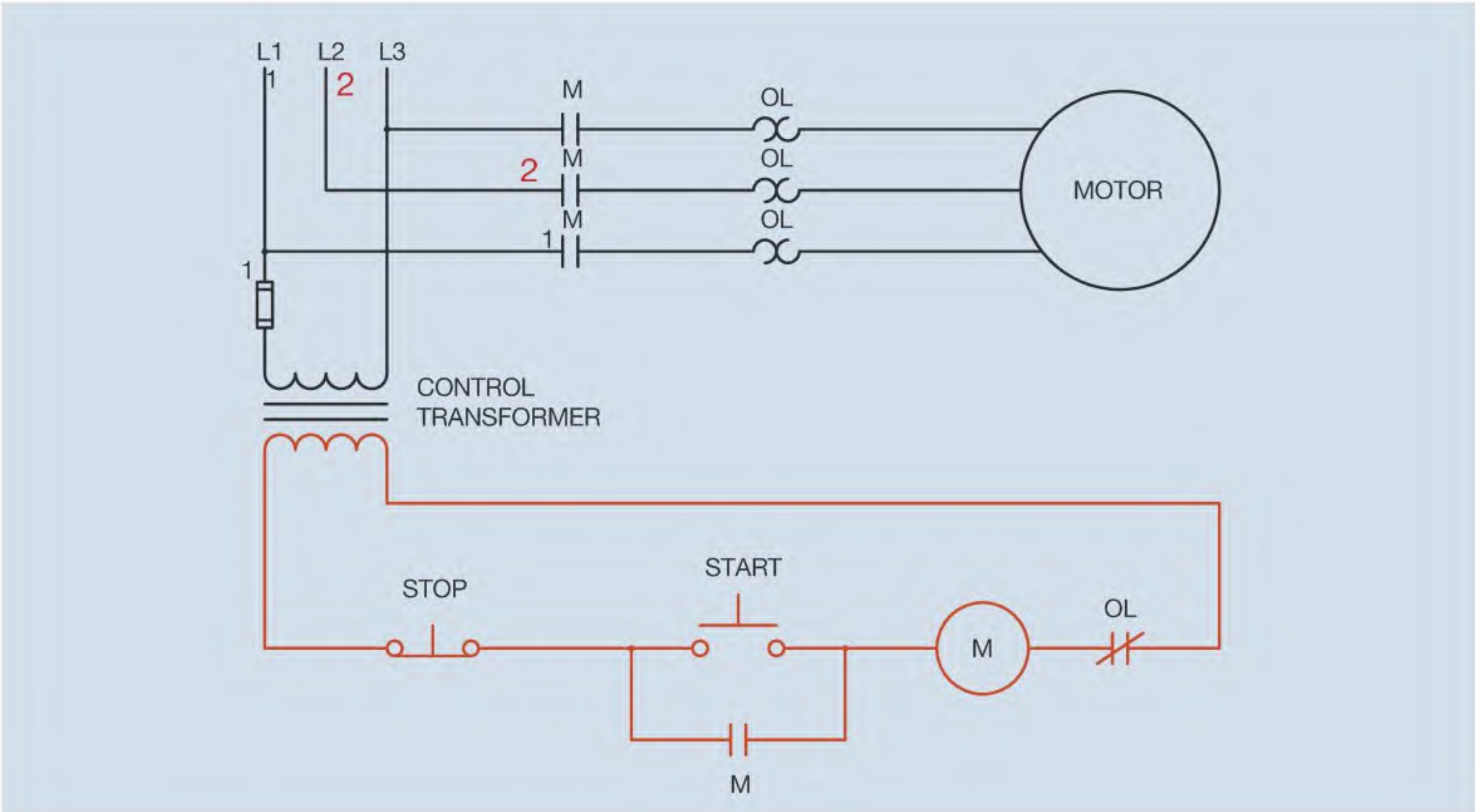


Figure 7–7 A number 2 is placed beside each component connected to Line 2.

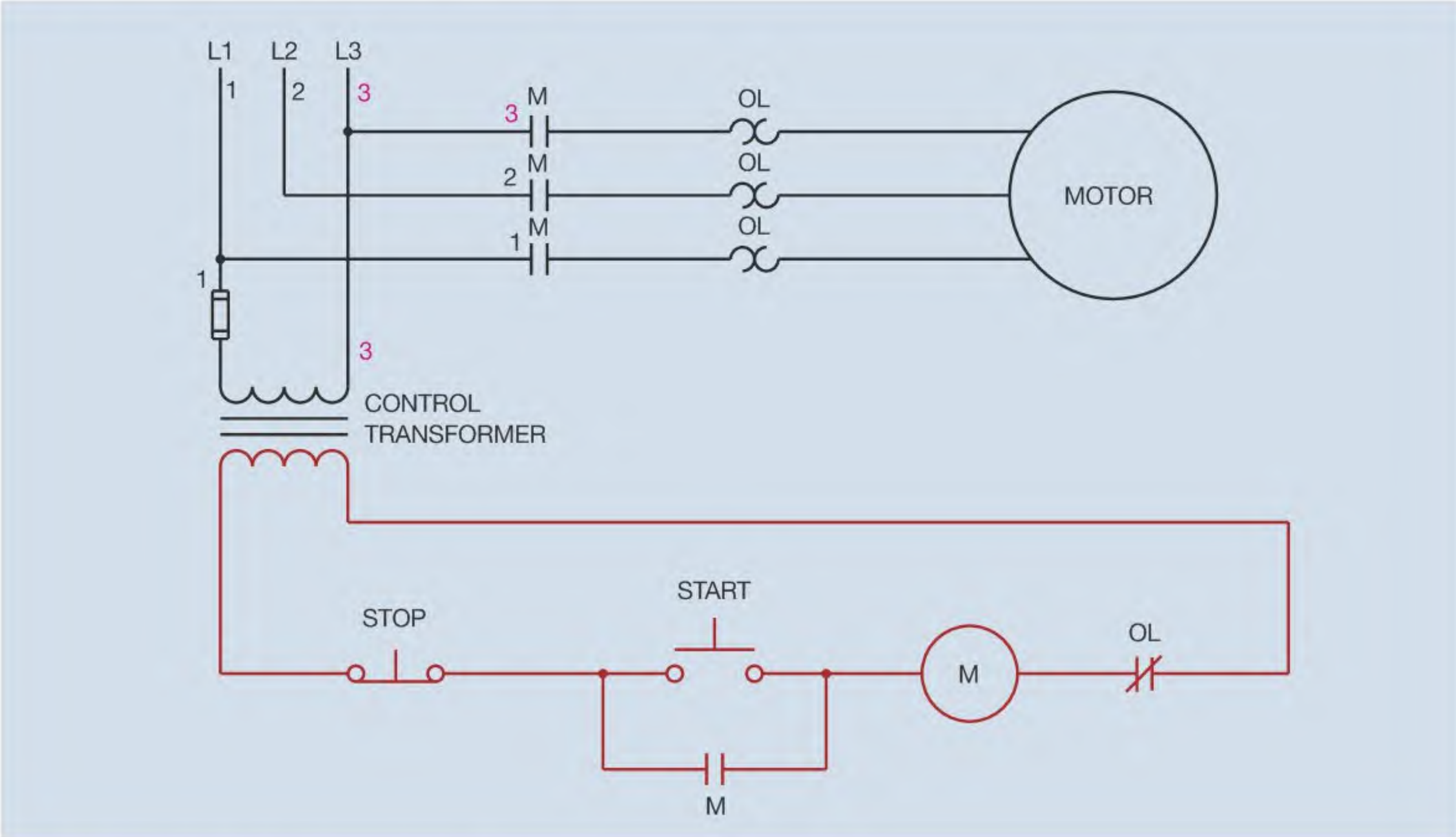


Figure 7–8 A number 3 is placed beside each component connected to Line 3.

side of the START button and M auxiliary contact and on one side of M coil. Number 13 is placed on the other side of the coil to one side of the normally closed overload contact. Number 14 is placed on the other side of the normally closed overload contact and on the other side of the control transformer secondary winding (Figure 7–10).

Numbering the Components

Now that the components on the schematic have been numbered, the next step is to place the same numbers on the corresponding components of the wiring diagram. The schematic diagram in Figure 7–10 shows that the number 1 has been placed beside L1, the fuse on the control transformer, and one side of a load contact on M starter (Figure 7–11). The number 2 is placed beside L2 and the second load contact on M starter (Figure 7–12). The number 3 is placed beside L3, the third load contact on M starter, and the other side of the primary winding on the control transformer. Numbers 4, 5, 6, 7, 8, and 9 are placed beside the components that correspond to those on the schematic diagram (Figure 7–13). Note on connection points 4, 5, and 6 from the output of the load contacts to the overload heaters, that these connections are factory made on a motor starter and do not have to be made in the field. These connections are not shown in the diagram for the sake of simplicity. If a separate contactor and overload relay are being used, however, these connections will have to be made. Recall that a contactor is a relay that contains *load* contacts and may or may not contain auxiliary contacts. A motor starter is a contactor and overload relay combined.

The number 10 starts at the secondary winding of the control transformer and goes to one side of the normally closed STOP push button. When making this connection, ensure that the connection is made to the normally closed side of the push button. Because this is a double-acting push button, it contains both normally closed and normally open contacts (Figure 7–14).

The number 11 starts at the other side of the normally closed STOP button and goes to one side of the normally open START push button and to one side of a normally open M auxiliary contact (Figure 7–15). The starter in this example shows three auxiliary contacts—two normally open and one normally closed. It makes no difference which normally open contact is used.

This same procedure is followed until all circuit components have been numbered with the number that corresponds to the same component on the schematic diagram (Figure 7–16 on page 111).

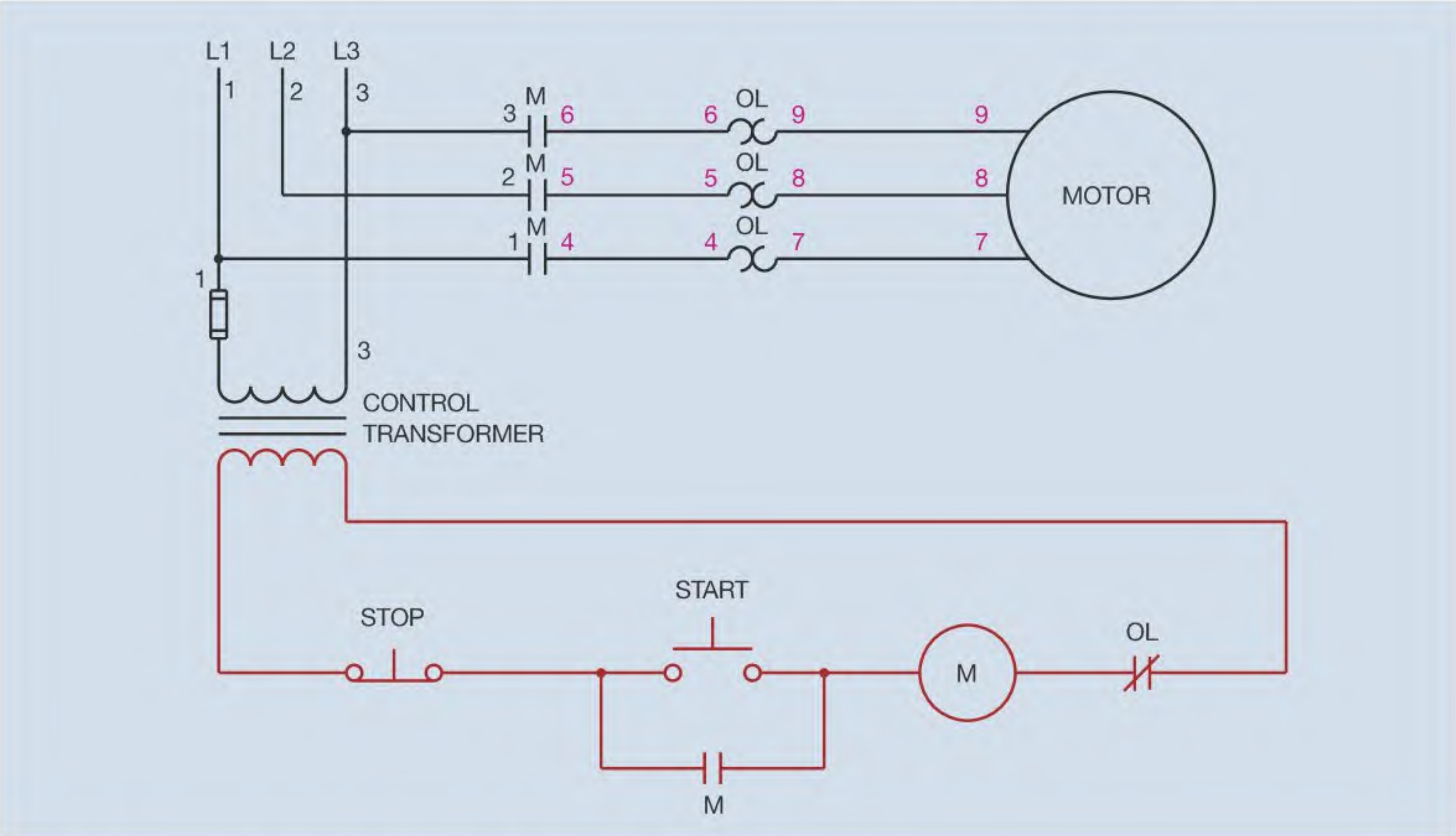


Figure 7–9 The number changes each time you proceed across a component.

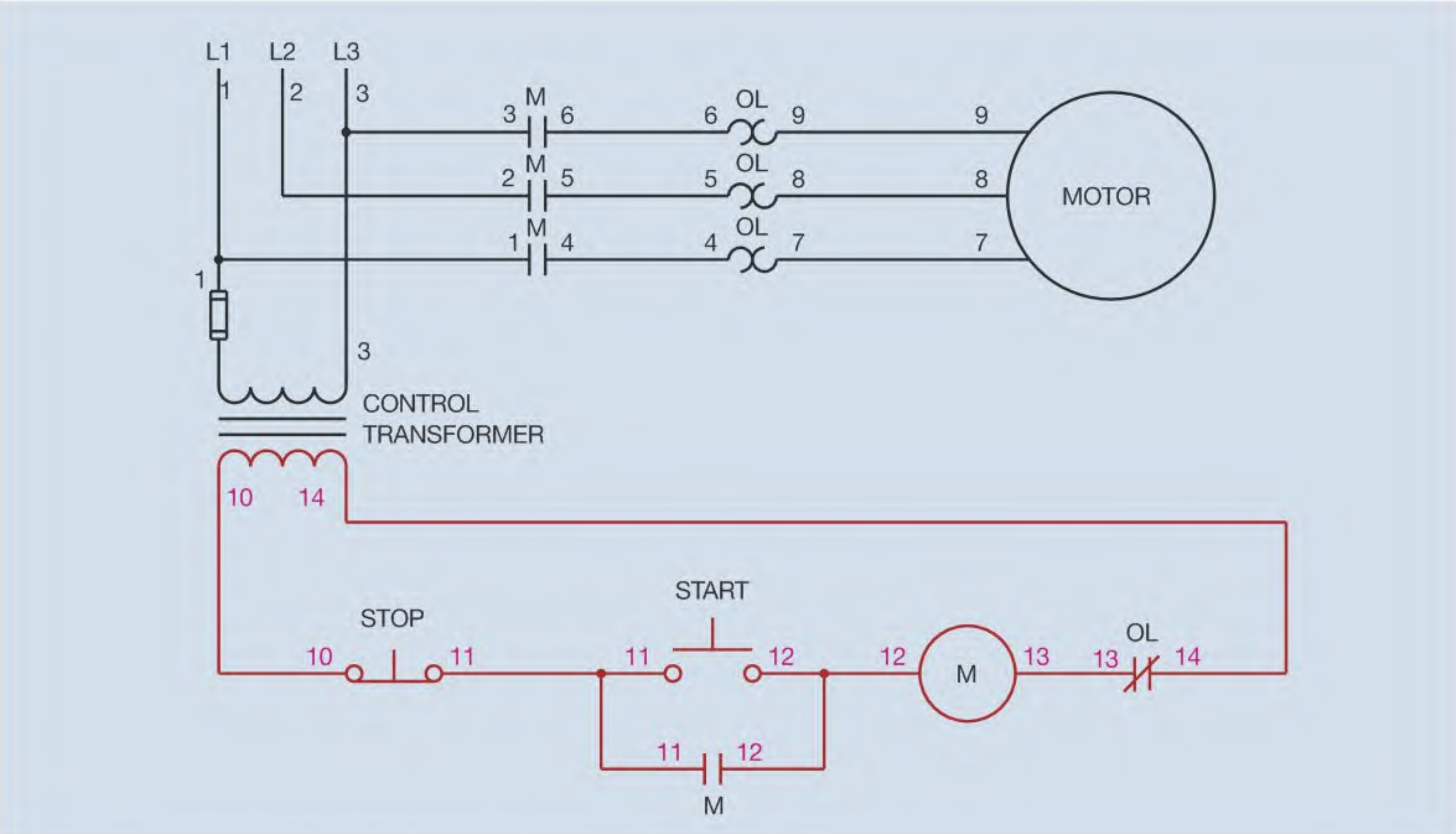


Figure 7–10 Numbers are placed beside all components.

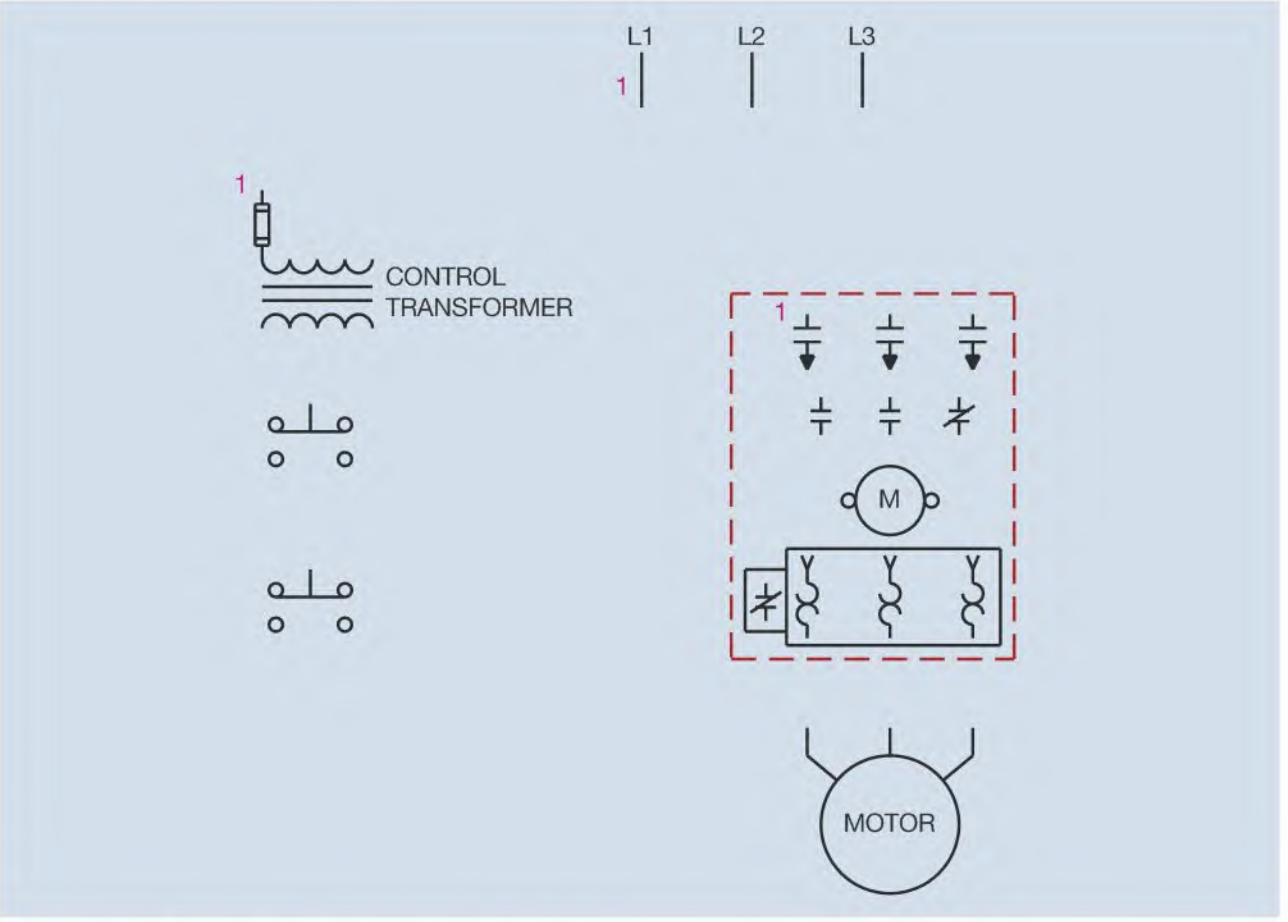


Figure 7–11 A number 1 is placed beside Line 1, the control transformer fuse, and M load contact.

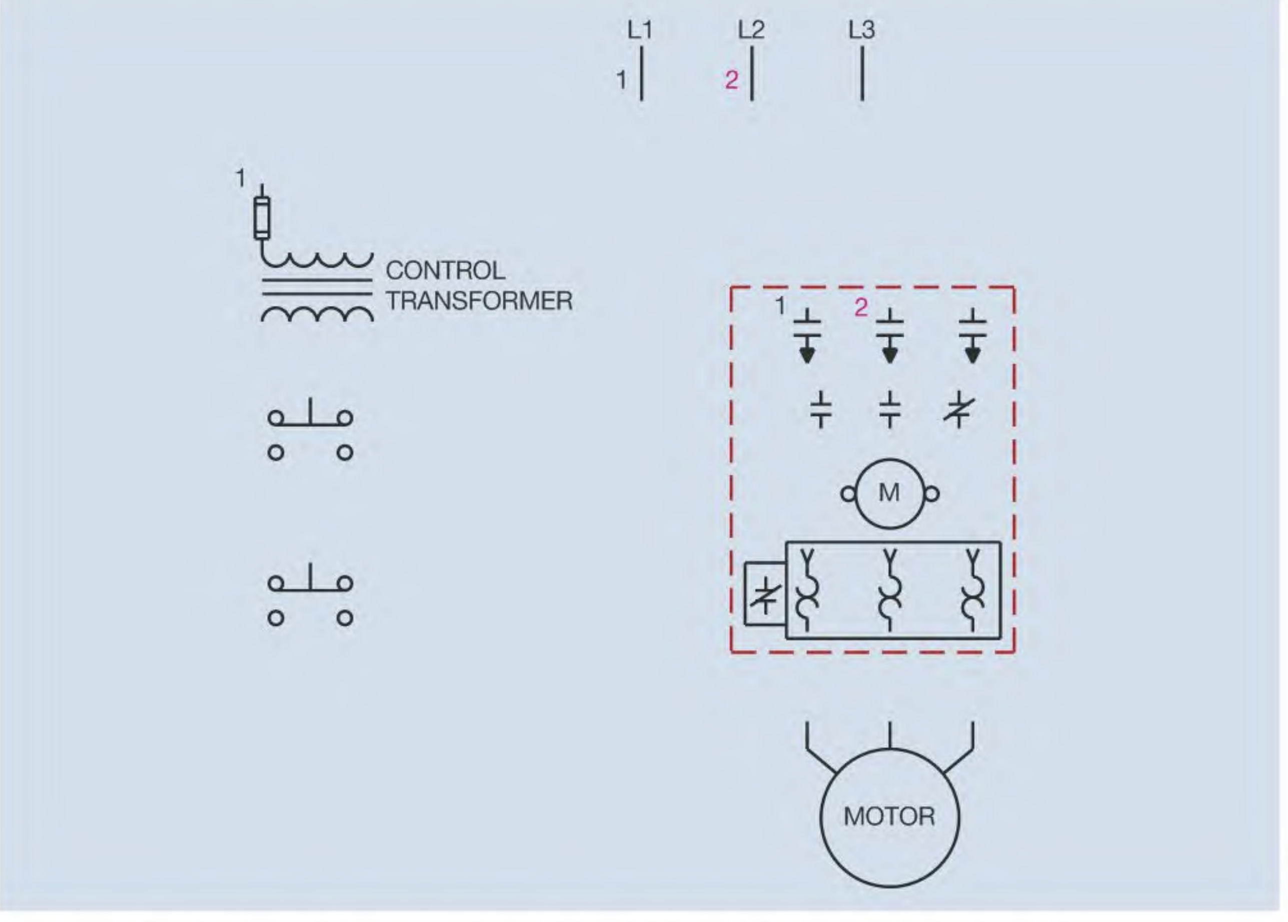


Figure 7–12 The number 2 is placed beside Line 2 and the second load contact on M starter.

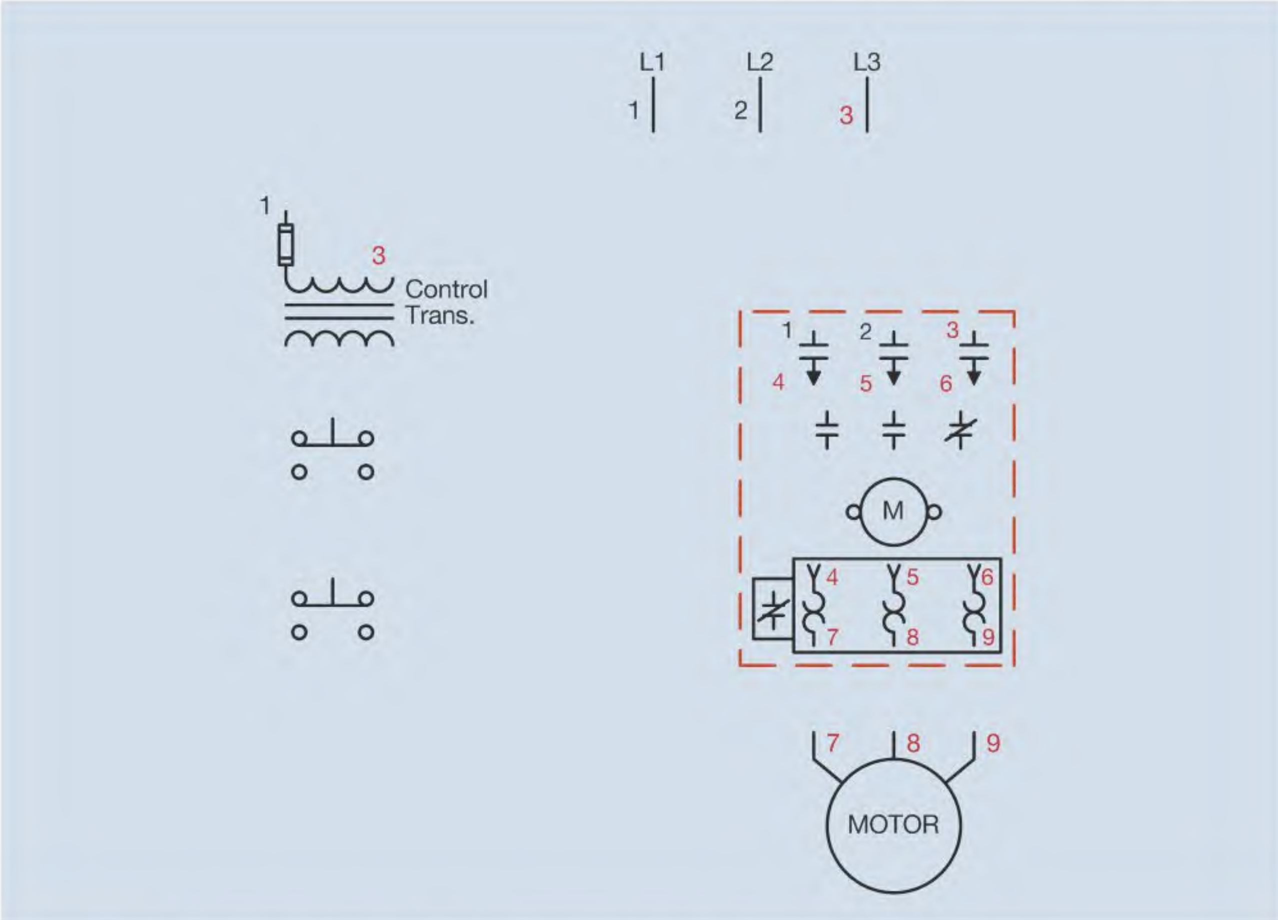


Figure 7–13 Numbers 3, 4, 5, 6, 7, 8, and 9 are placed beside the proper components.

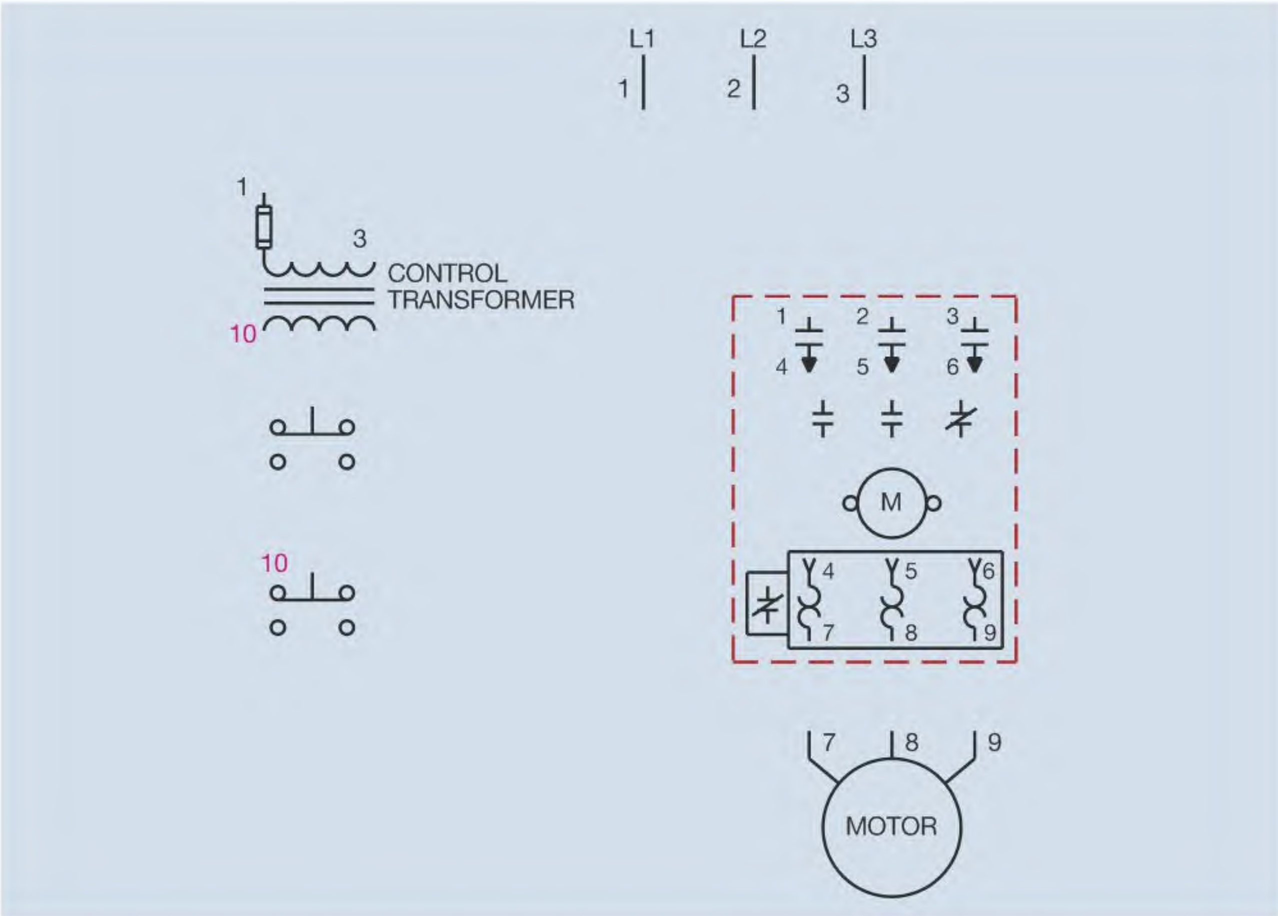


Figure 7–14 Wire number 10 connects from the transformer secondary to the STOP button.

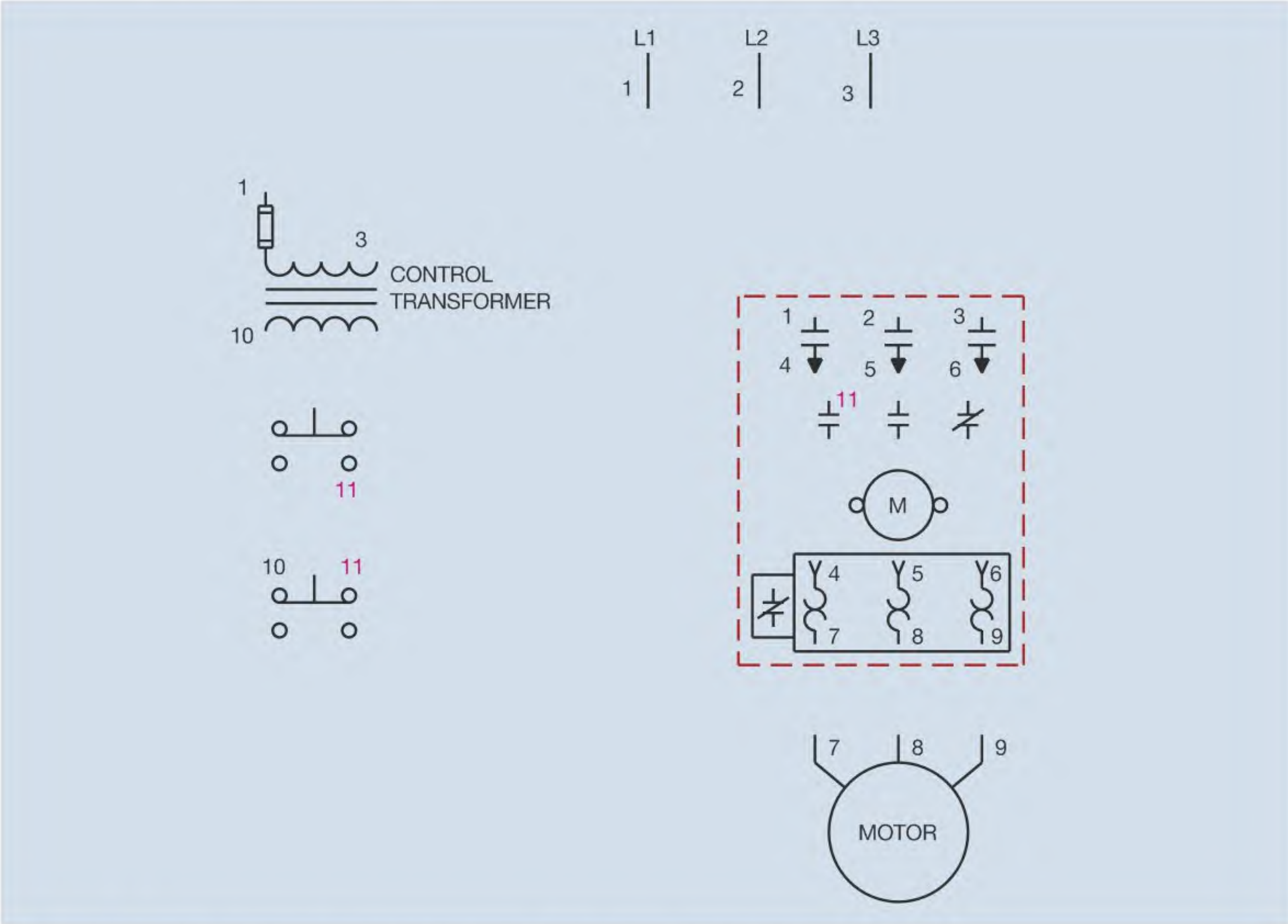


Figure 7–15 Number 11 connects to the STOP button, START button, and holding contact.

Connecting the Wires

Now that numbers have been placed beside the components, wiring the circuit becomes a matter of connecting numbers. Connect all components labeled with a number 1 together (Figure 7–17). All components number with a 2 are connected together (Figure 7–18). All components numbered with a 3 are connected together (Figure 7–19). This procedure is followed until all the numbered components are connected together, with the exception of 4, 5, and 6 that are assumed to be factory connected (Figure 7–20 on page 113).

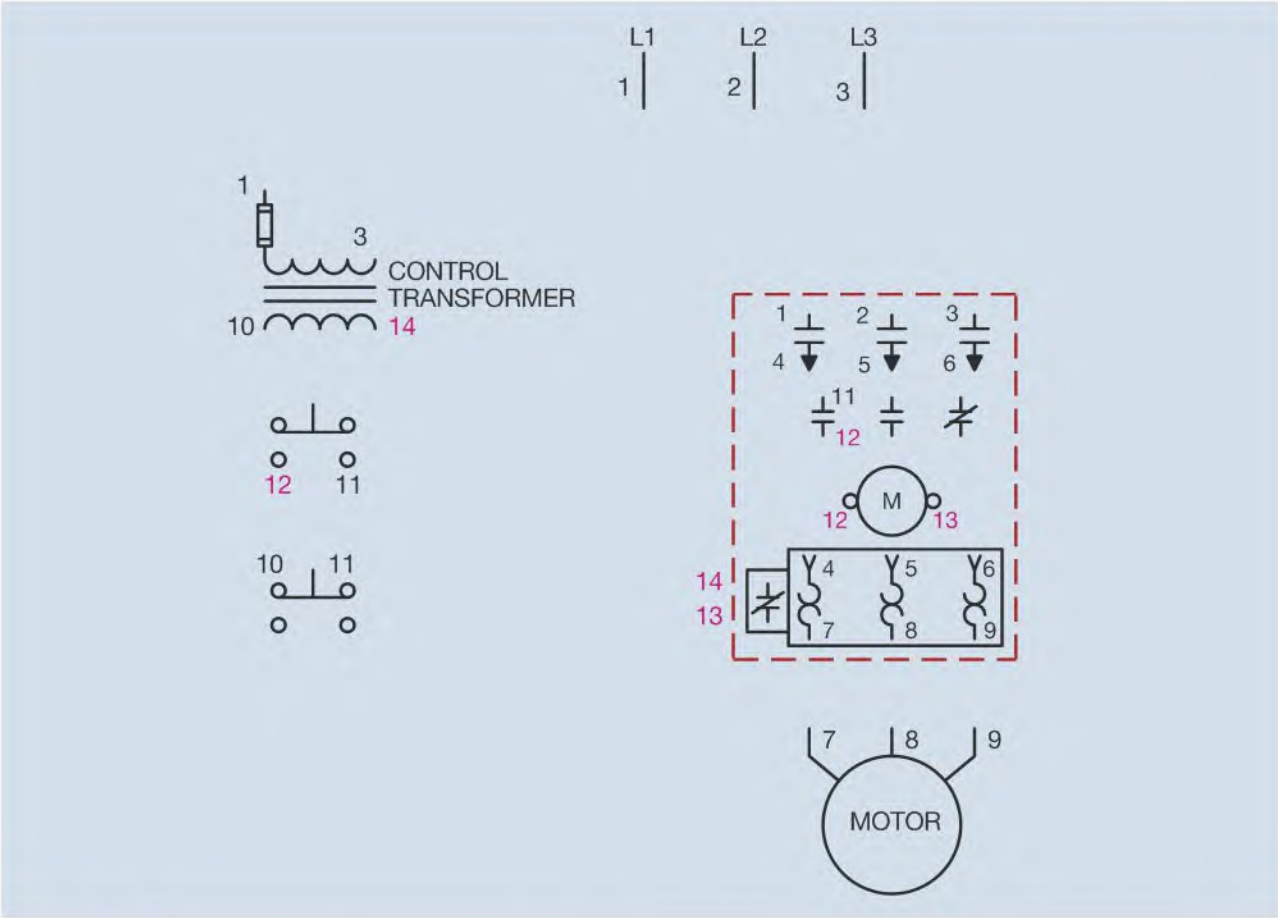


Figure 7–16 All components have been numbered.

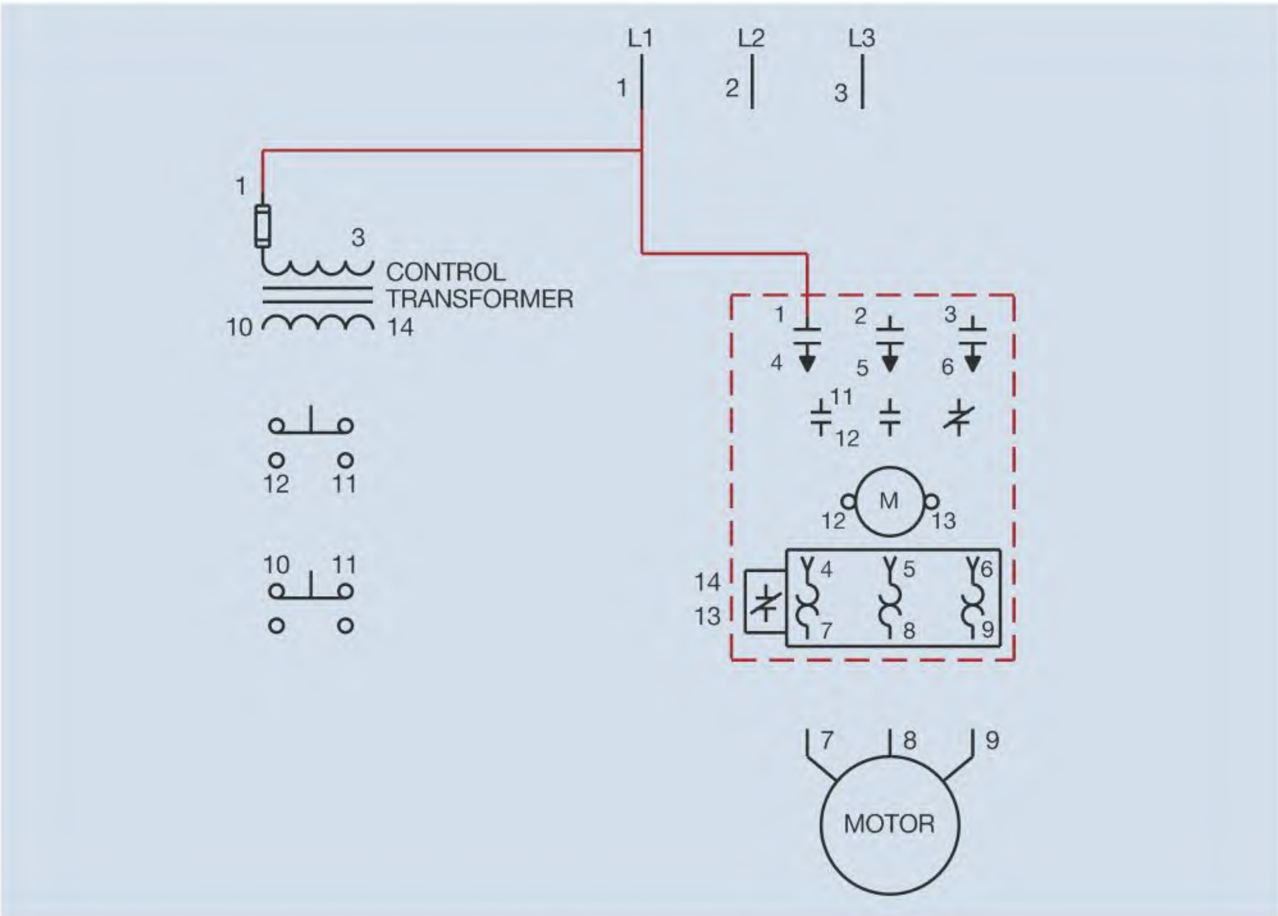


Figure 7–17 All the components with a number 1 are connected together.

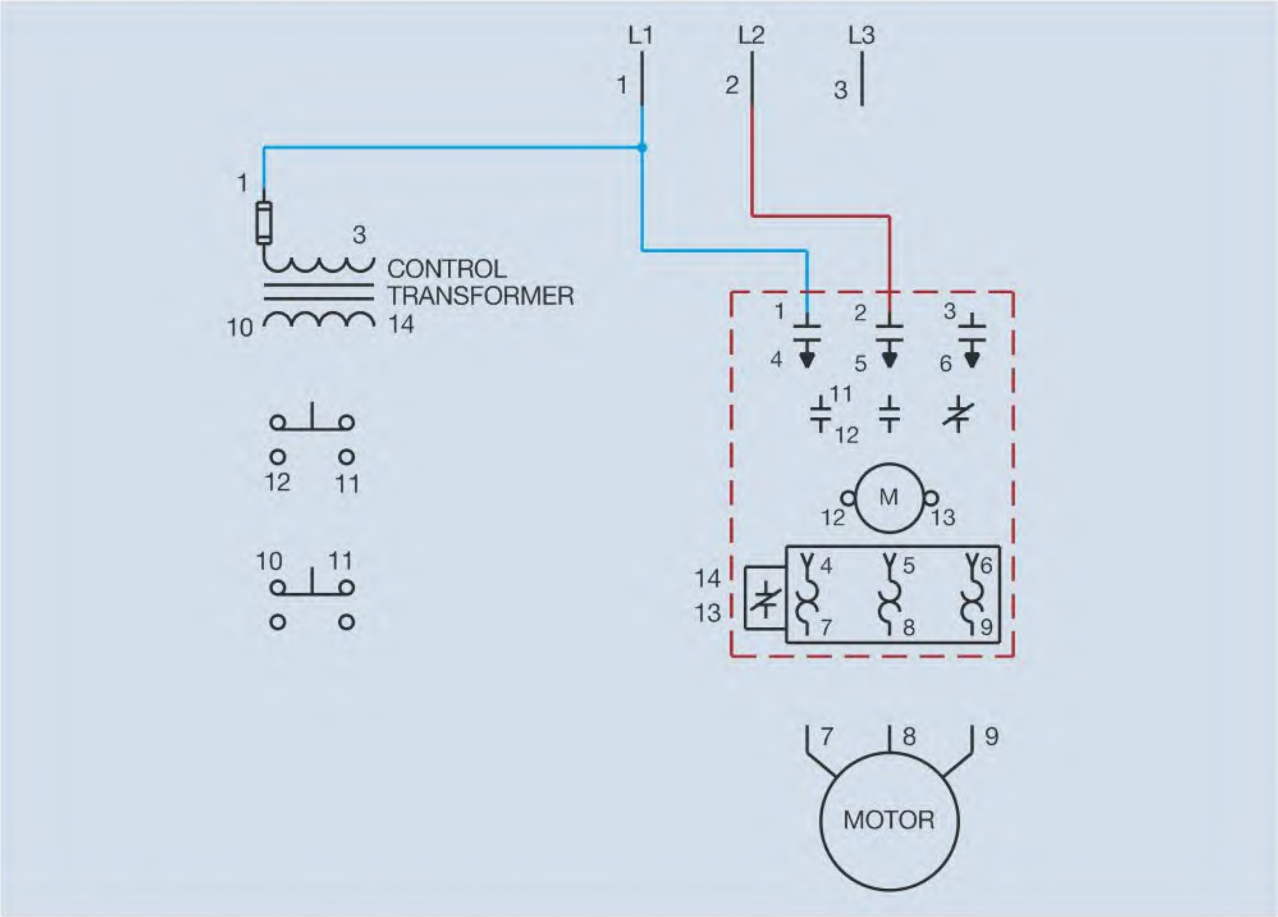


Figure 7–18 All components with a number 2 are connected together.

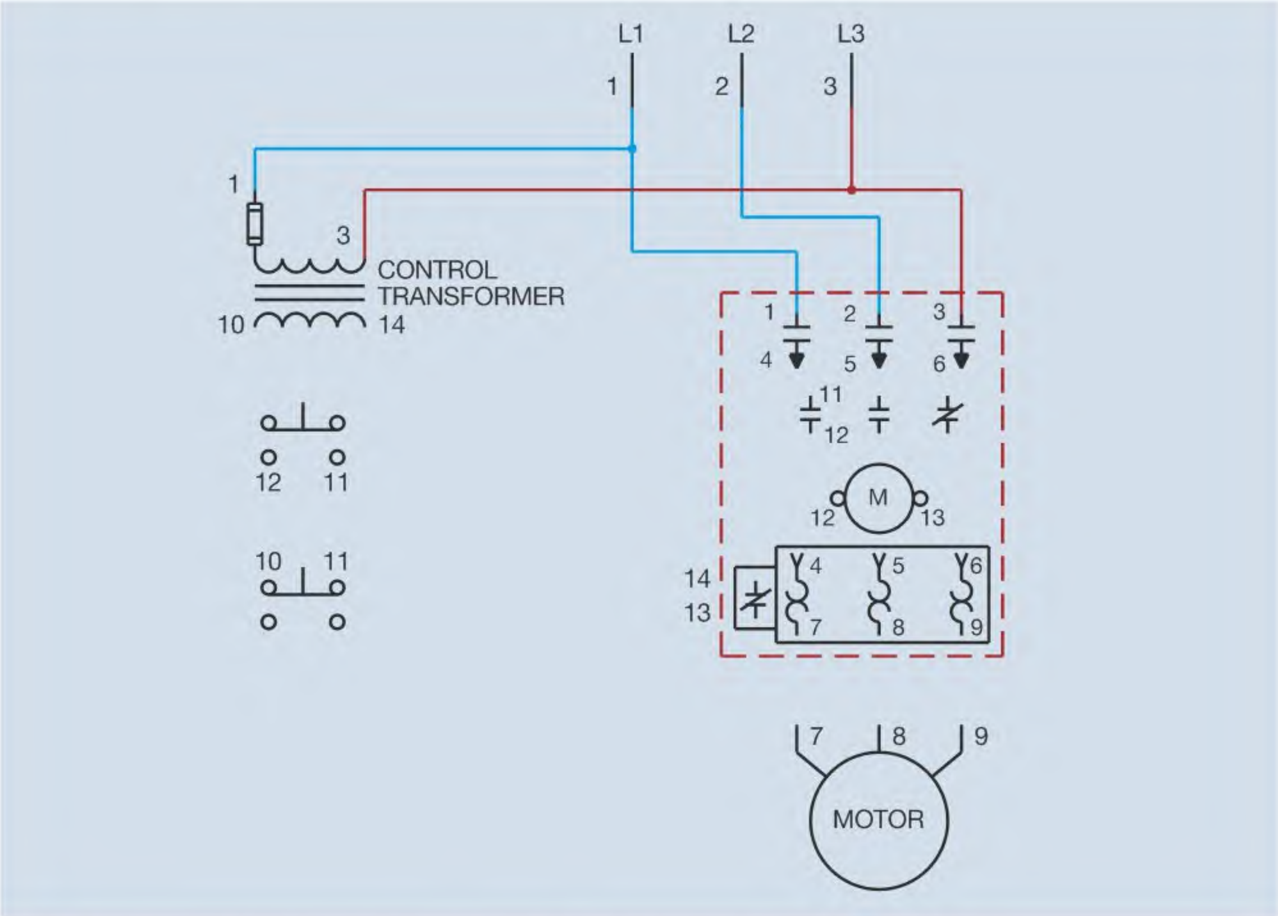


Figure 7–19 All the components with a number 3 are connected together.

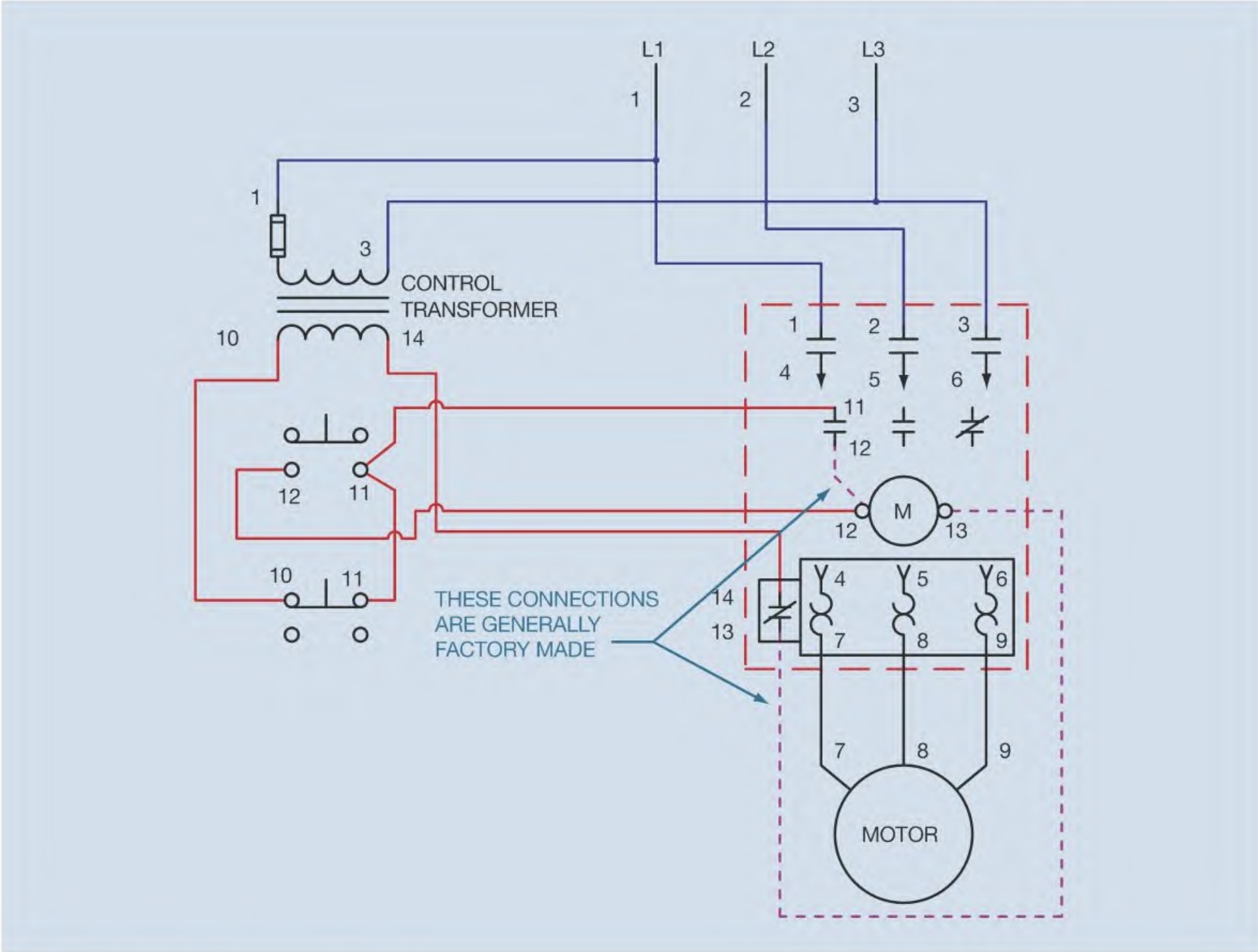


Figure 7–20 Completing the wiring diagram.

Review Questions

1. Refer to the circuit shown in Figure 7–10. If wire number 11 were disconnected at the normally open auxiliary M contact, how would the circuit operate?

2. Assume that when the START button is pressed M starter does not energize. List seven possible causes for this problem.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

   f. ______________________________

   g. ______________________________

3. Explain the difference between a motor starter and a contactor.

4. Refer to the schematic in Figure 7–10. Assume that when the START button is pressed, the control transformer fuse blows. What is the most like cause of this trouble?

5. Explain the difference between load and auxiliary contacts.

6. In a schematic diagram, are the components shown as they should be when the circuit is energized or de-energized?

7. In a schematic diagram, what does a dashed line drawn between two components indicate?

Chapter 8

MULTIPLE PUSH BUTTON STATIONS

Objectives

After studying this chapter the student will be able to:

- Place wire numbers on a schematic diagram.
- Place corresponding numbers on control components.
- Draw a wiring diagram from a schematic diagram.
- Connect a control circuit using two STOP and two START push buttons.
- Discuss how components are to be connected to perform the functions of START or STOP for a control circuit.

There may be times when it is desirable to have more than one START–STOP push button station to control a motor. In this chapter, the basic START–STOP push button control circuit discussed in Chapter 7 will be modified to include a second STOP and START push button.

When a component is used to perform the function of *stop* in a control circuit, it will generally be a normally closed component and be connected in series with the motor starter coil. In this example, a second STOP push button is to be added to an existing START–STOP control circuit. The second push button will be added to the control circuit by connecting it in series with the existing STOP push button (Figure 8–1).

When a component is used to perform the function of *start* it is generally normally open and connected in parallel with the existing START button (Figure 8–2). If either START button is pressed, a circuit will be completed to M coil. When M coil energizes all M contacts change position. The three load contacts connected between the three phase power line and the motor close to connect the motor to the line. The normally open auxiliary contact connected in parallel with the two START buttons close to maintain the circuit to M coil when the START button is released.

Developing a Wiring Diagram

Now that the circuit logic has been developed in the form of a schematic diagram, a wiring diagram will be drawn from the schematic. The components needed to connect this circuit are shown in Figure 8–3. Following the same procedure discussed in Chapter 7, wire numbers will be placed on the schematic diagram (Figure 8–4). After wire numbers are placed on the schematic, corresponding numbers will be placed on the control components (Figure 8–5).

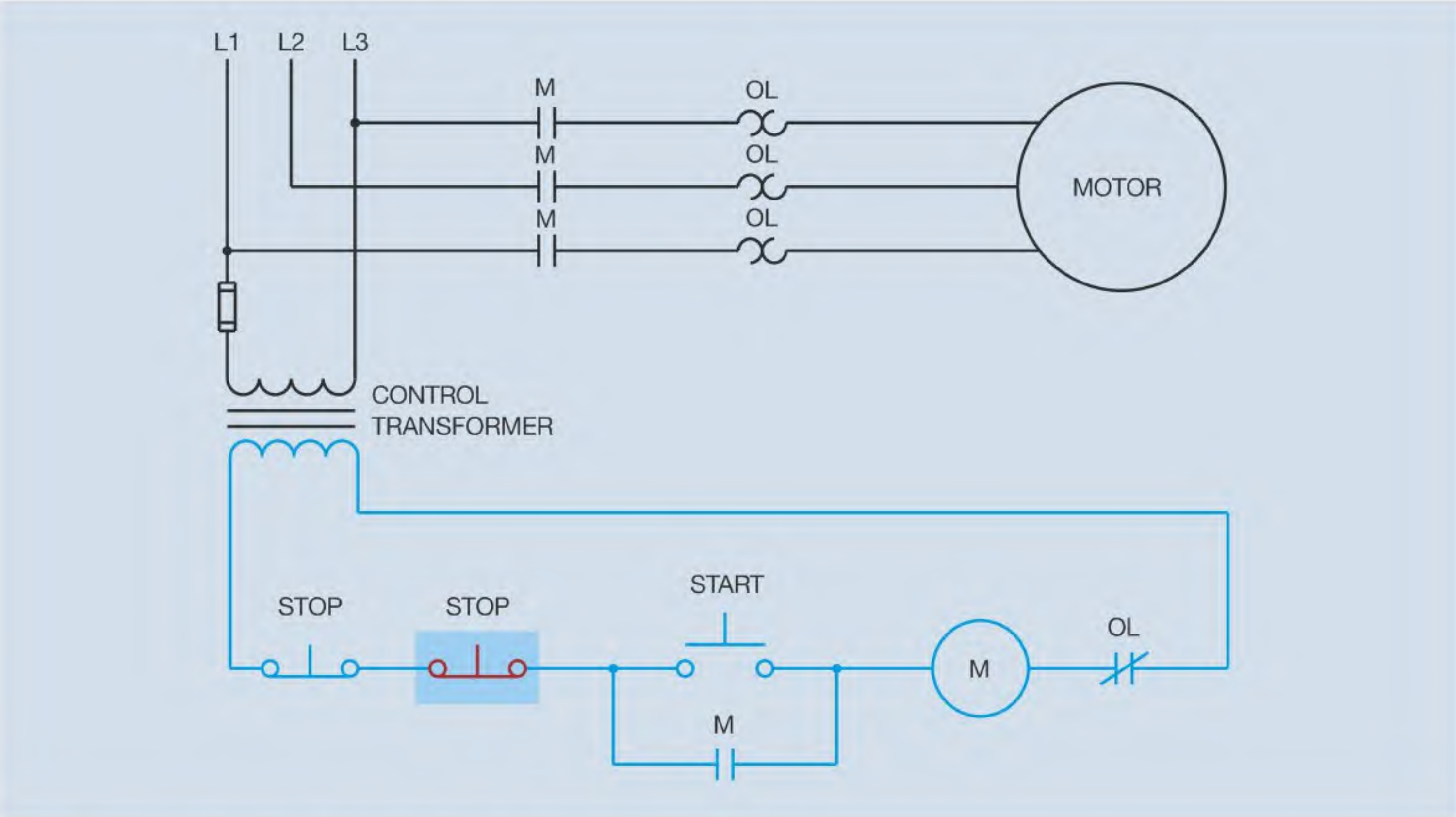


Figure 8–1 Adding a STOP button to the circuit.

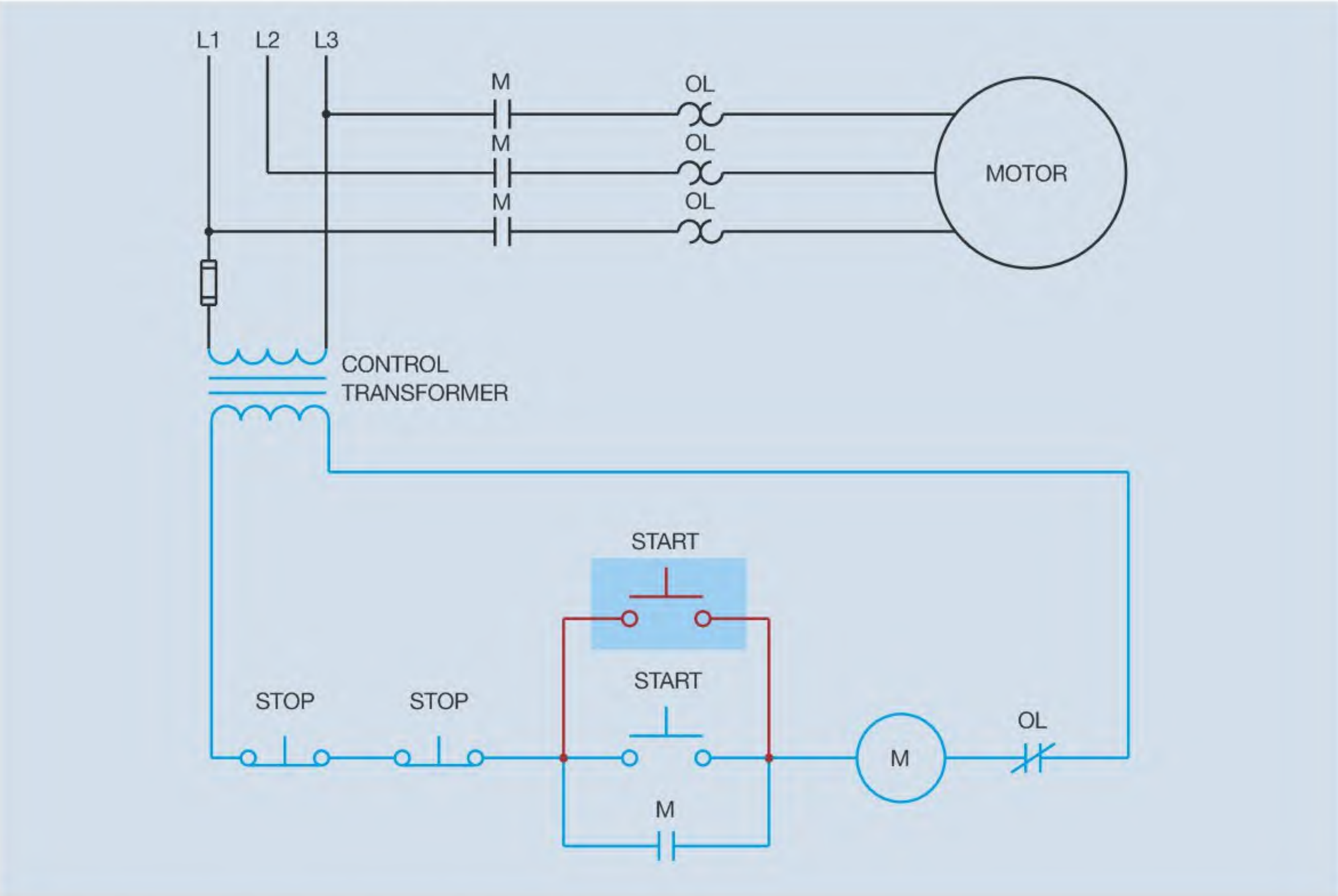


Figure 8–2 A second START button is added to the circuit.

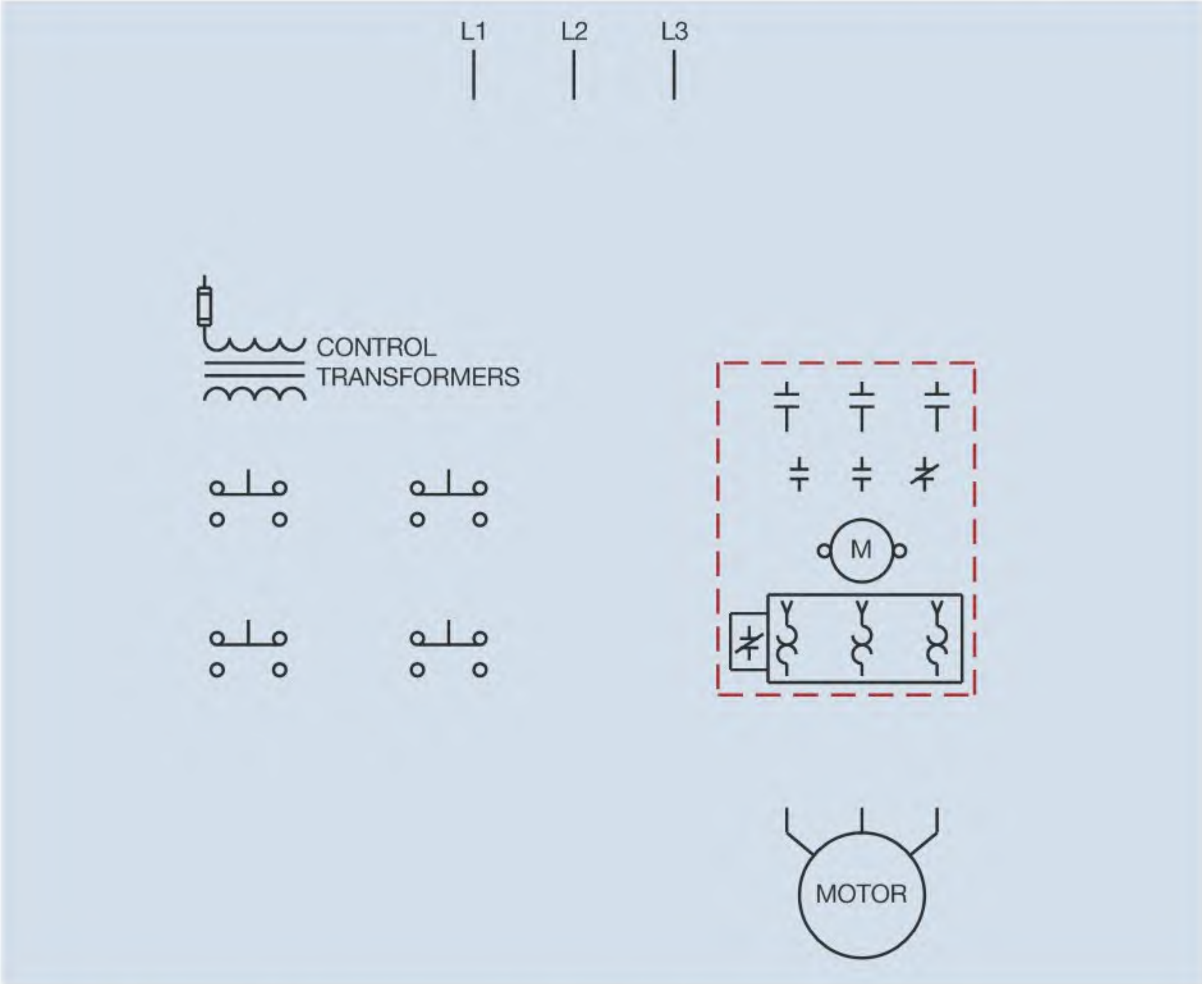


Figure 8–3 Components needed to produce a wiring diagram.

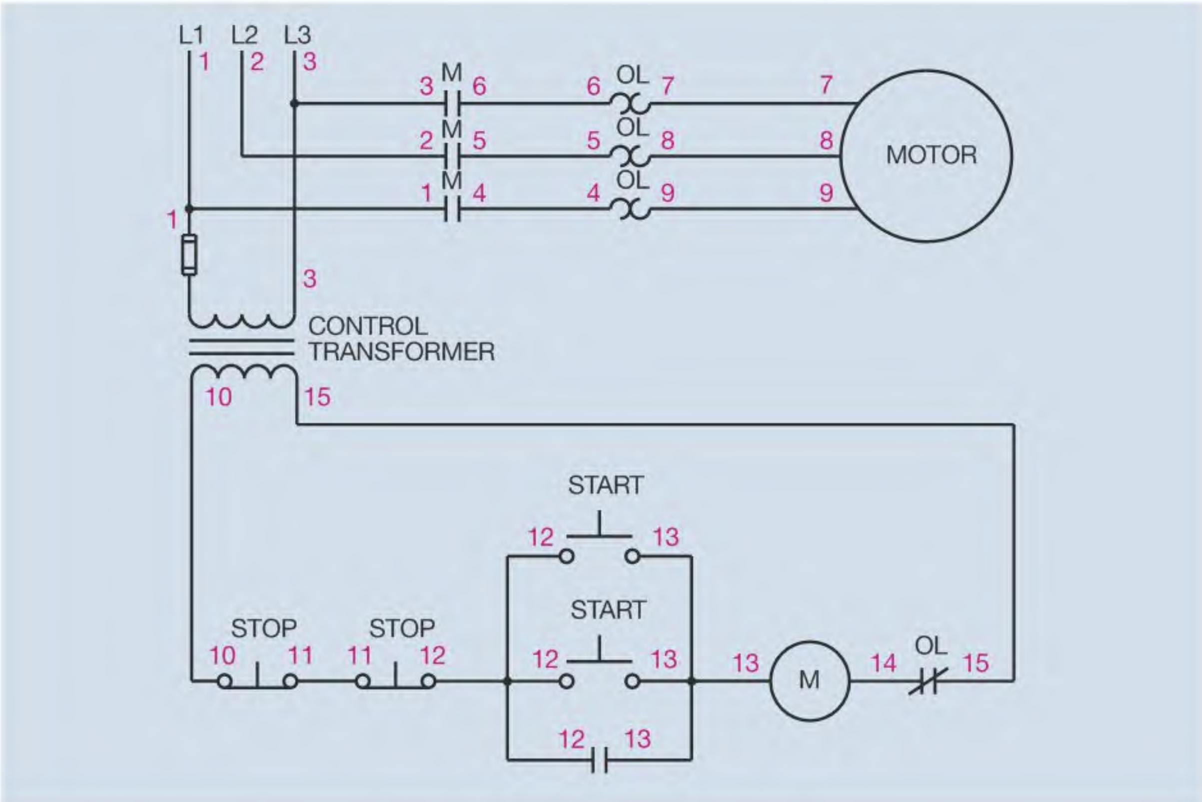


Figure 8–4 Numbering the schematic diagram.

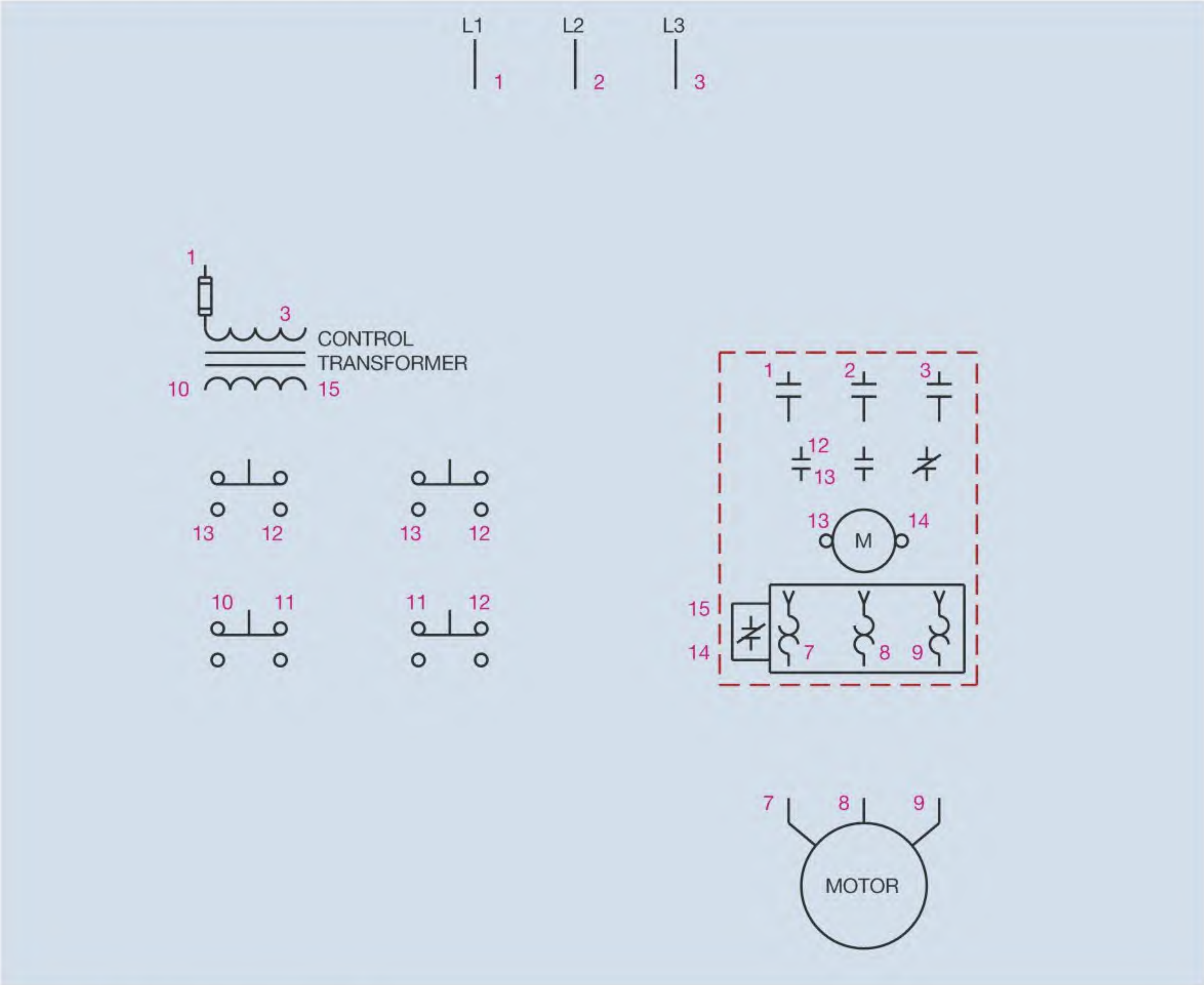


Figure 8–5 Numbering the components.

Review Questions

1. When a component is to be used for the function of start, is the component generally normally open or normally closed?
2. When a component is to be used for the function of stop, is the component generally normally open or normally closed?
3. The two STOP push buttons in Figure 8–2 are connected in series with each other. What would be the action of the circuit if they were to be connected in parallel as shown in Figure 8–6?
4. What would be the action of the circuit if both START buttons were to be connected in series as shown in Figure 8–7?
5. Following the procedure discussed in Chapter 7, place wire numbers on the schematic in Figure 8–7. Place corresponding wire numbers on the components shown in Figure 8–8.

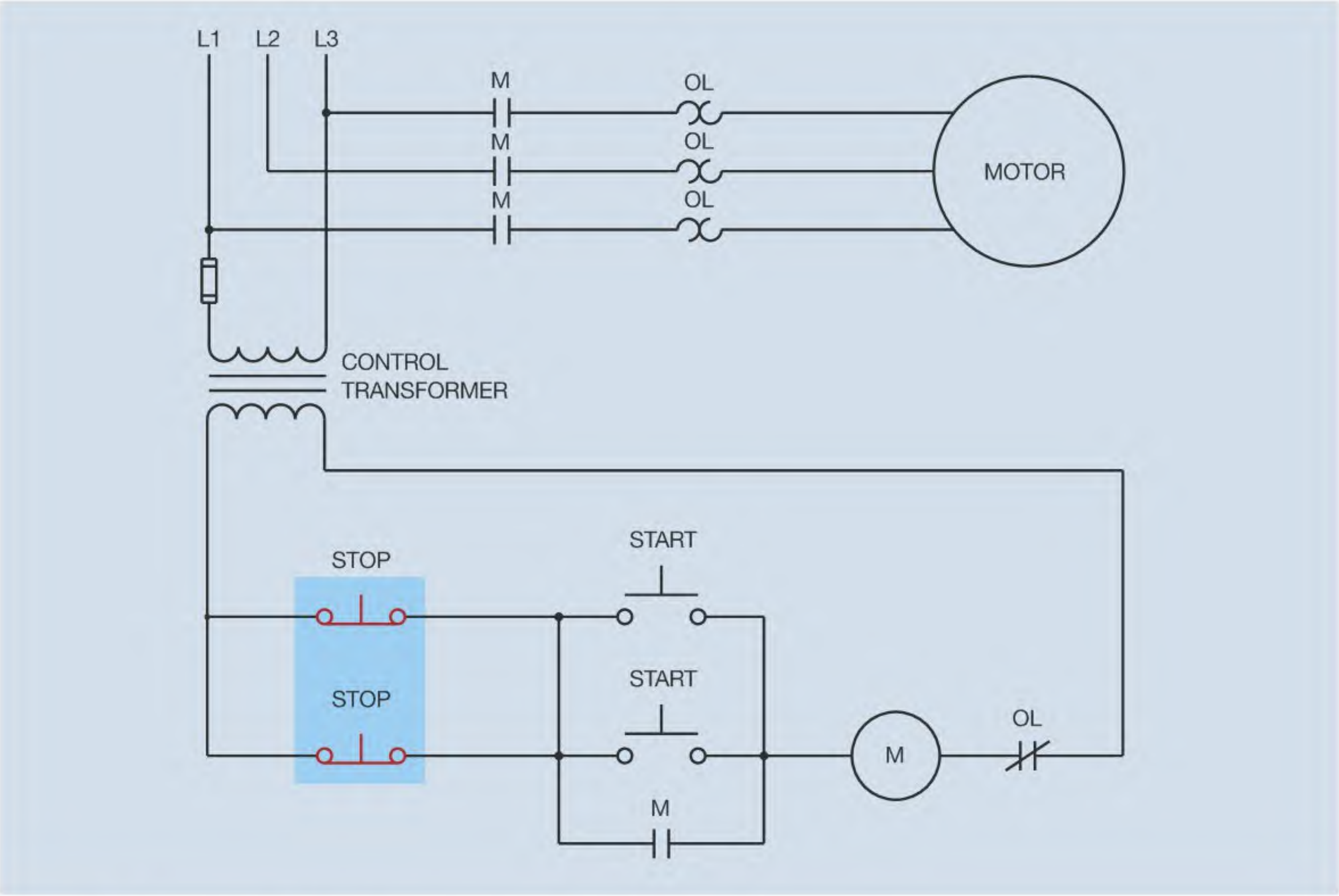


Figure 8–6 The STOP buttons have been connected in parallel.

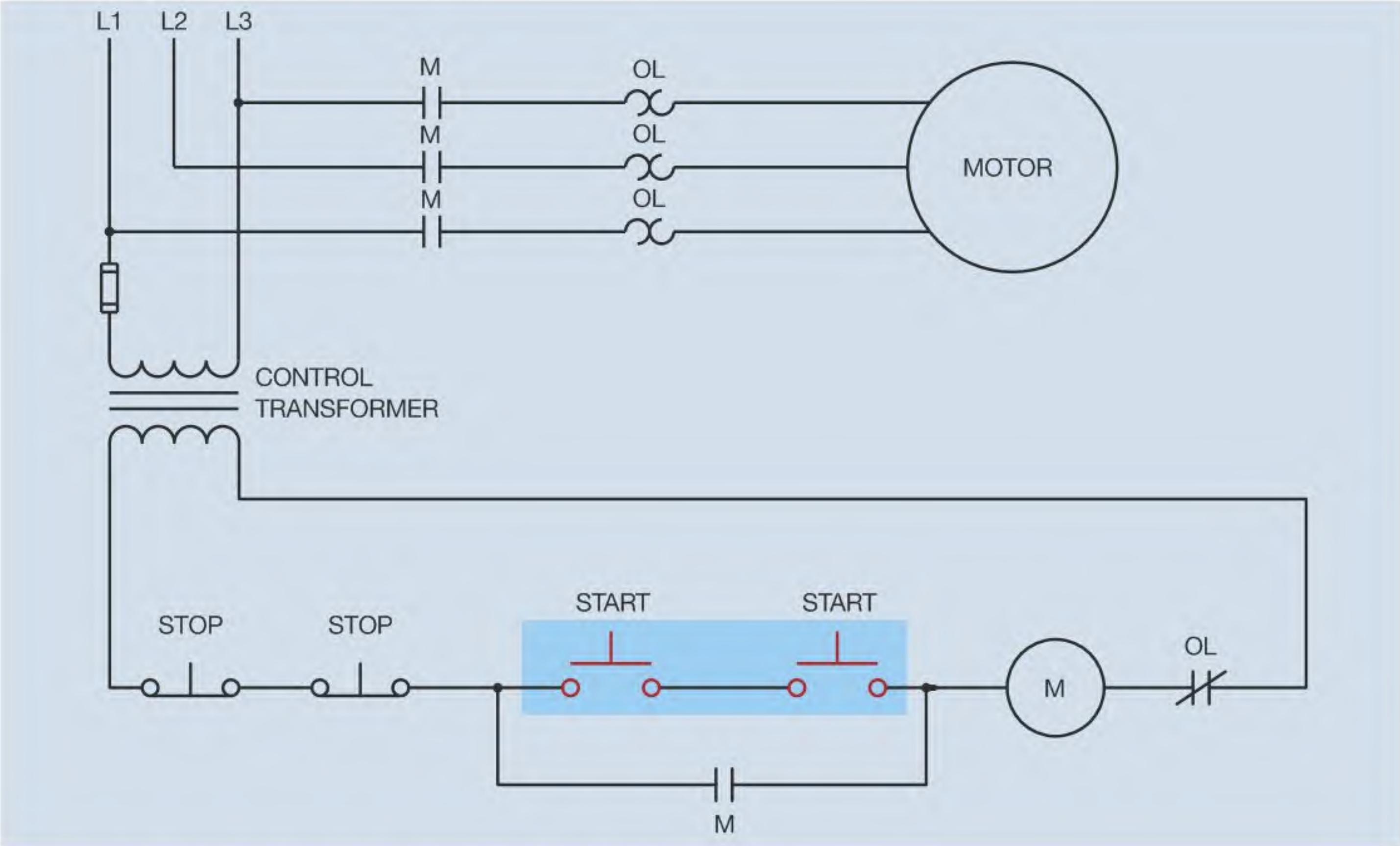


Figure 8–7 The START buttons are connected in series.

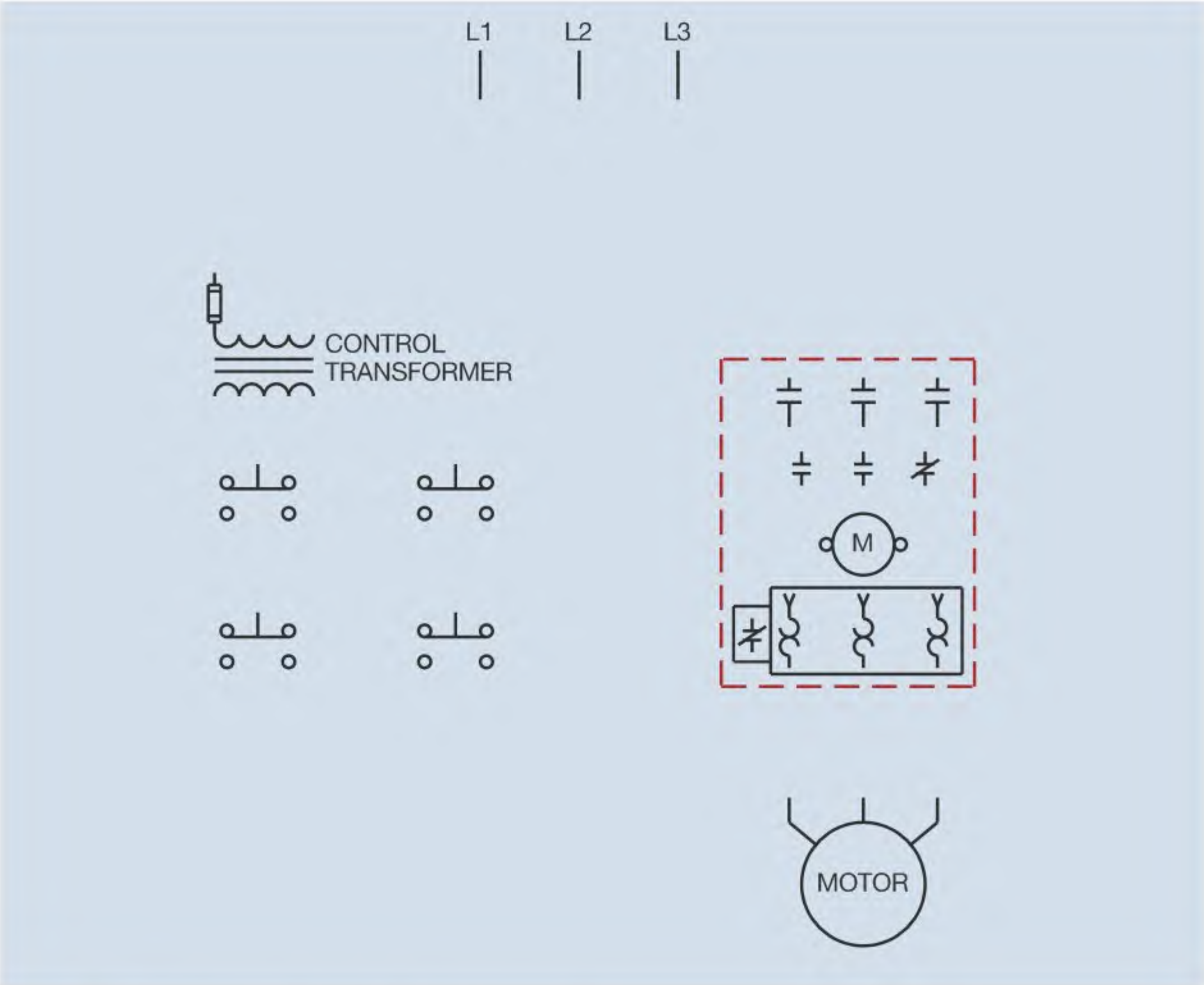


Figure 8–8 Add wire numbers to these components.

Chapter 9

FORWARD–REVERSE CONTROL

Objectives

After studying this chapter the student will be able to:

- Discuss cautions that must be observed in reversing circuits.
- Explain how to reverse a three phase motor.
- Discuss interlocking methods.
- Connect a forward–reverse motor control circuit.

The direction of rotation of any three phase motor can be reversed by changing any two motor T leads (Figure 9–1). Because the motor is connected to the power line regardless of which direction it operates, a separate contactor is needed for each direction. If the reversing starters adhere to NEMA standards, T leads 1 and 3 will be changed (Figure 9–2). Because only one motor is in operation, however, only one overload relay is needed to protect the motor. True reversing controllers contain two separate contactors and one overload relay built into one unit. A vertical reversing starter with overload relay is shown in Figure 9–3, and a horizontal reversing starter without overload relay is shown in Figure 9–4.

Interlocking

Interlocking prevents some action from taking place until some other action has been performed. In the case of reversing starters, interlocking is used to prevent both contactors from being energized at the same time. Having both contactors energized would result in two of the three phase lines being shorted together. Interlocking forces one contactor to be de-energized before the other one can be energized. Three methods can be employed to assure interlocking. Many reversing controls use all three.

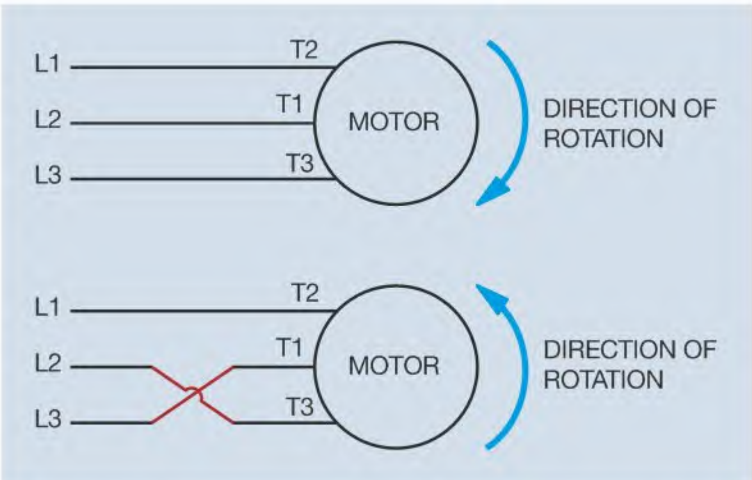


Figure 9–1 The direction of rotation of any three phase motor can be changed by reversing connection to any two motor T leads.

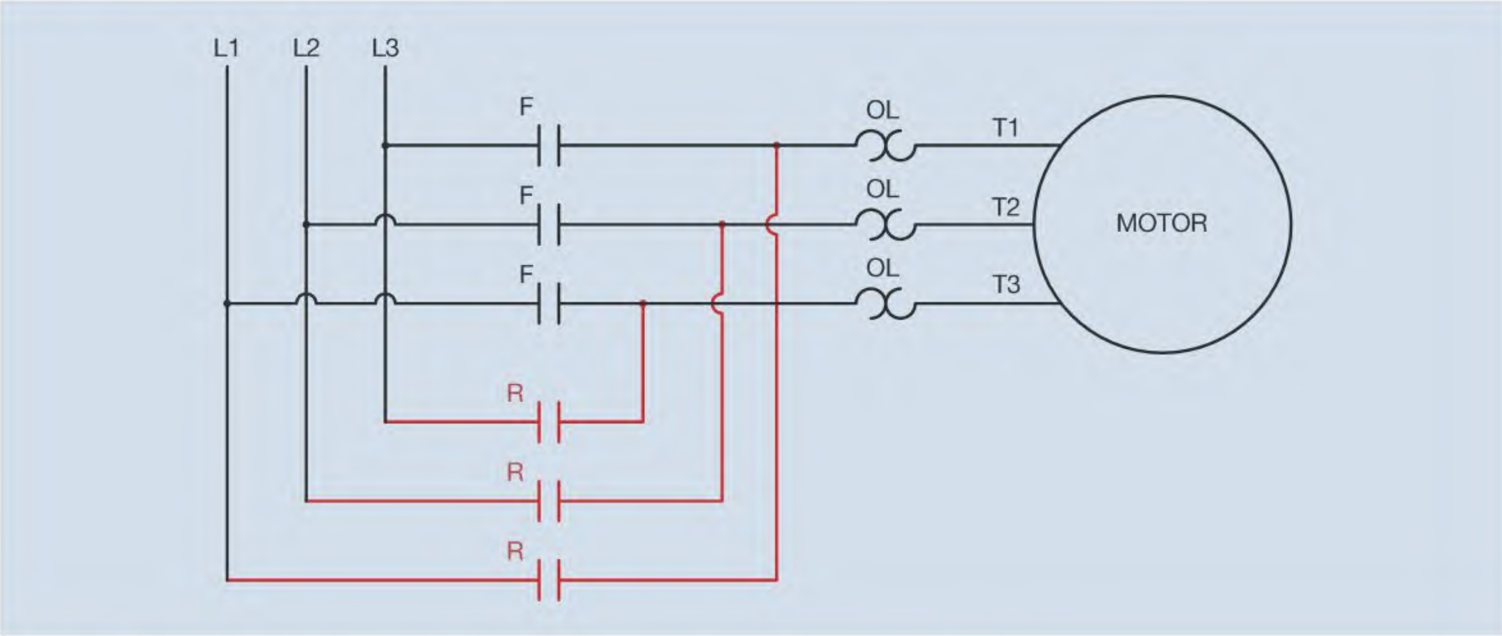


Figure 9–2 Magnetic reversing starters generally change T leads 1 and 3 to reverse the motor.

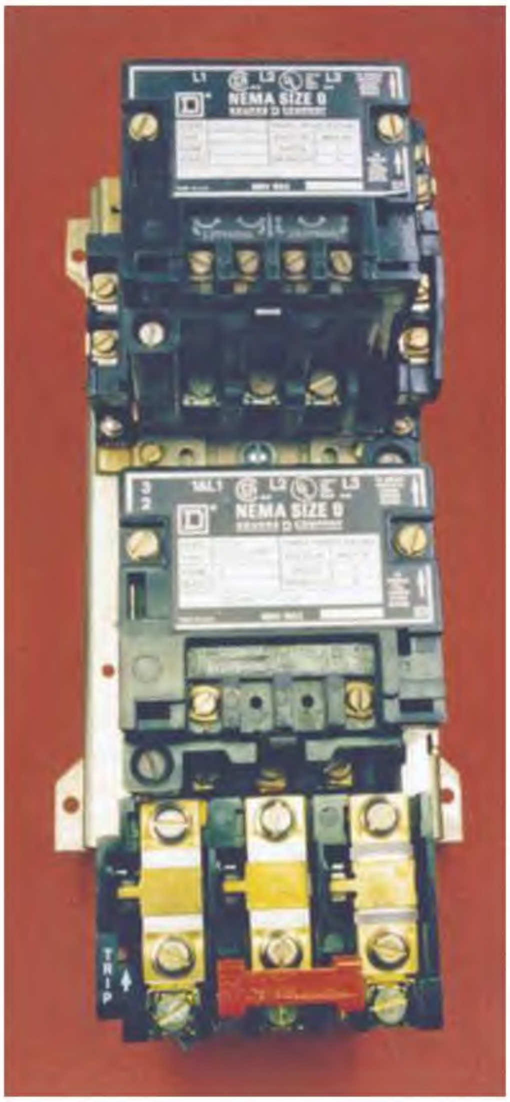


Figure 9–3 Vertical reversing starter with overload relay.

Courtesy Schneider Electric USA, Inc.

Figure 9–4 Horizontal reversing starter without overload relay.

Mechanical Interlocking

Most reversing controllers contain mechanical interlocks as well as electrical interlocks. Mechanical interlocking is accomplished by using the contactors to operate a mechanical lever that prevents the other contactor from closing while one is energized. Mechanical interlocks are supplied by the manufacturer and are built into reversing starters. In a schematic diagram, mechanical interlocks are shown as dashed lines from each coil joining at a solid line (Figure 9–5).

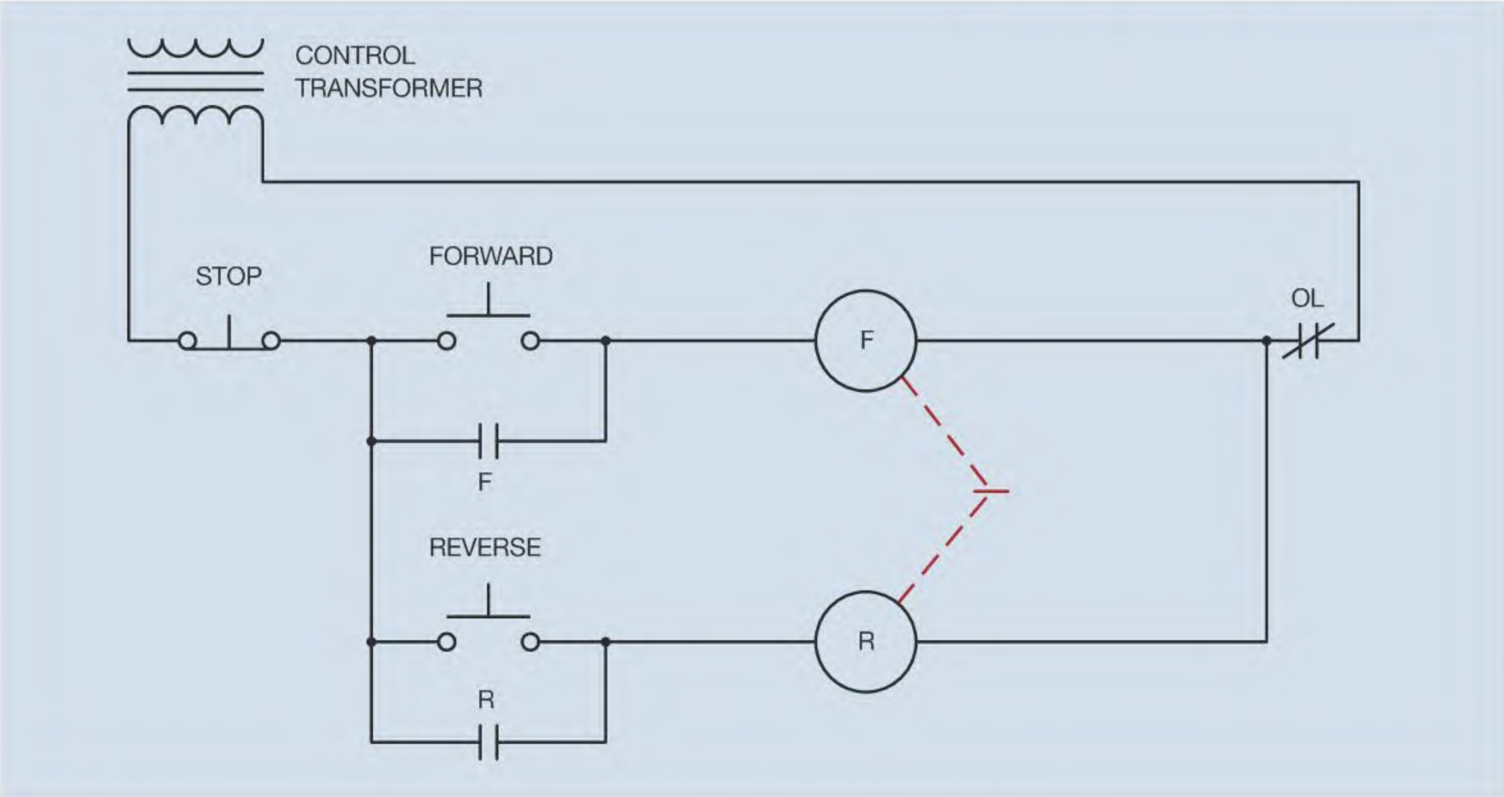


Figure 9–5 Mechanical interlocks are indicated by dashed lines extending from each coil.

Electrical Interlocking

Two methods of electrical interlocking are available. One method is accomplished with the use of double-acting push buttons (Figure 9–6). The dashed lines drawn between the push buttons indicate that they are mechanically connected. Both push buttons will be pushed at the same time. The normally closed part of the forward push button is connected in series with R coil, and the normally closed part of the reverse push button is connected in series with F coil. If the motor is running in the forward direction and the reverse push button is pressed, the normally closed part of the push button opens and disconnects F coil from the line before the normally open part closes to energize R coil. The normally closed section of either push button has the same effect on the circuit as pressing the STOP button.

The second method of electrical interlocking is accomplished by connecting the normally closed auxiliary contacts on one contactor in series with the coil of the other contactor (Figure 9–7). Assume that the forward push button is pressed and F coil energizes. This causes all F contacts to change position. The three F load contacts close and connect the motor to the line. The normally open F auxiliary contact closes to maintain the circuit when the forward push button is released, and the normally closed F auxiliary contact connected in series with R coil opens (Figure 9–8).

If the opposite direction of rotation is desired, the STOP button must be pressed first. If the reverse push button were to be pressed first, the now open F auxiliary contact connected in series with R coil would prevent a complete circuit from being established. Once the STOP button has been pressed, however, F coil de-energizes and all F contacts return to their normal position. The reverse push button can now be pressed to energize R coil (Figure 9–9). When R coil energizes, all R contacts change position. The three R load contacts close and connect the motor to the line. Notice, however, that two of the motor T leads are connected to different lines. The normally closed R auxiliary contact opens to prevent the possibility of F coil being energized until R coil is de-energized.

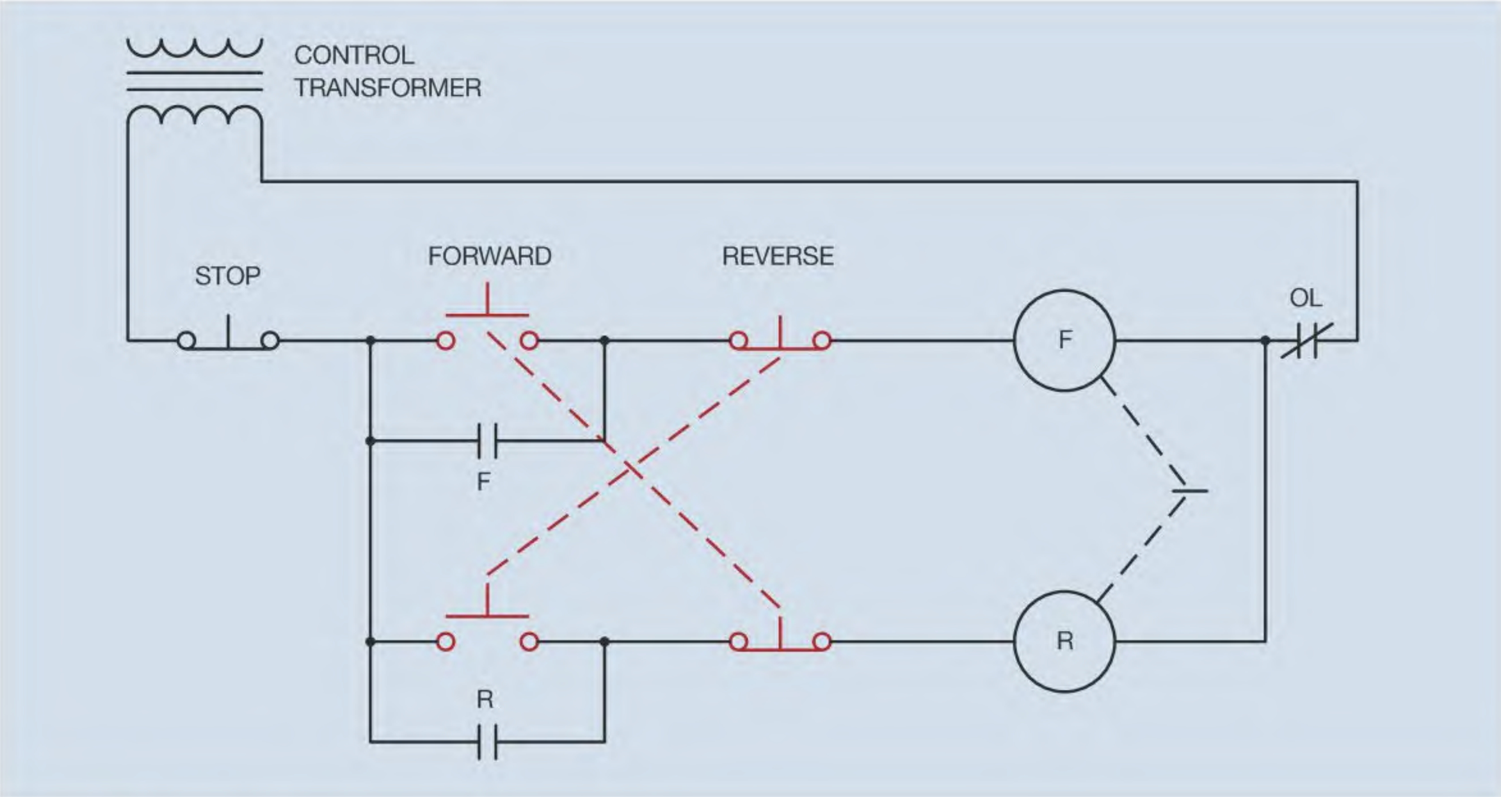


Figure 9–6 Interlocking with double-acting push buttons.

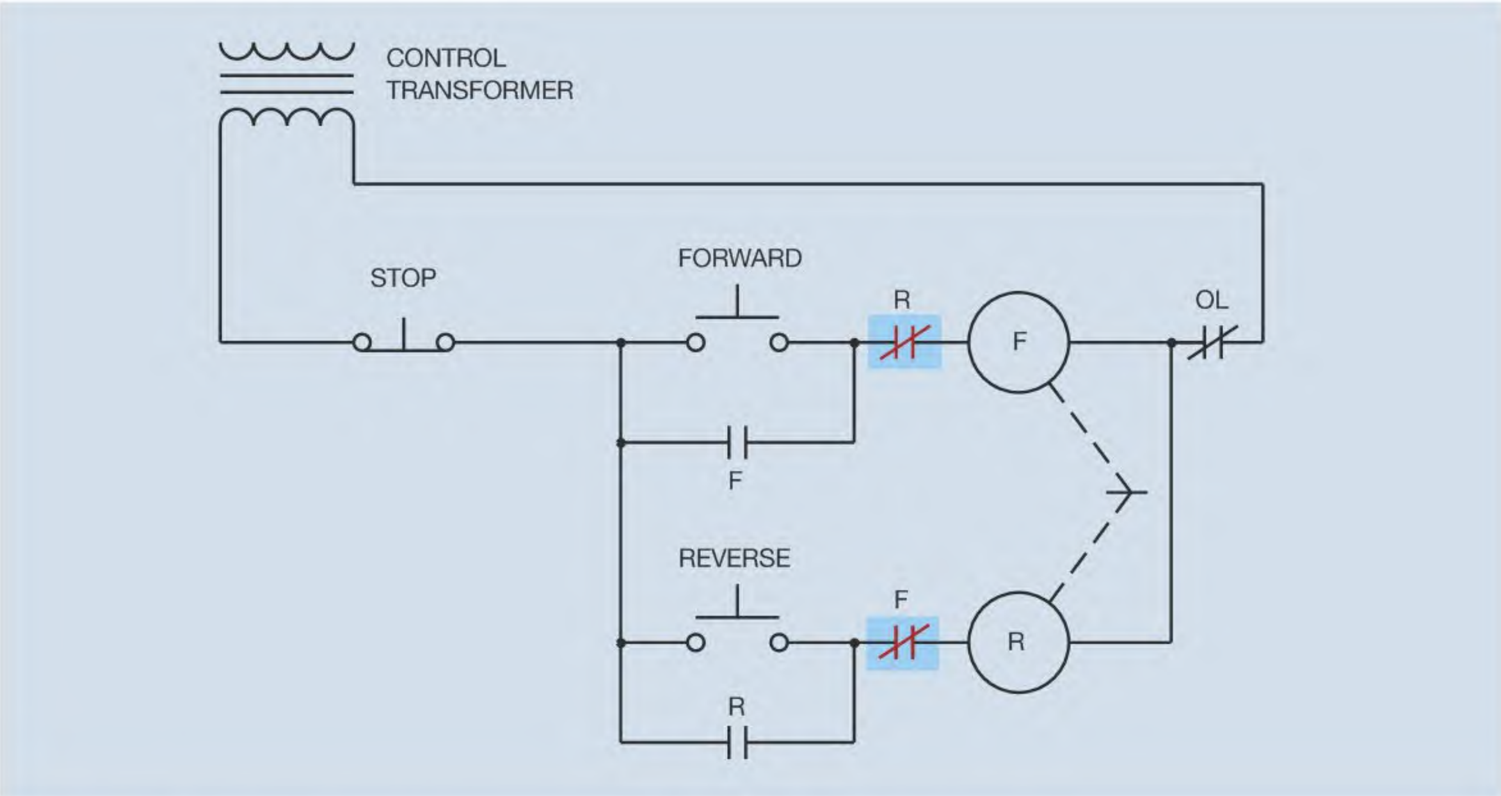


Figure 9–7 Electrical interlocking is also accomplished with normally closed auxiliary contacts.

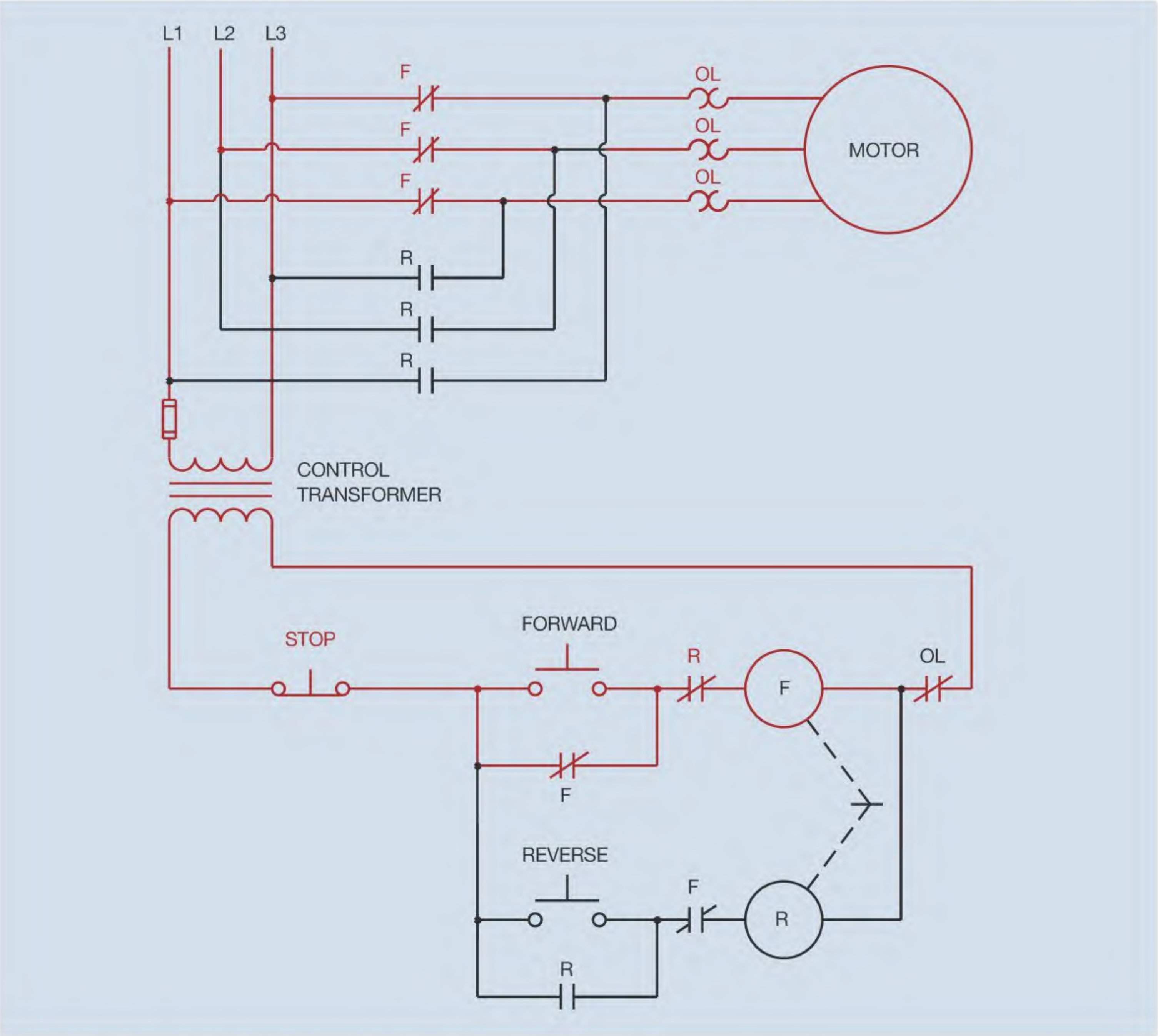


Figure 9–8 Motor operating in the forward direction.

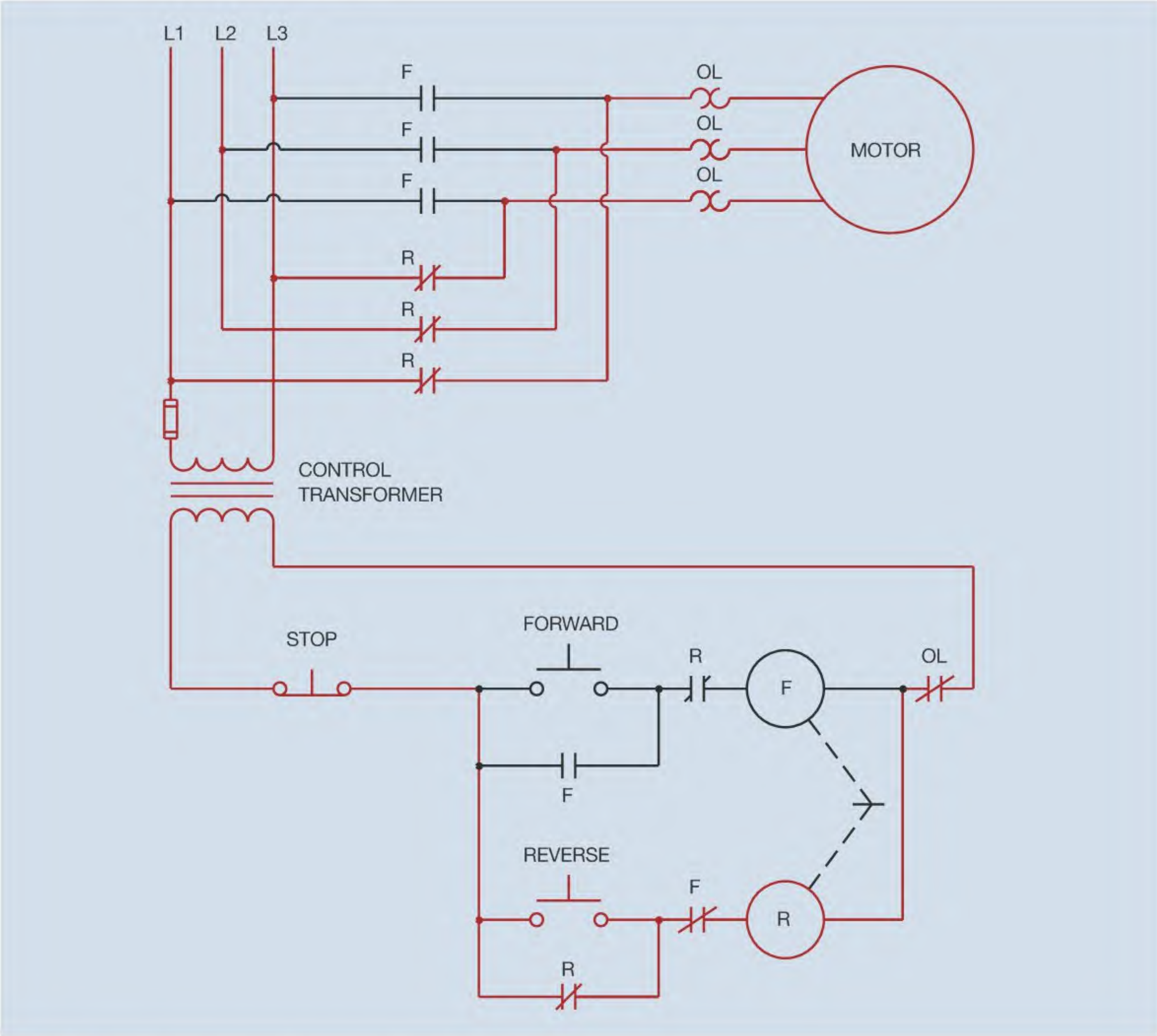


Figure 9–9 Motor operating in the reverse direction.

Developing a Wiring Diagram

The same basic procedure will be used to develop a wiring diagram from the schematic as was followed in the previous chapters. The components needed to construct this circuit are shown in Figure 9–10. In this example it is assumed that two contactors and a separate three phase overload relay will be used.

The first step is to place wire numbers on the schematic diagram. A suggested numbering sequence is shown in Figure 9–11. The next step is to place the wire numbers beside the corresponding components of the wiring diagram as in Figure 9–12. The circuit with connecting wires is shown in Figure 9–13.

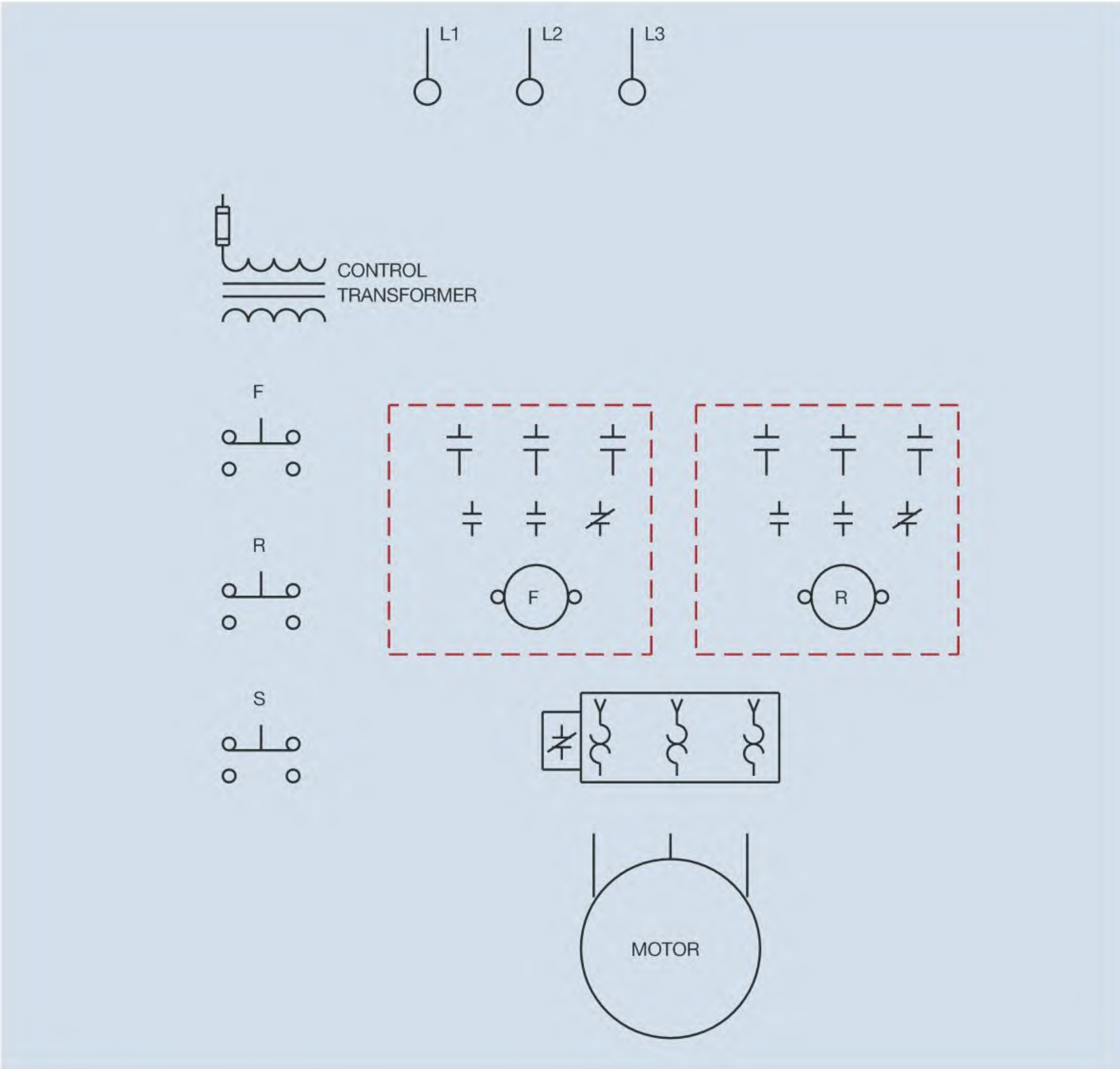


Figure 9–10 Components needed to construct a reversing control.

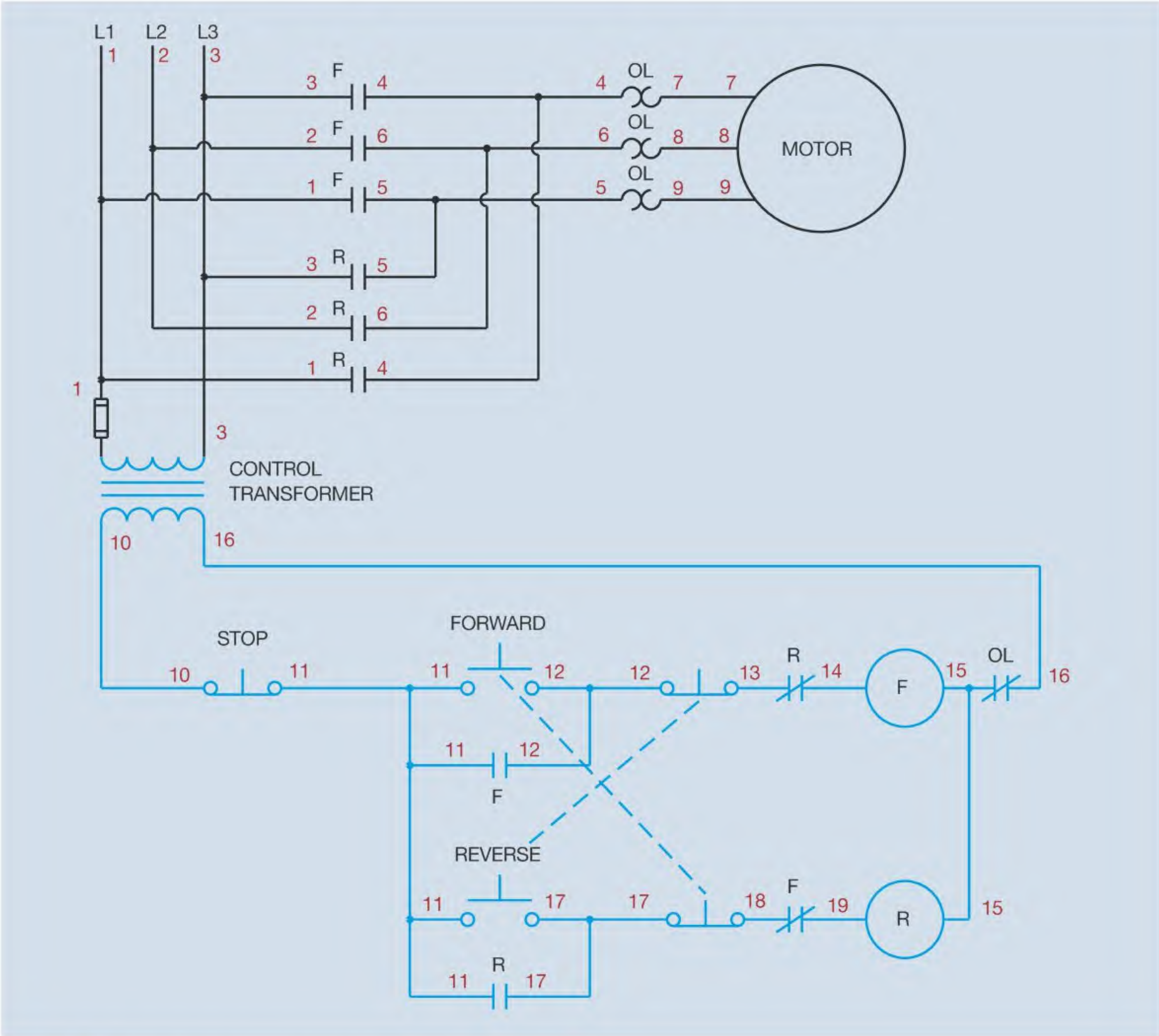


Figure 9–11 Placing numbers on the schematic.

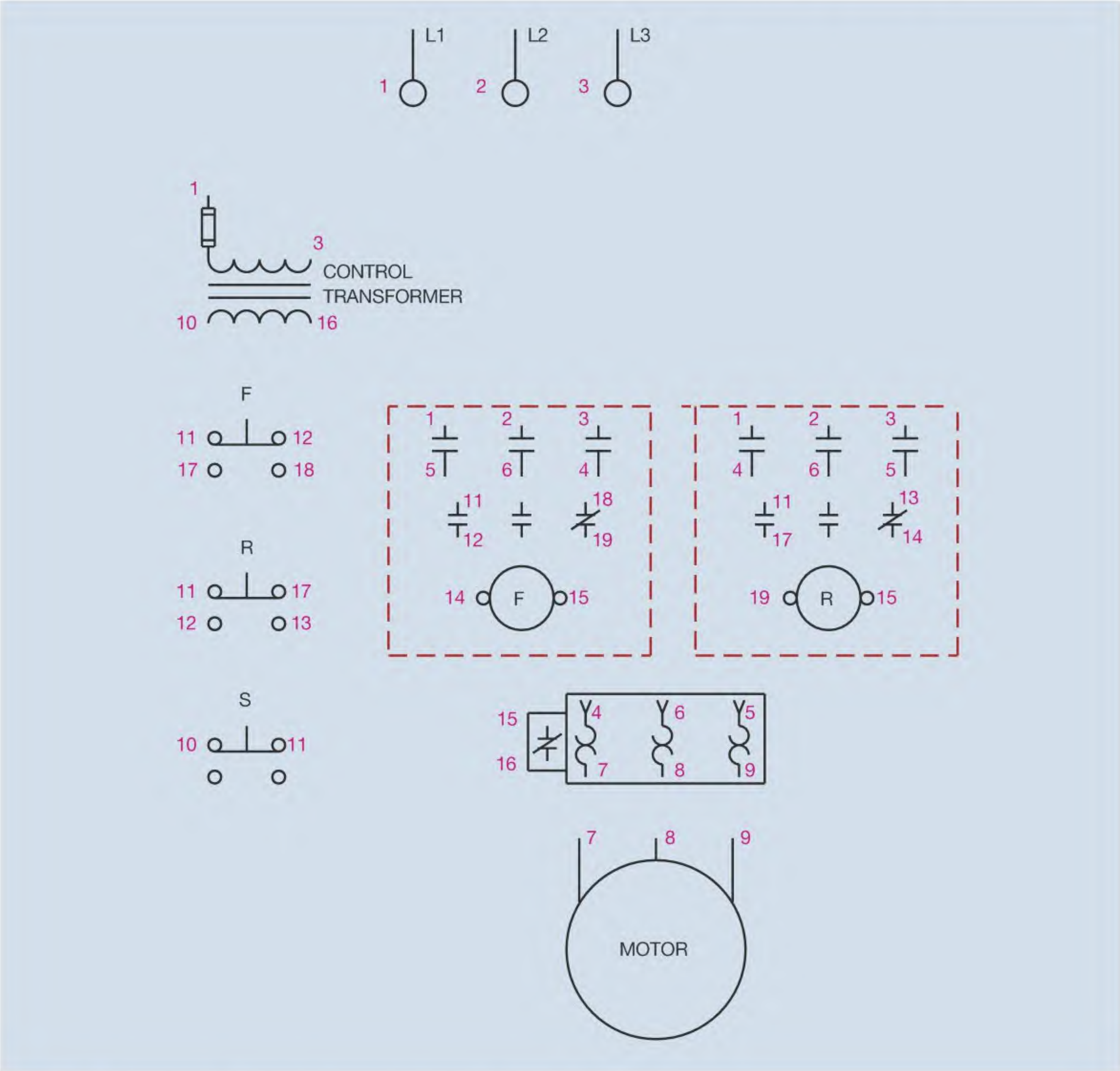


Figure 9–12 Components needed to construct a reversing control circuit.

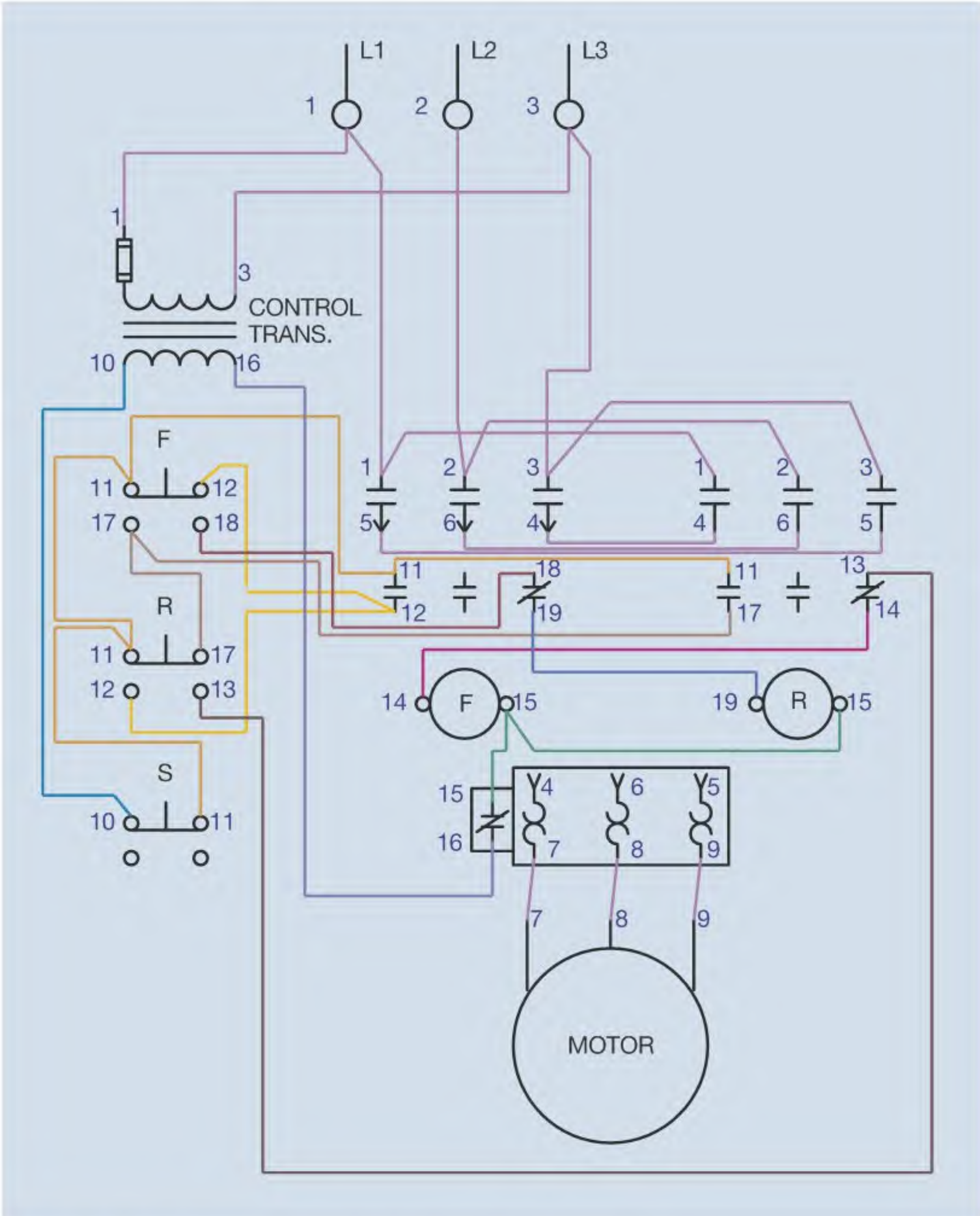


Figure 9–13 Forward–reverse circuit shown with connecting wires.

Review Questions

1. How can the direction of rotation of a three phase motor be changed?
2. What is interlocking?
3. Referring to the schematic shown in Figure 9–7, how would the circuit operate if the normally closed R contact connected in series with F coil were to be connected normally open?
4. What would be the danger, if any, if the circuit were to be wired as stated in question 3?
5. How would the circuit operate if the normally closed auxiliary contacts were to be connected so that F contact was connected in series with F coil and R contact was connected in series with R coil (Figure 9–7)?
6. Assume that the circuit shown in Figure 9–7 were to be connected as shown in Figure 9–14. In what way would the operation of the circuit be different, if at all?

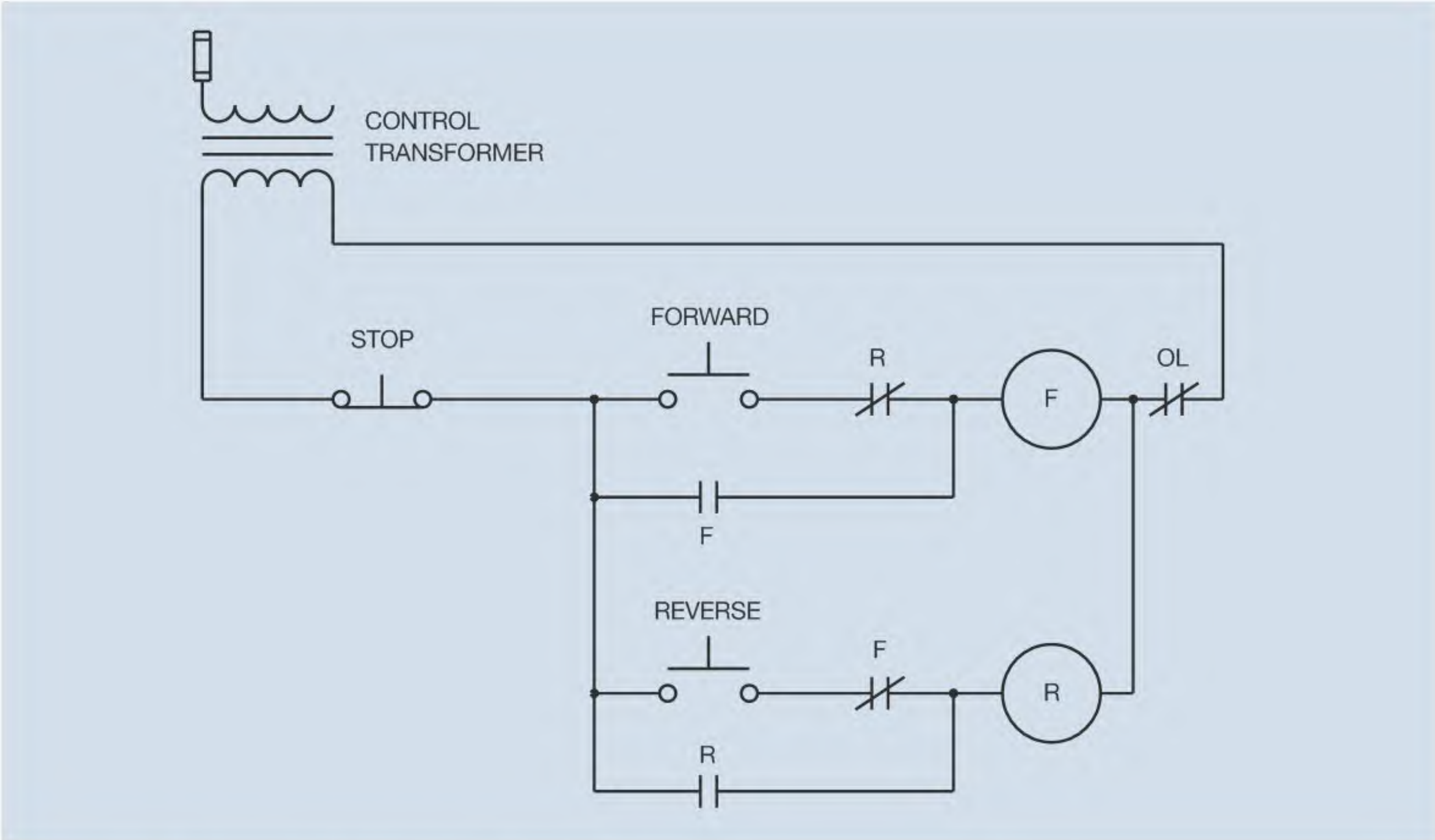


Figure 9–14 The position of the holding contacts has been changed.

Chapter 10

JOGGING AND INCHING

Objectives

After studying this chapter the student will be able to:

- Define the term *jogging*.
- State the purpose of jogging.
- State difference between jogging and inching.
- Describe the operation of a jogging control circuit using control relays.
- Describe the operation of a jogging control circuit using a selector switch.
- Connect a jogging circuit.

The definition of jogging or inching as described by NEMA is *"the quickly repeated closure of a circuit to start a motor from rest for the purpose of accomplishing small movements of the driven machine."* The term *jogging* actually means to start a motor with short jabs of power at full voltage. The term *inching* means to start a motor with short jabs of power at reduced voltage. Although the two terms mean different things, they are often used interchangeably because they are accomplished by preventing a holding circuit.

Jogging Circuits

Various jogging circuits will be presented in this chapter. As with many other types of control circuits, jogging can be accomplished in different ways. Basically, jogging is accomplished by preventing the holding contact from sealing the circuit around the START push button when the motor starter energizes. It should also be noted that jogging circuits require special motor starters rated for jogging duty.

One of the simplest jogging circuits is shown in Figure 10–1. This circuit is basically a START–STOP push button control circuit that has been reconnected so that the START button is in parallel with both the STOP button and holding contact. To jog the motor, simply hold down the STOP button and jog the circuit by pressing the START button. To run the motor, release the STOP button and press the START button. If the motor is in operation, the STOP button breaks the circuit to the holding contact and de-energizes M coil.

Double-Acting Push Buttons

Jogging can also be accomplished using a double-acting push button. Two circuits of that type are shown in Figure 10–2. The normally closed section of the jog push button is connected in such a manner that when the button is pushed, it will defeat the holding contact and prevent it from sealing the circuit. The normally open section of the jog button completes a circuit to energize the coil of the motor starter. When the button is released, the normally open section breaks the circuit to M coil before the normally closed section reconnects to the circuit. This permits the starter to reopen the holding contacts before the normally closed section of the jog button reconnects. Although this circuit is sometimes used for jogging, it does have a severe problem. The action of either of these two circuits depends on the normally open M auxiliary contact (holding contact) used to seal the circuit being open before the normally closed section of the jog button makes connection. Because push buttons employ a spring to return the contacts to their normal position, if a person's finger slips off the jog button, it is possible for the spring to reestablish connection with the normally closed contacts before the holding

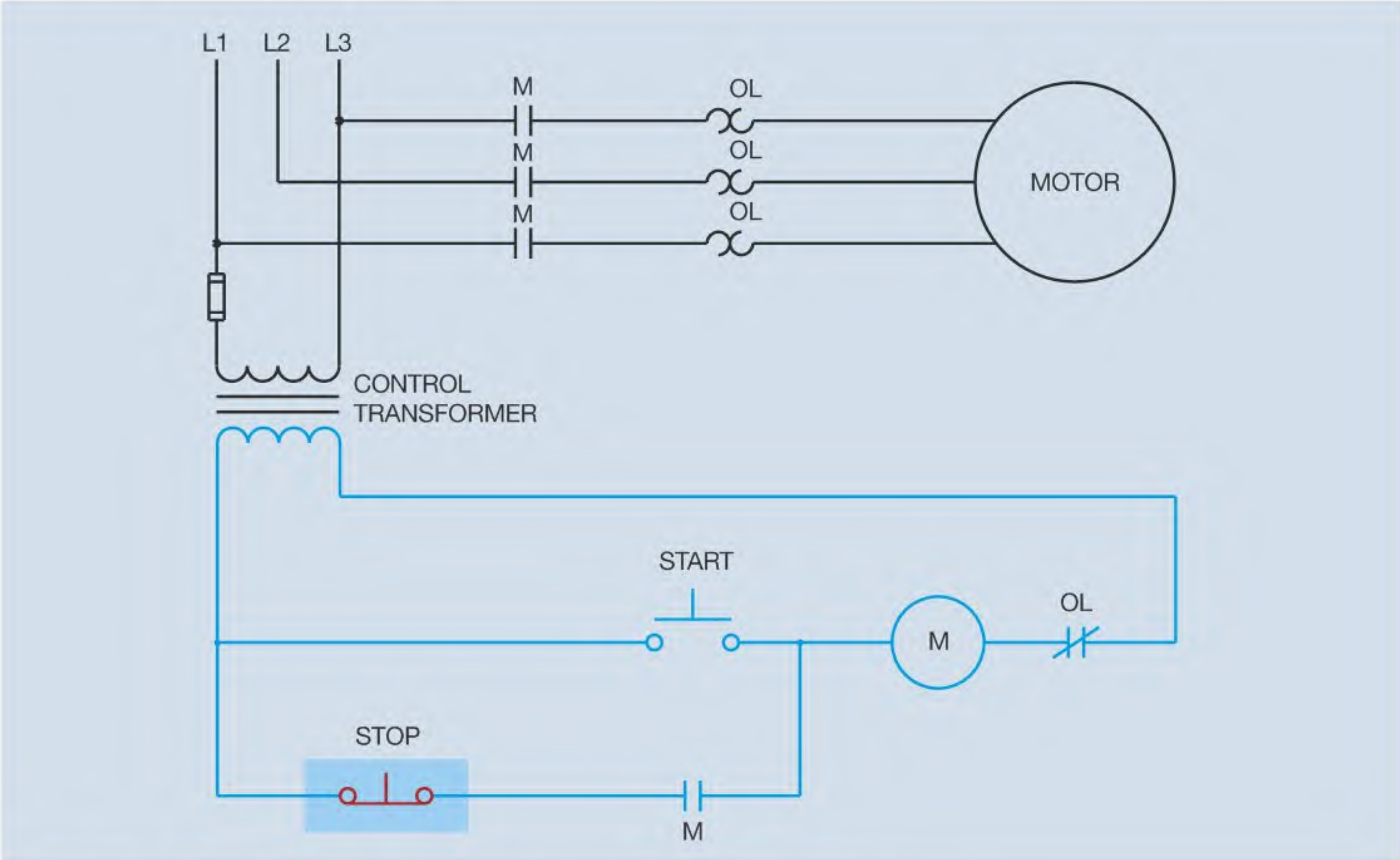


Figure 10–1 The STOP button prevents the holding contact from sealing the circuit.

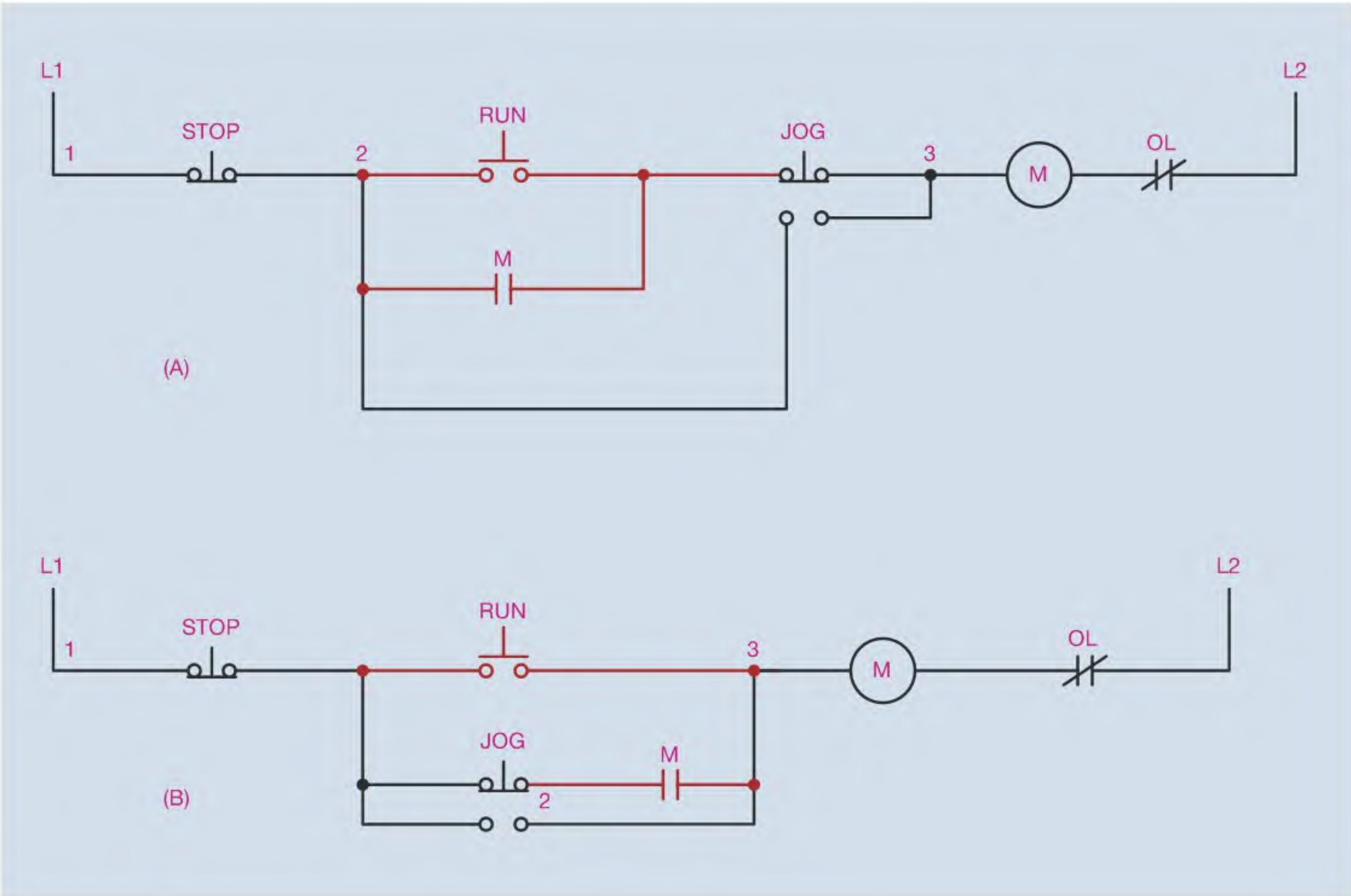


Figure 10–2 Double-acting push buttons are used to provide jogging control.

contact has time to reopen. This would cause the motor to continue running instead of stopping. In some cases, this could become a significant safety hazard.

Using a Control Relay

The addition of a control relay to the jog circuit eliminates the problem of the holding contacts making connection before the normally closed section of the jog push button makes connection. Two circuits that employ a control relay to provide jogging are shown in Figure 10–3. In both of these circuits, the control relay provides the auxiliary holding contacts, not the M starter. The jog push button energizes the coil of M motor starter, but does not energize the coil of control relay CR. The START push button is used to energize the coil of CR relay. When energized, CR relay contacts provide connection to M coil. The use of control relays in a jogging circuit is very popular because of the simplicity and safety offered.

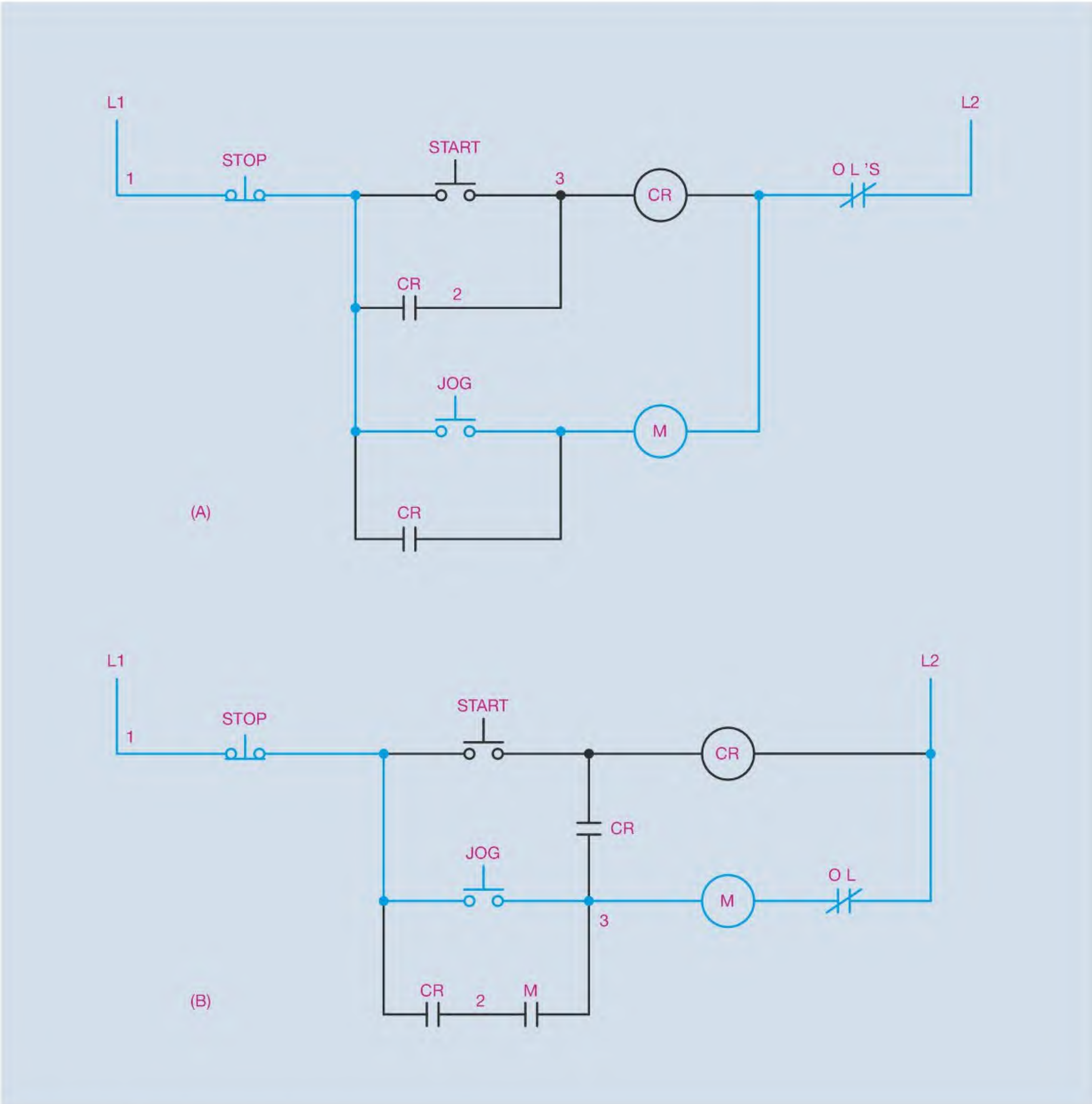


Figure 10–3 Control relays provide jogging control.

A jogging circuit for a forward–reverse control is shown in Figure 10–4. Note that a control relay is used to provide jogging in either direction. When the forward jog push button is pressed, the normally open section makes connection and provides power to F coil. This causes F load contacts to close and connect the motor to the power line. The normally open F auxiliary contact closes, also, but the normally closed section of the forward jog button is now open, preventing coil CR from being energized. Because CR contact remains open, the circuit to F coil cannot be sealed by the normally open F auxiliary contact.

If the forward START button is pressed, a circuit is completed to F coil causing all F contacts to change position. The normally open F auxiliary contact closes and provides a path through the normally closed section

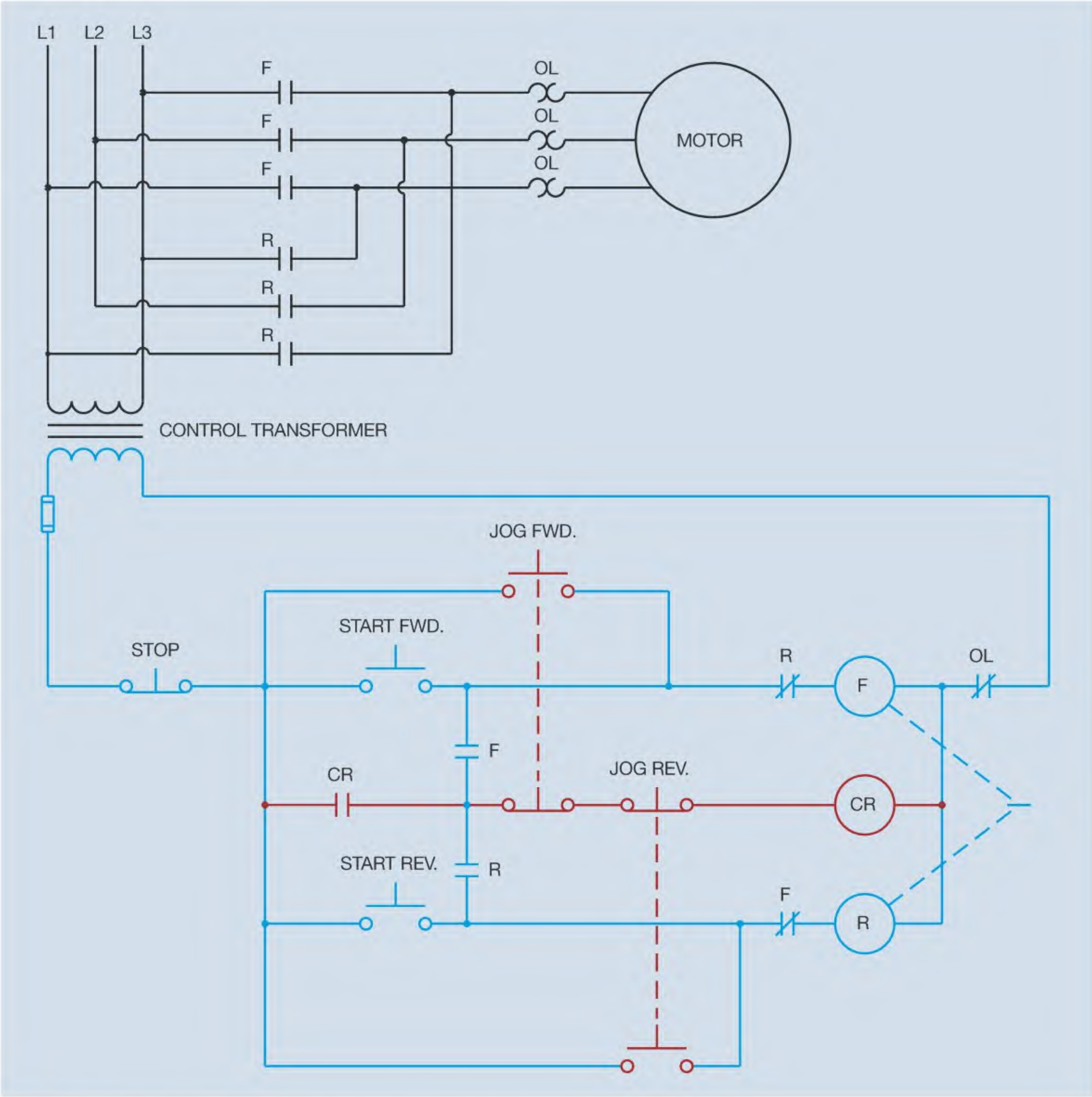


Figure 10–4 Jogging using a control relay on a forward–reverse control.

of both jog buttons to CR coil. This causes CR auxiliary contact to close and provide a current path through the now closed F auxiliary contact to F coil, sealing the circuit when the forward push button is released. The reverse jog button and reverse START button operate the same way. Note also that normally closed F and R auxiliary contacts are used to provide interlocking for the forward–reverse control.

Jogging Controlled by a Selector Switch

Another method of obtaining jogging control is with the use of a selector switch. The switch is used to break the connection to the holding contacts (Figure 10–5). In this circuit a single pole, single throw toggle switch is used. When the switch is in the ON position, connection is made to the holding contacts. If the switch is in the OFF position the holding contacts cannot seal the circuit when the START button is released. Note that the START button acts as both the START and jog button for this circuit. A selector switch can be used to provide the same basic type control (Figure 10–6).

Inching Controls

As stated previously, jogging and inching are very similar in that both are accomplished by providing short jabs of power to a motor to help position certain pieces

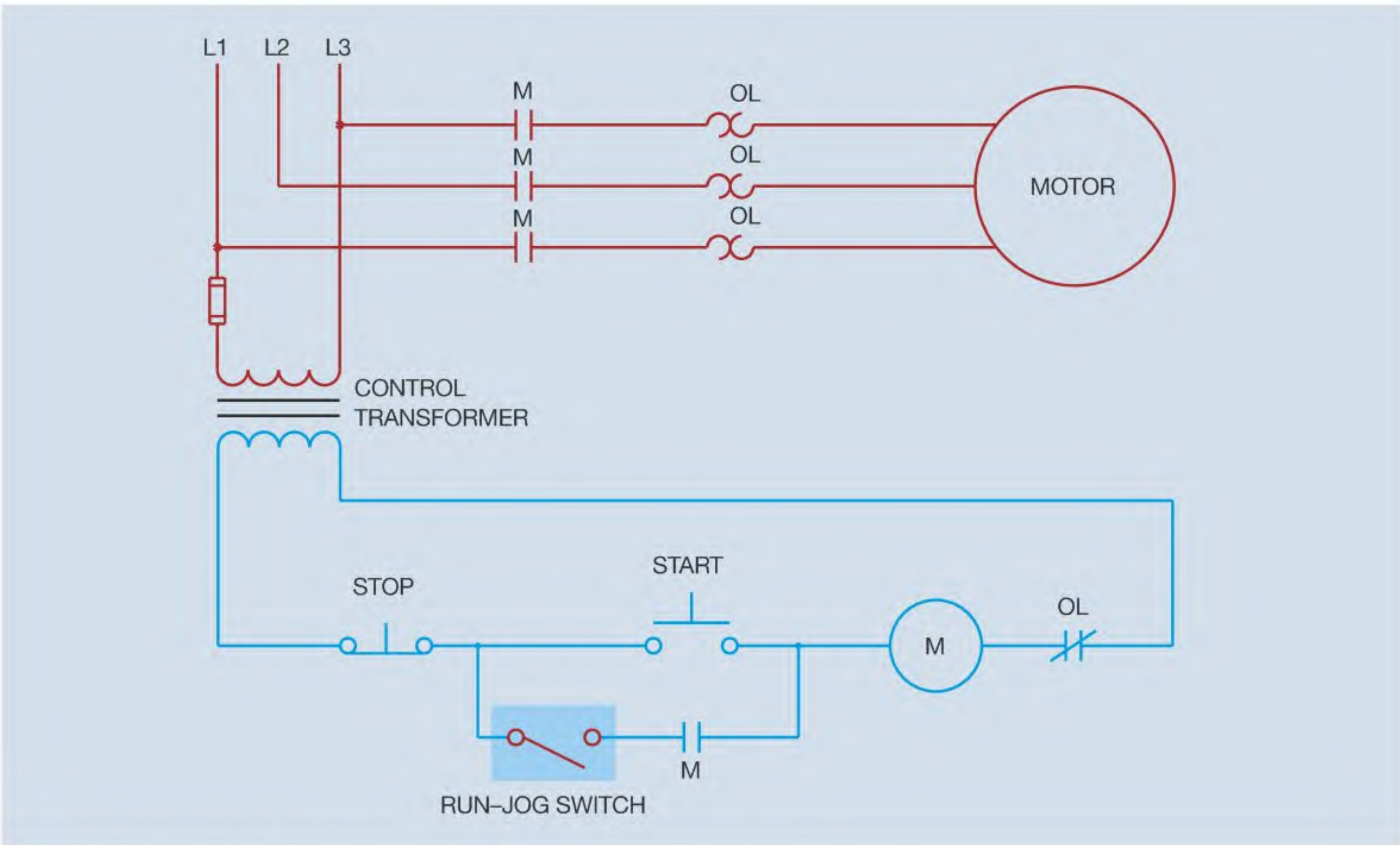


Figure 10–5 A single pole, single throw toggle switch provides jog or run control.

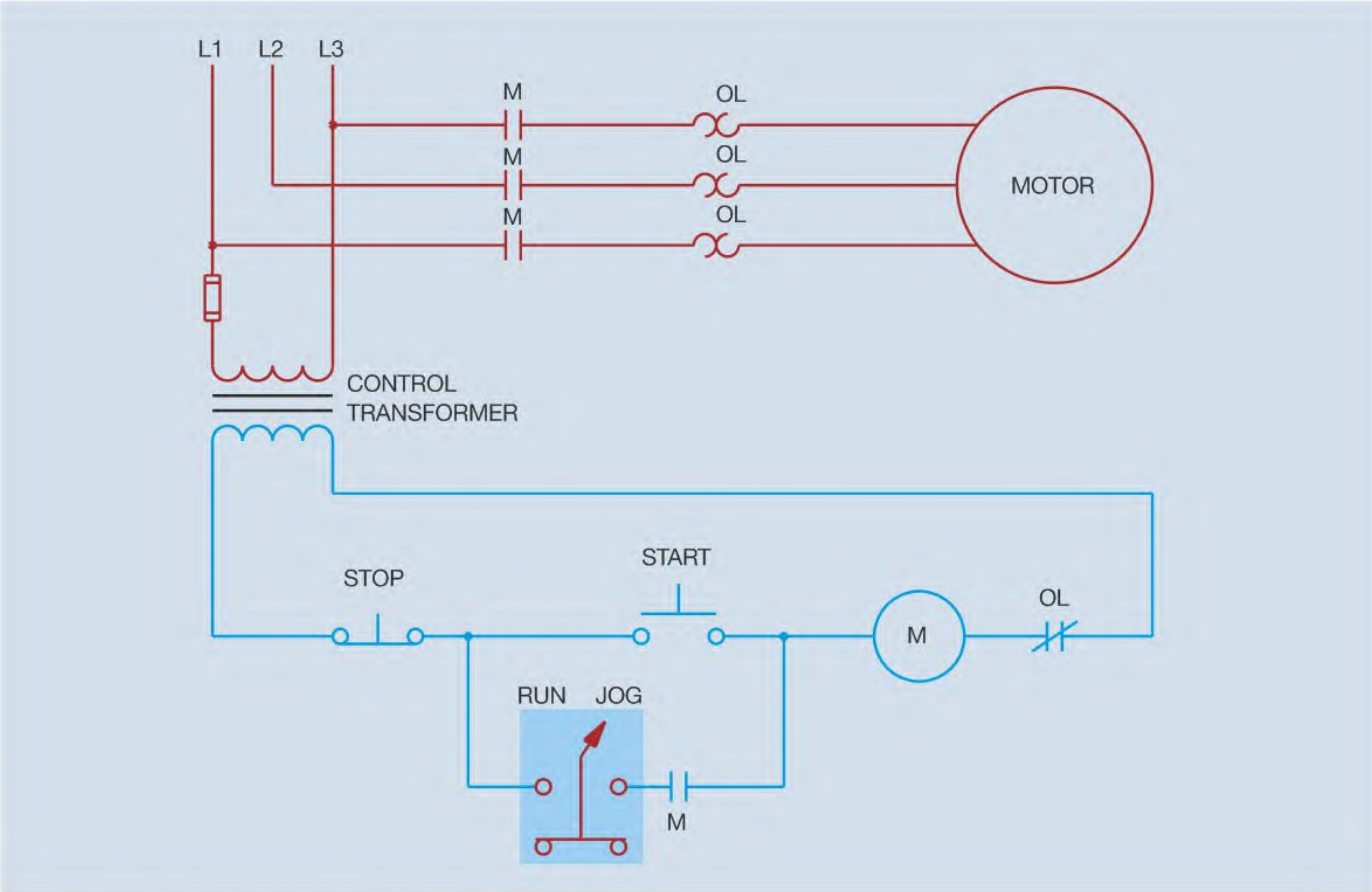


Figure 10–6 A selector switch provides run–jog control.

of machinery. Inching, however, is accomplished by providing a reduced amount of power to the motor. Transformers can be used to reduce the amount of voltage applied to the motor during inching, or reactors or resistors can be connected in series with the motor to reduce the current supplied by the power line. In the circuit shown in Figure 10–7, resistors are connected in series with the motor during inching. Notice that inching control requires the use of a separate contactor because the power supplied to the motor must be separate from full line voltage.

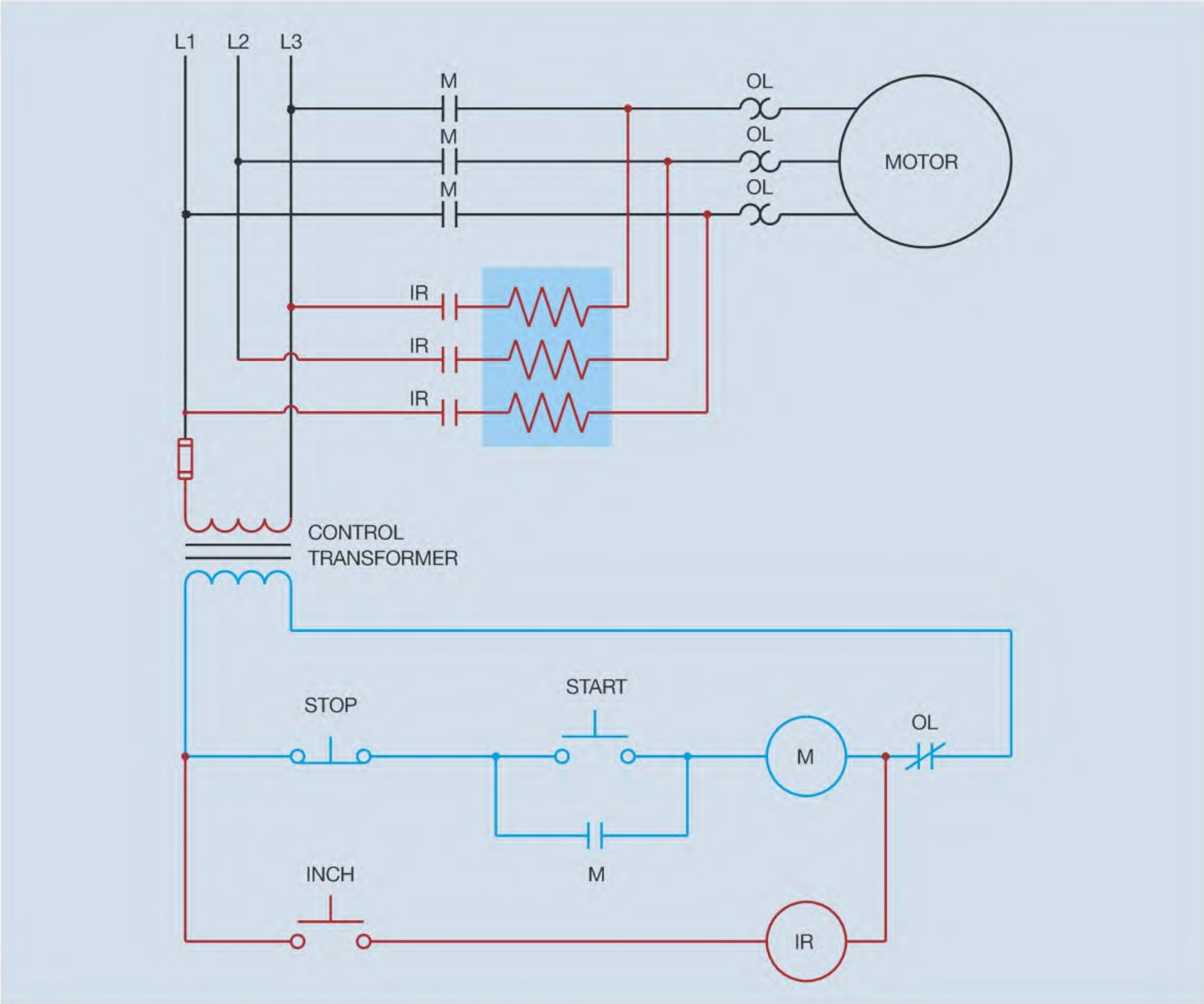


Figure 10–7 Resistors are used to reduce power to the motor.

Review Questions

1. Explain the difference between inching and jogging.
2. What is the main purpose of jogging?
3. Refer to the circuit shown in Figure 10–8. In this circuit, the jog button has been connected incorrectly. The normally closed section has been connected in parallel with the run push button and the normally open section has been connected in series with the holding contacts. Explain how this circuit operates.
4. Refer to the circuit shown in Figure 10–9. In this circuit the jog push button has again been connected incorrectly. The normally closed section of the button has been connected in series with the normally open run push button and the normally open section of the jog button is connecting in parallel with the holding contacts. Explain how this circuit operates.

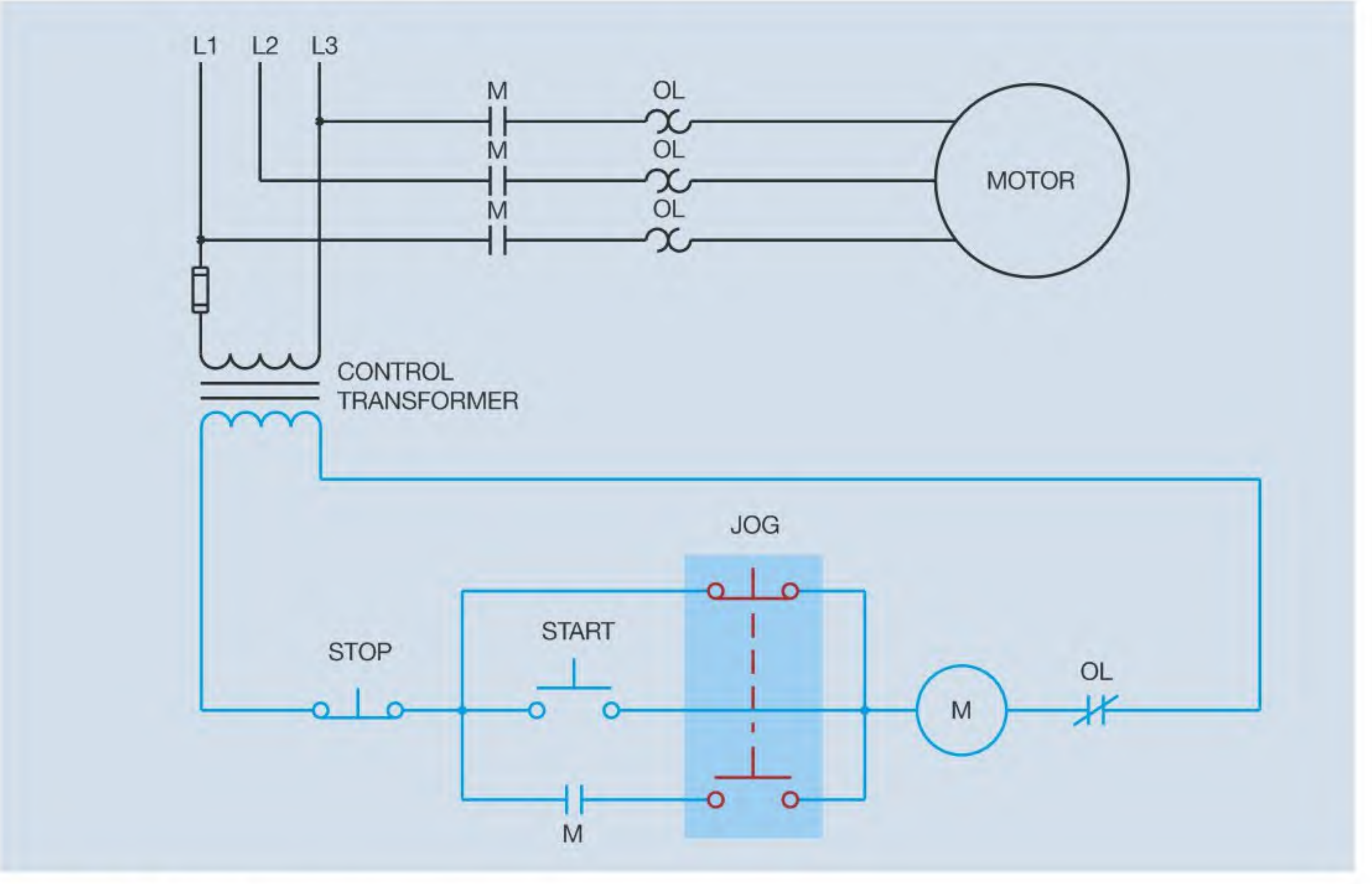


Figure 10–8 The jog button is connected incorrectly.

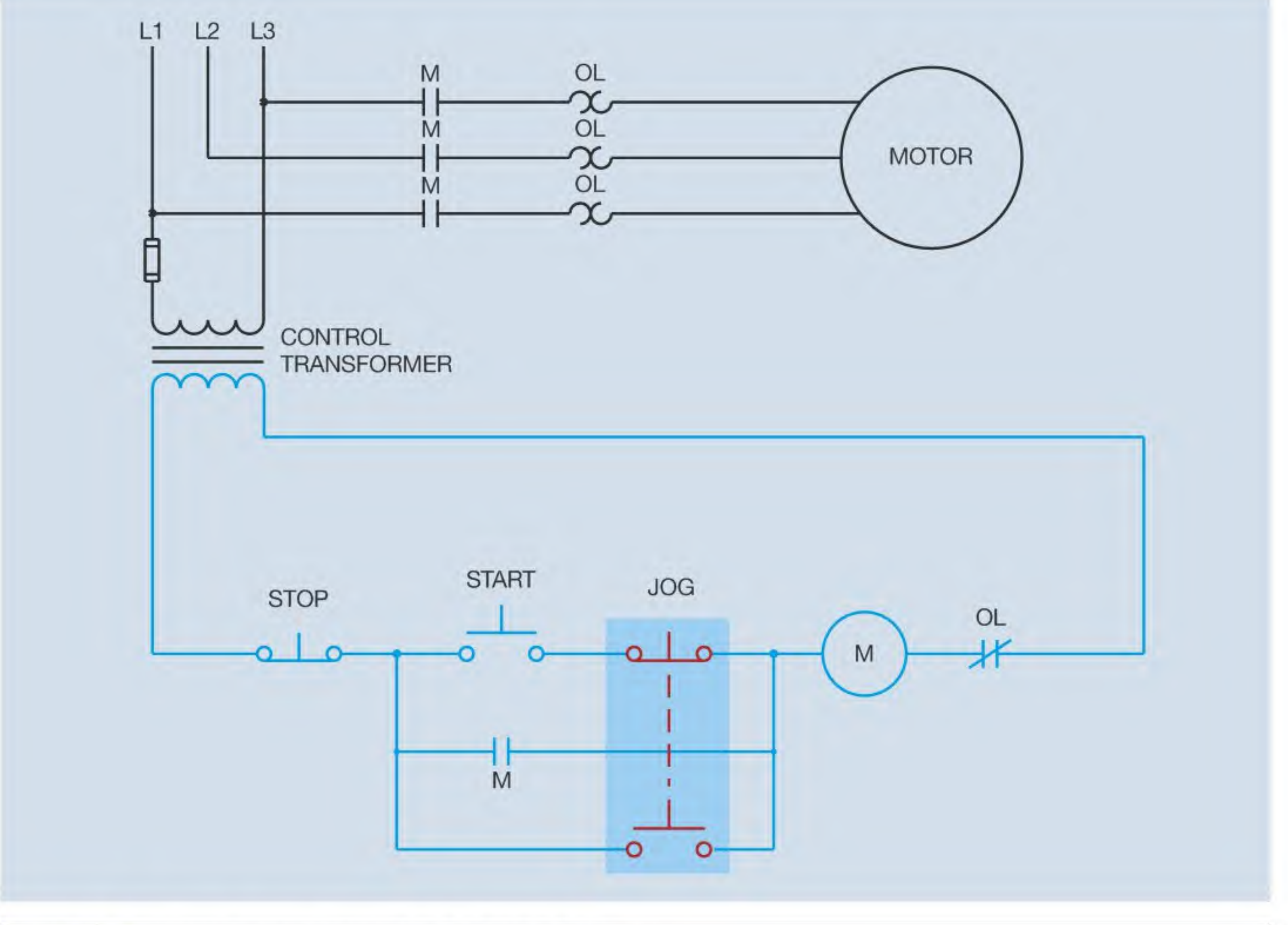


Figure 10–9 Another incorrect connection for the jog button.

Chapter 11

TIMING RELAYS

Objectives

After studying this chapter the student will be able to:

- Identify the primary types of timing relays.
- Explain the basic steps in the operation of the common timing relays.
- List the factors that affect the selection of a timing relay for a particular use.
- List applications of several types of timing relays.
- Draw simple circuit diagrams using timing relays.
- Identify *on-* and *off*-delay timing wiring symbols.

Time delay relays can be divided into two general classifications: the on-delay relay and the off-delay relay. The on-delay relay is often referred to as DOE, which stands for "Delay On Energize." The off-delay relay is often referred to as DODE, which stands for "Delay On De-Energize."

Timer relays are similar to other control relays in that they use a coil to control the operation of some number of contacts. The difference between a control relay and a timer relay is that the contacts of the timer relay delay changing their position when the coil is energized or de-energized. When power is connected to the coil of an on-delay timer, the contacts delay changing position for some period of time. For this example, assume that the timer has been set for a delay of 10 seconds. Also assume that the contact is normally open. When voltage is connected to the coil of the on-delay timer, the contacts remain in the open position for 10 seconds and then close. When voltage is removed and the coil is de-energized, the timed contact immediately changes back to its normally open position. The contact symbols for an on-delay relay are shown in Figure 11–1.

The operation of the off-delay timer is the opposite of the operation of the on-delay timer. For this example, again assume that the timer has been set for a delay of 10 seconds, and also assume that the contact is normally open. When voltage is applied to the coil of the off-delay timer, the contact changes immediately from open to closed. When the coil is de-energized, however, the timed contact remains in the closed position for 10 seconds before it reopens. The contact symbols for an off-delay relay are shown in Figure 11–2. Time delay relays can have normally open, normally closed, or a combination of normally open and normally closed contacts.

Figure 11–1 On-delay normally open and normally closed contacts.

Although the contact symbols shown in Figures 11–1 and 11–2 are standard NEMA symbols for on-delay and off-delay contacts, some control schematics may use a different method of indicating timed contacts. The abbreviations TO and TC are used with some control schematics to indicate a time-operated contact. *TO stands for time opening, and TC stands for time closing*. If these abbreviations are used with standard contact symbols, their meaning can be confusing. Figure 11–3 shows a standard normally open contact symbol with the abbreviation TC written beneath it. This contact must be connected to an on-delay relay if it is to be time delayed when closing. Figure 11–4 shows the same contact with the abbreviation TO beneath it. If this contact is to be time delayed when opening, it must be operated by an off-delay timer. These abbreviations can also be used with standard NEMA symbols as shown in Figure 11–5.

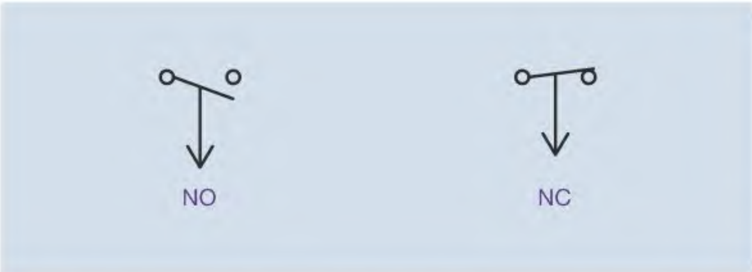


Figure 11–2 Off-delay normally open and normally closed contacts.

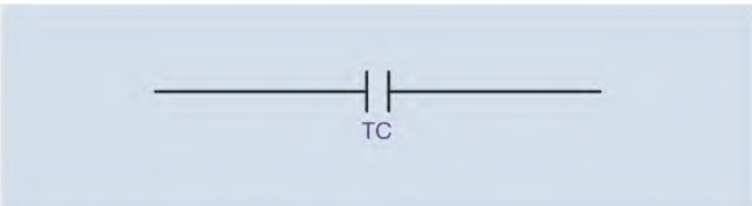


Figure 11–3 Time closing contact.

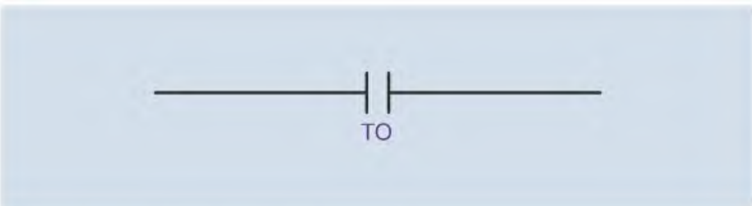


Figure 11–4 Time opening contact.

Figure 11–5 Contact A is an on-delay contact with the abbreviation NOTC (normally open time closing). Contact B is an off-delay contact with the abbreviation NOTO (normally open time opening).

Pneumatic Timers

Pneumatic, or air **timers**, operate by restricting the flow of air through an orifice to a rubber bellows or diaphragm. Figure 11–6 illustrates the principle of operation of a simple bellows timer. If rod "A" pushes against the end of the bellows, air is forced out of the bellows through the check valve as the bellows contracts. When the bellows is moved back, contact TR changes from an open to a closed contact. When rod "A" is pulled away from the bellows, the spring tries to return the bellows to its original position. Before the bellows can be returned to its original position, however, air must enter the bellows through the air inlet port. The rate at which the air is permitted to enter the bellows is controlled by the needle valve. When the bellows returns to its original position, contact TR returns to its normally open position.

Pneumatic timers are popular throughout industry because they have the following characteristics:

A. They are unaffected by variations in ambient temperature or atmospheric pressure.

B. They are adjustable over a wide range of time periods.

C. They have good repeat accuracy.

D. They are available with a variety of contact and timing arrangements.

Some pneumatic timers are designed to permit the timer to be changed from on delay to off delay, and the contact arrangement to be changed to normally opened or normally closed (Figure 11–7). This type of flexibility is another reason for the popularity of pneumatic timers.

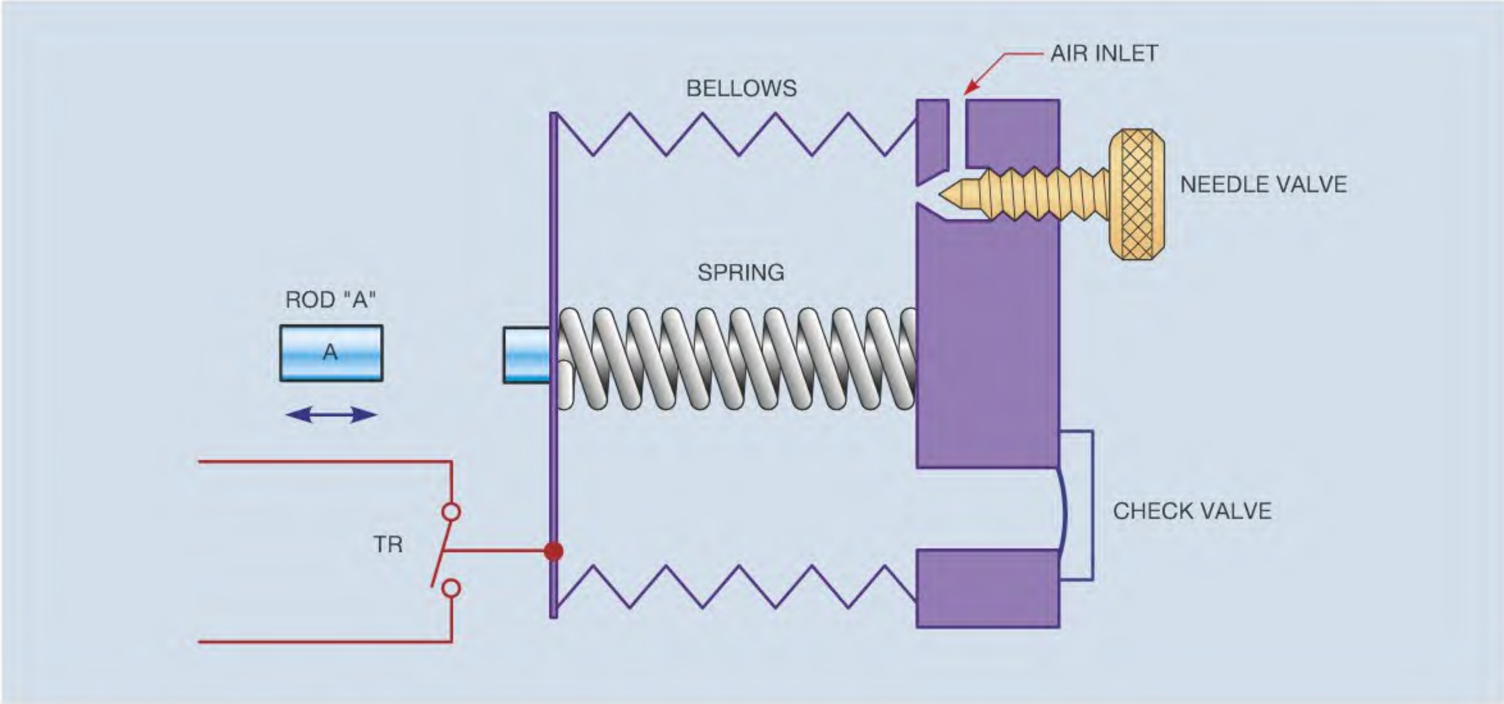


Figure 11–6 Bellows-operated pneumatic timer.

Figure 11–7 Pneumatic timer.

Many timers are made with contacts that operate with the coil as well as time delayed contacts. When these contacts are used, they are generally referred to as *instantaneous contacts* and indicated on a schematic diagram by the abbreviation, inst., printed below the contact (Figure 11–8). These instantaneous contacts change

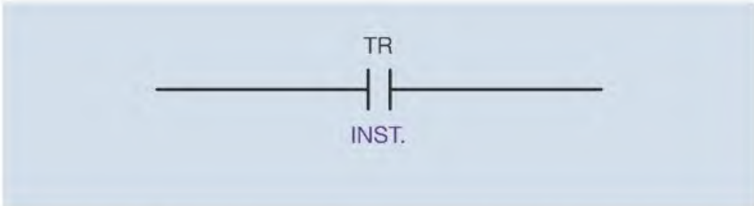


Figure 11–8 Normally open instantaneous contact of a timer relay.

their positions immediately when the coil is energized and change back to their normal positions immediately when the coil is de-energized.

Clock Timers

Another timer frequently used is the **clock timer** (Figure 11–9). Clock timers use a small AC synchronous motor similar to the motor found in a wall clock to provide the time measurement for the timer. The length of time of one clock timer may vary greatly from the length of time of another. For example, one timer may have a full range of 0 to 5 seconds and another timer may have a full range of 0 to 5 hours. The same type of timer motor could be used with both timers. The gear ratio connected to the motor would determine

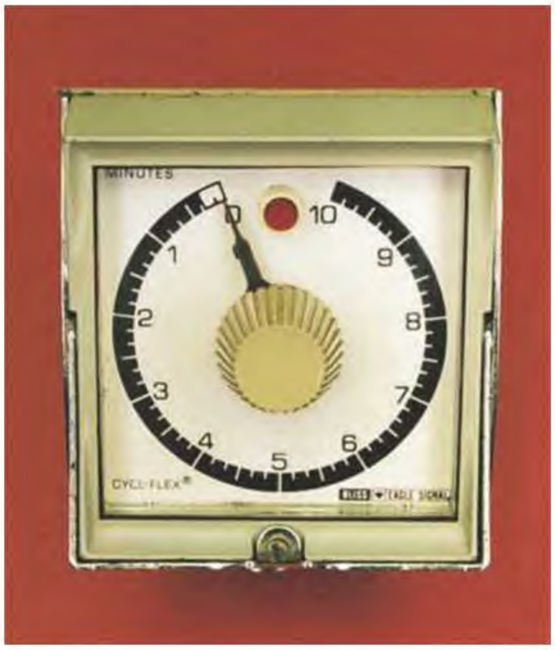


Figure 11–9 Clock-driven timer.

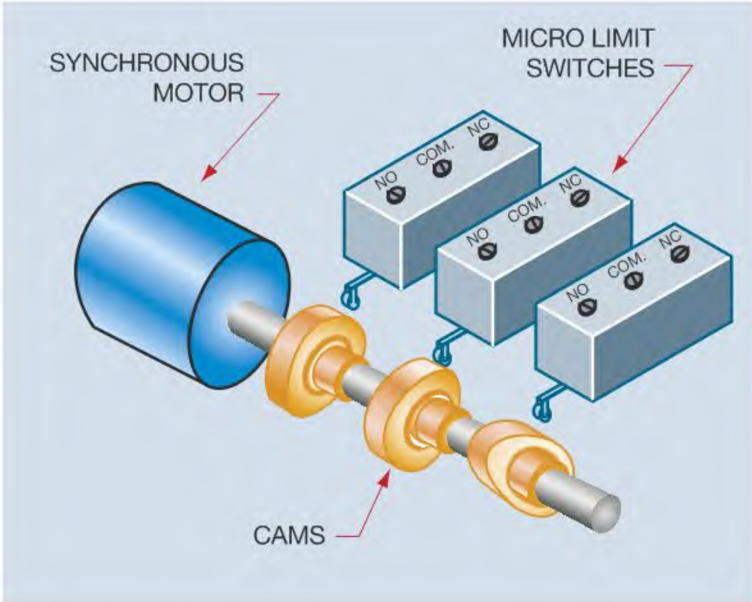


Figure 11–10 Cam switch.

the full range of time for the timer. Some advantages of clock timers are:

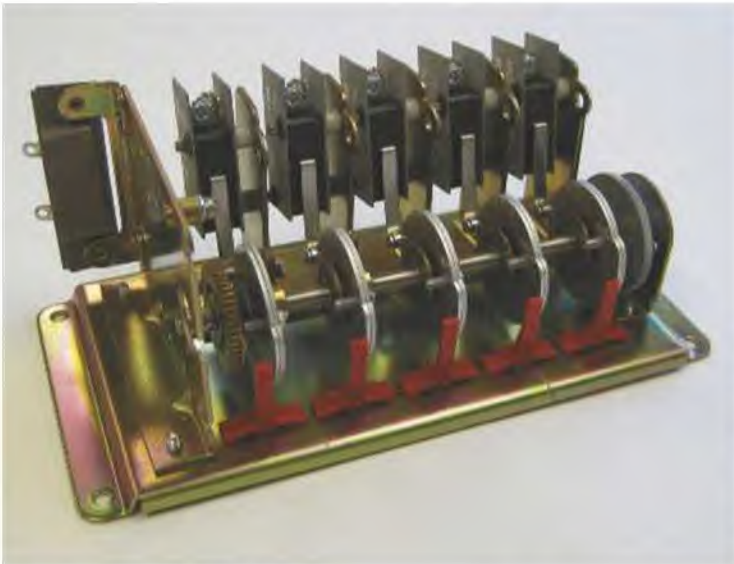
A. They have extremely high repeat accuracy.

B. Readjustment of the time setting is simple and can be done quickly. Clock timers are generally used when the machine operator must make adjustments of the time length.

Cam or Sequence Timers

Cam timers are generally used to operate several switches. The operation of the switches is controlled by the action of adjustable cams attached to a common shaft. The shaft is turned by a small synchronous motor (Figure 11–10). Cam timers are also known as sequence timers because they repeat the same action as long as the motor is turning the cams. They are often used to control flashing lights that must turn on or off in a certain sequence, such as the lights that appear to move from one place to another, or lights that spell out a word one letter at a time. A motor-driven cam timer is shown in Figure 11–11.

Programmable logic controllers (PLCs) are most often used to perform the functions of a cam timer. PLCs can be programmed as a sequencer and drive hundreds of outputs. It is much simpler to program the outputs of the PLC than it is to set all the cams on a mechanical timer.



Courtesy Industrial Timer Co.

Figure 11–11 Motor-driven process timer. Often referred to as a cam timer.

Electronic Timers

Electronic timers use solid-state components to provide the time delay desired. Some of these timers use an RC time constant to obtain the time base and others use quartz clocks as the time base (Figure 11–12). RC time constants are inexpensive and have good repeat times. The quartz timers, however, are extremely accurate and can often be set for 0.1 second times. These timers are generally housed in a plastic case and are designed to be plugged into some type of socket. An electronic timer that is designed to be plugged into a standard 8 pin relay socket is shown in Figure 11–13. The length of the time delay can be set by adjusting the control knob shown on top of the timer.

Eight pin electron timers similar to the one shown in Figure 11–13 are intended to be used as on-delay timers only. Many electronic timers are designed to plug into an 11 pin relay or tube socket (Figure 11–14) and are more flexible. Two such timers are shown in Figures 11–15A and 11–15B. Either of these timers can be used as an on-delay

Courtesy Rockwell Automation Inc.

Figure 11–12 Digital clock timer.

Figure 11–14 11 pin relay sockets.

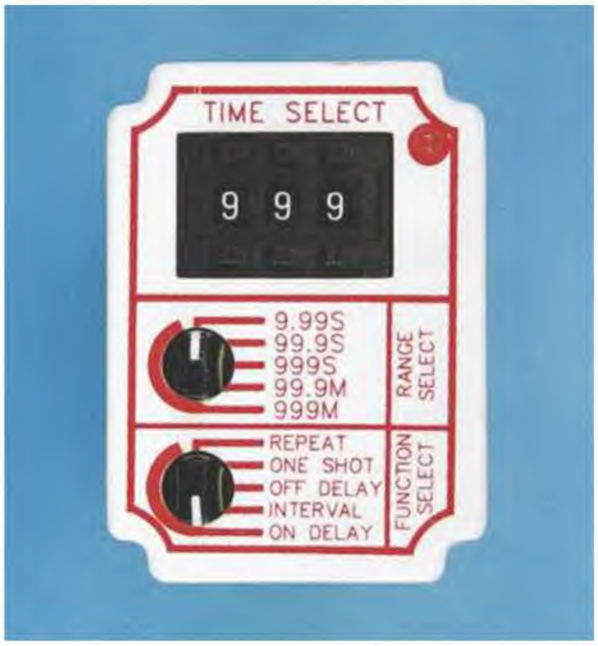


Figure 11–15A Dayton electronic timer.

Figure 11–13 Electronic timer.

Figure 11–15B Allen-Bradley electronic timer.

timer, an off-delay timer, a pulse timer, or as a one-shot timer. Pulse timers continually turn on and off at regular intervals. A timing period chart for a pulse timer set for a delay of 1 second is shown in Figure 11–16. A one-shot timer operates for one time period only. A timing period chart for a one-shot timer set for 2 seconds is shown in Figure 11–17.

Most electronic timers can be set for a wide range of times. The timer shown in Figure 11–15A uses a thumbwheel switch to enter the timer setting. The top selector switch can be used to set the full range value from 9.99 seconds to 999 minutes. This timer has a range from 0.01 second to 999 minutes (16 hrs. 39 min.). The timer shown in Figure 11–15B can be set for a range of 0.01 second to 100 hours by adjusting the range and units settings on the front of the timer. Most electronic timers have similar capabilities.

Connecting 11 Pin Timers

Connecting 11 pin timers into a circuit is generally a little more involved than simply connecting the coil to power. The manufacturer's instructions should always be consulted before trying to connect one of these timers. Although most electronic timers are similar in how they are connected, there are differences. The pin connection diagram for the timer shown in Figure 11–15A is shown in Figure 11–18. Notice that a normally open push button switch is shown across terminals 5 and 6. This switch is used to start the action of the timer when it is set to function as an off-delay timer or as a one-shot timer. The reason is that when the timer is to function as an off-delay timer, power must be applied to the timer at all times to permit the internal timing circuit to operate. If power is removed, the internal timer cannot function. The START switch is actually used to initiate the operation of the timer when it is set to function in the off-delay mode. Recall the logic of an off-delay timer: *When the coil is energized, the contacts change position immediately. When the coil is de-energized, the contacts delay returning to their normal position.* According to the pin chart shown in Figure 11–18, pins 2 and 10 connect to the coil of the timer. To use this timer in the off-delay mode, power must be connected to pins 2 and 10 at all times. Shorting pins 5 and 6 together causes the timed contacts to change position immediately. When the short circuit between pins 5 and 6 is removed, the time sequence begins. At the end of the preset time period, the contacts return to their normal position.

If electronic off-delay timers are to replace pneumatic off-delay timers in a control circuit, it is generally

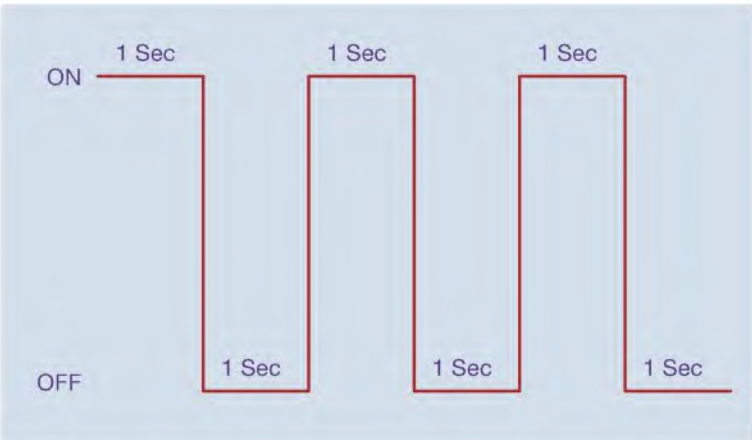


Figure 11–16 Time chart for pulse timer.

Figure 11–17 Time chart for a one-shot timer.

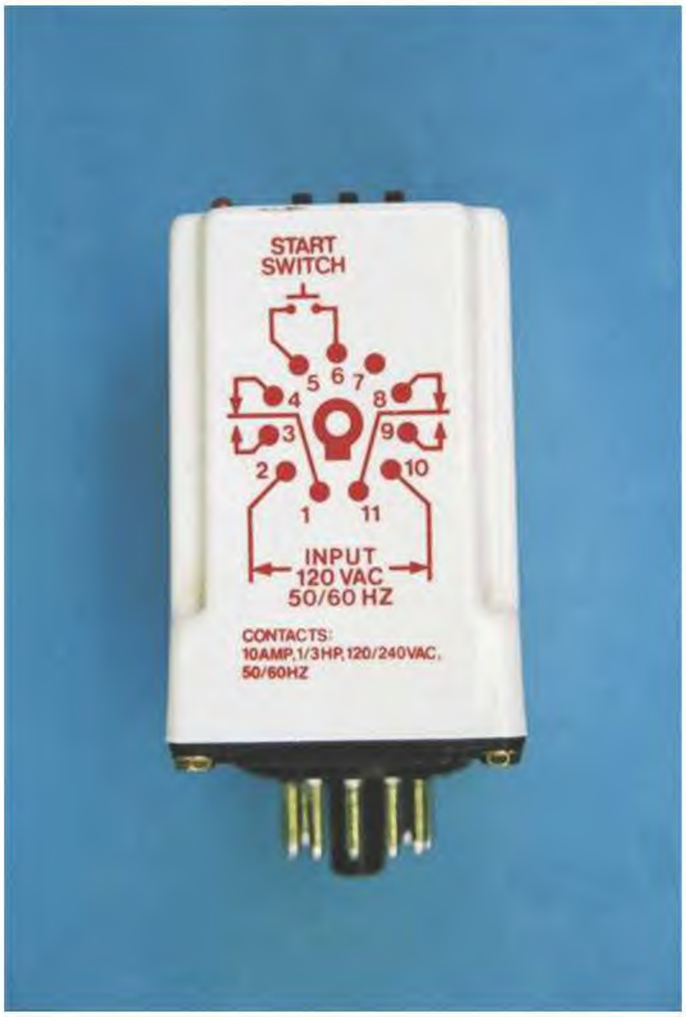


Figure 11–18 Pin connection diagram for Dayton timer.

necessary to modify the circuit. For example, in the circuit shown in Figure 11–19, it is assumed that starters 1M and 2M control the operation of two motors and timer TR is a pneumatic off-delay timer. When the START button is pressed both motors start at the same time. The motors continue to operate until the STOP button is pressed, which causes motor #1 to stop running immediately. Motor #2, however, will continue to run for a period of 5 seconds before stopping.

Now assume that the pneumatic off-delay timer is replaced with an electronic off-delay timer (Figure 11–20). In this circuit, notice that the coil of the timer is connected directly across the incoming power, which permits it to remain energized at all times. In the circuit shown in Figure 11–19, the timer actually operates with starter 1M. When coil 1M energizes, timer TR energizes at the same time. When coil 1M de-energizes, timer TR de-energizes also. For this reason, a normally open auxiliary contact on starter 1M will be used to control the operation of the electronic off-delay timer. In the circuit shown in Figure 11–20 a set of normally open 1M contacts is connected to pins 5 and 6 of the timer. When coil 1M energizes, contact 1M closes and shorts pins 5 and 6, causing the normally open TR contacts to close and energize starter coil 2M. When coil 1M is de-energized, the contacts reopen and timer TR begins timing. After 5 seconds contacts TR reopen and de-energize starter coil 2M.

All electronic timers are similar, but there are generally differences in how they are to be connected. The connection diagram for the timer shown in Figure 11–15B is shown in Figure 11–21. Notice that this timer contains RESET, START, and GATE pins. Connecting pin 2 to pin 5 activates the GATE function, which interrupts or suspends the operation of the internal clock. Connecting pin 2 to pin 6 activates the START function, which operates in the same manner as the timer shown in Figure 11–15A. Connecting pin 2 to pin 7 activates the RESET function, which resets the internal clock to zero. If this timer were to be used in the circuit shown in Figure 11–20, it would have to be modified as shown in Figure 11–22 by connecting the 1M normally open contact to pins 2 and 6 instead of pins 5 and 6.

Construction of a Simple Electronic Timer

The schematic for a simple on-delay timer is shown in Figure 11–23. The timer operates as follows: When switch S1 is closed, current flows through **resistor** RT and begins charging **capacitor** C1. When capacitor C1 has been charged to the trigger value of the **unijunction transistor, the UJT** turns on and discharges capacitor C1 through resistor R2 to ground. The sudden discharge of capacitor C1 causes a spike voltage to appear across resistor R2. This voltage spike travels through capacitor C2 and fires the gate of the SCR. When the SCR turns on, current is provided to the coil of relay K1.

Resistor R1 limits the current flow through the UJT. Resistor R3 is used to keep the SCR turned off until the UJT provides the pulse to fire the gate. Diode D1 is used to protect the circuit from the spike voltage produced by the collapsing magnetic field around coil K1 when the current is turned off.

By adjusting resistor RT, capacitor C1 can be charged at different rates. In this manner, the relay can be adjusted for time. Once the SCR has turned on, it will remain on until switch S1 is opened.

Programmable controllers, which will be discussed in a later chapter, contain "internal" electronic

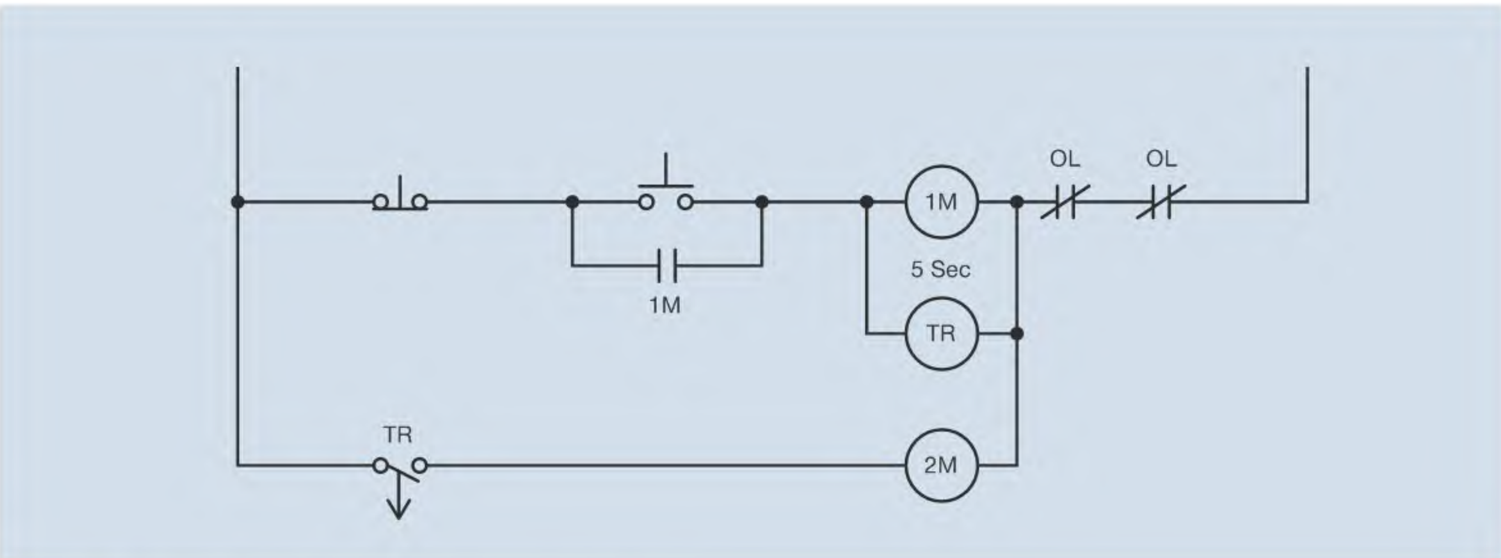


Figure 11–19 Off-delay timer circuit using a pneumatic timer.

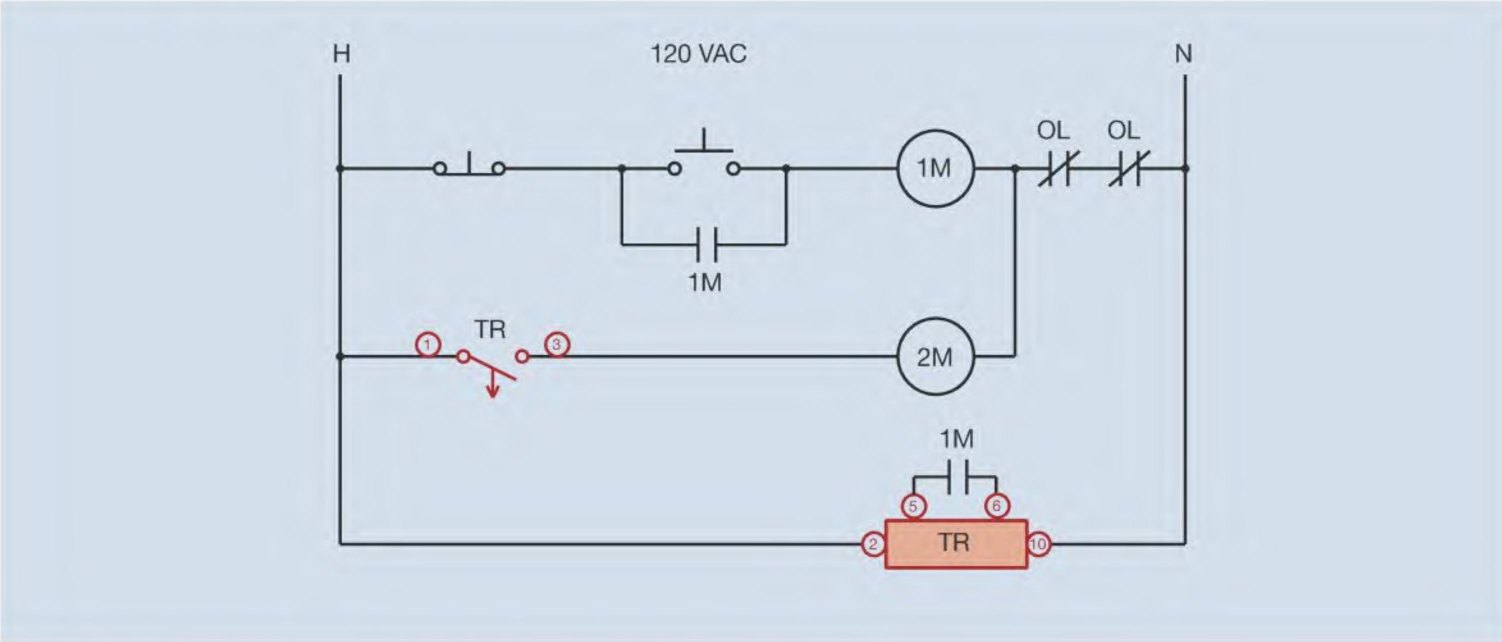


Figure 11–20 Modifying the circuit for an electronic off-delay timer.

Figure 11–21 Pin connection diagram for Allen-Bradley timer.

timers. Most programmable logic controllers (PLCs) use a quartz-operated clock as the time base. When the controller is programmed, the timers can be set in time increments of 0.1 second. This, of course, provides very accurate time delays for the controller.

Making an On-Delay Timer Function as an Off-Delay Timer

On-delay timers can be used to perform the same logic function as off-delay timers. There may be instances that an off-delay timer is needed and only on-delay timers are available. When this is the case, the circuit can be amended to permit the on-delay timer to perform the logic of an off-delay timer. In the circuit shown in Figure 11–19, motors 1 and 2 start at approximately the same time. When the stop button is pressed, motor 1 stops operating immediately but motor 2 continues to operate for an additional 5 seconds. Now assume that off-delay timer TR is to be replaced with an on-delay timer. In the circuit shown in Figure 11–19, off-delay timer TR begins its time sequence when motor starter coil 1M is de-energized. In order to use an on-delay timer to perform this function it will be necessary to start the timing sequence when motor starter coil 1M de-energizes. Another consideration is timer contact TR. In the circuit shown in Figure 11–19, off-delay timed contact TR is shown normally open. When timer coil TR is energized, this contact will close immediately permitting motor starter 2M to energize. In order to replace off-delay contact TR with an on-delay timed contact, it will be necessary to connect the contact normally closed as shown in Figure 11–24. Since the timed TR contact is now closed, a normally open contact controlled by 1M starter is connected in series with it to prevent power from being provided to coil 2M. A normally open 2M contact has been connected in parallel with the normally open 1M contact to maintain a current path when starter 1M is de-energized.

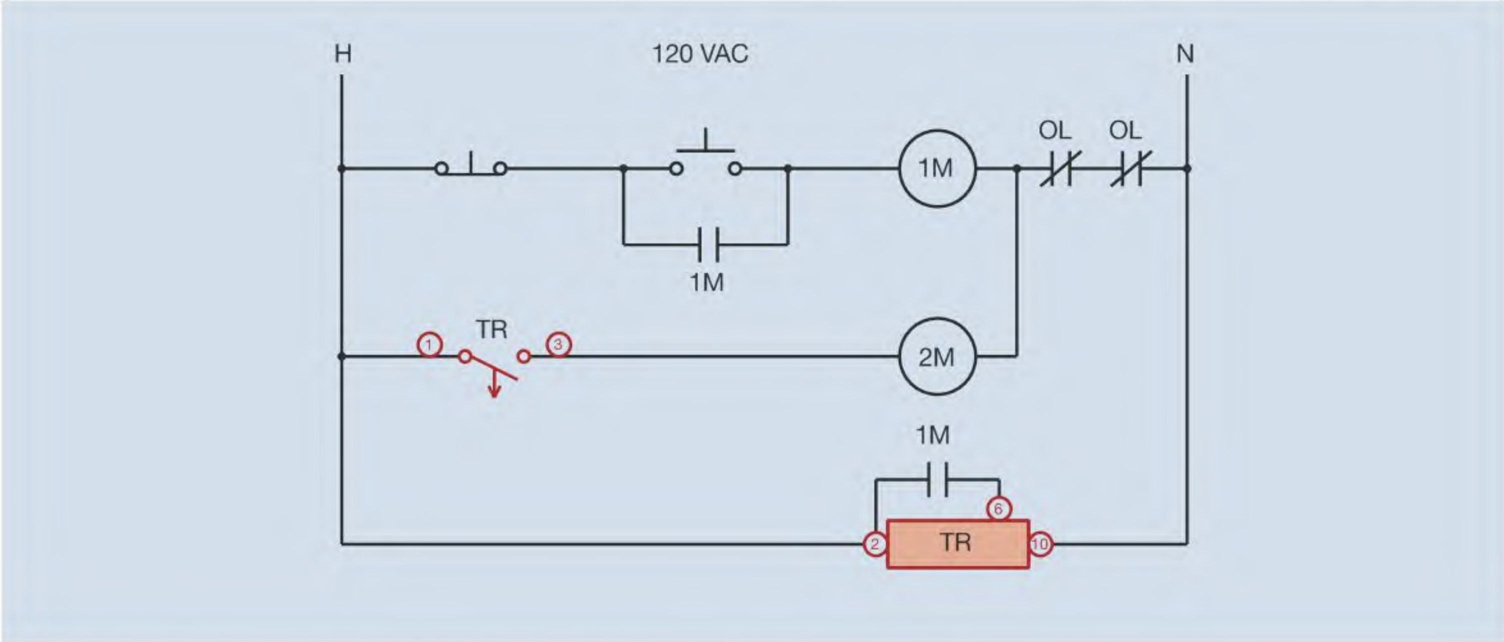


Figure 11–22 Replacing the Dayton timer with the Allen-Bradley timer.

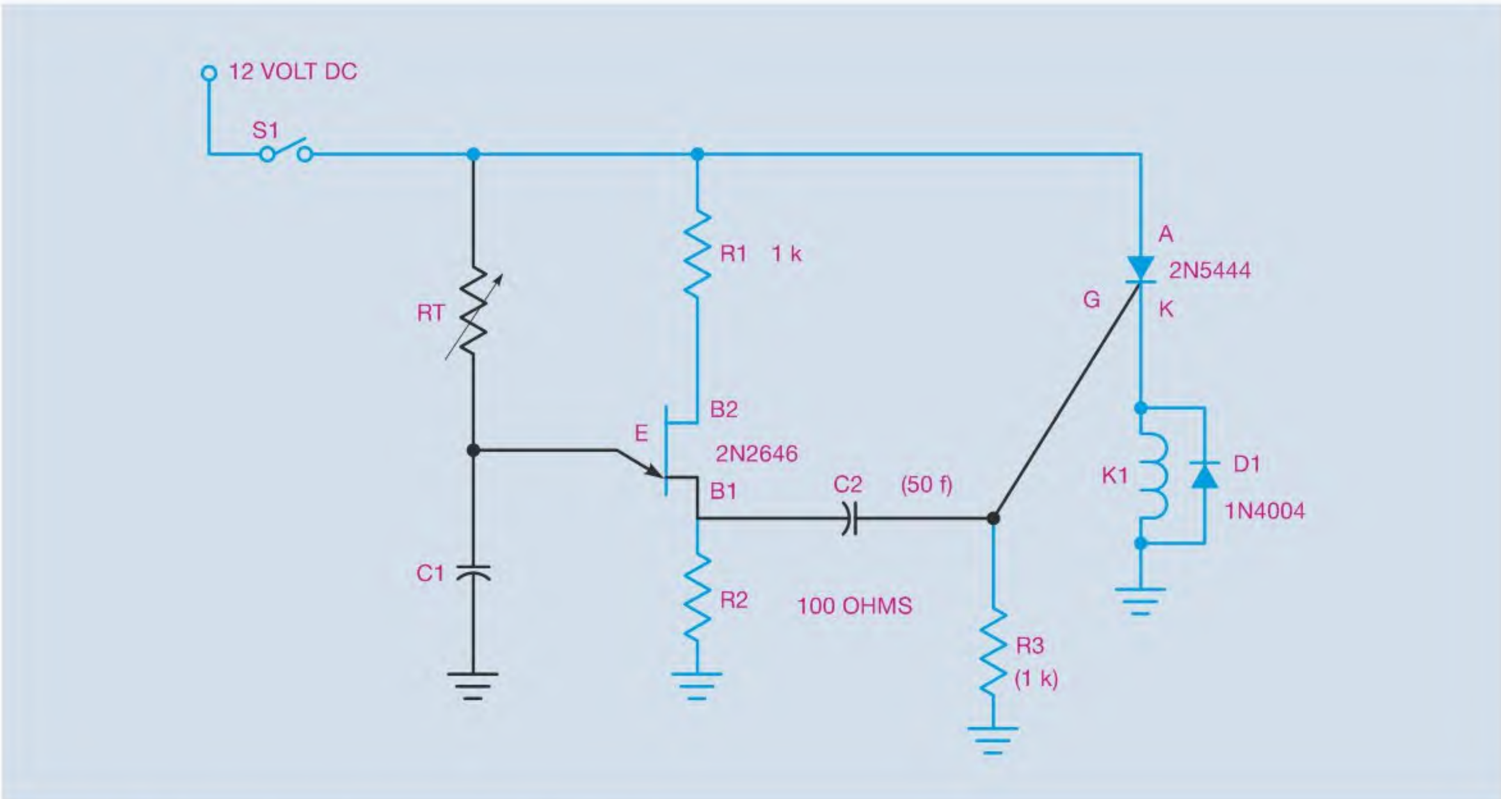


Figure 11–23 Schematic of electronic on-delay timer.

Timer TR must begin its time sequence when coil 1M is de-energized. To accomplish this, a normally closed contact controlled by starter coil 1M is connected in series with the coil of timer TR. Since the 1M contact is normally closed, a normally open contact controlled by starter coil 2M is connected in series to prevent power from being applied to timer coil TR when the circuit is turned off.

The operation of the circuit is as follows:

1. When the start button is pressed, starter 1M energizes and all 1M contacts change position, Figure 11–25.
2. Coil 2M energizes and both normally open 2M auxiliary contacts close. The circuit to timer coil TR is interrupted by the now open normally closed 1M contact.

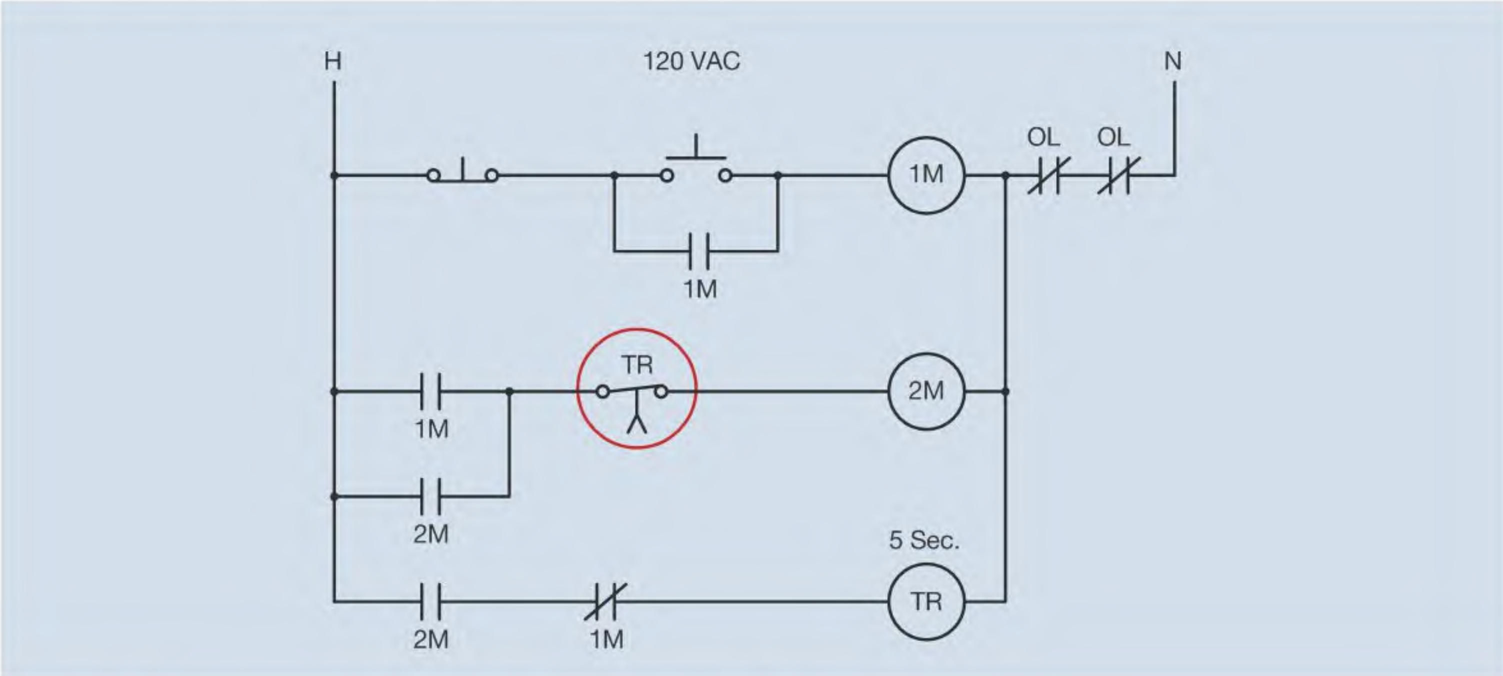


Figure 11–24 Using an on-delay timer to perform the logic of an off-delay timer.

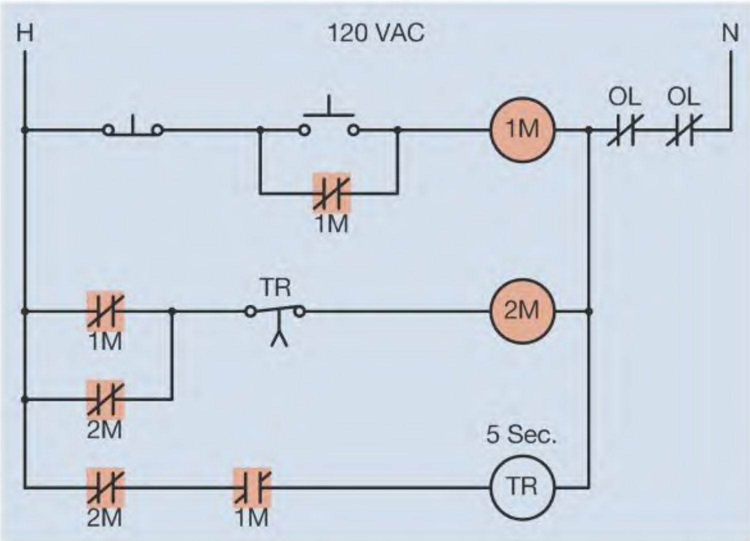


Figure 11–25 Starters 1M and 2M energize causing all 1M and 2M contacts to change position.

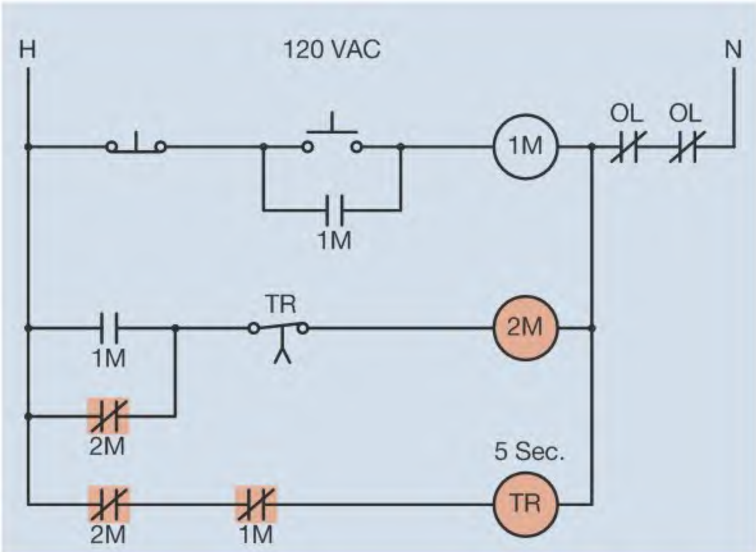


Figure 11–26 Starter 1M de-energizes causing timer TR to begin its time sequence.

3. When the start button is pressed, coil 1M de-energizes and all 1M contacts return to their normal position, Figure 11–26. A circuit path is maintained to starter coil 2M by the closed 2M contact connected in parallel with the now open 1M contact.
4. When the 1M contact connected in series with timer coil TR returned to the closed condition, a circuit was completed, starting the time sequence for timer TR.
5. At the end of the 5-second time period, timed contact TR opens and disconnects power to starter coil 2M, causing all 2M contacts to return to their normal position.
6. When the 2M contact connected in series with coil TR reopens, power is disconnected to timer coil TR, causing timed contact TR to return to its normally closed position. The circuit is now in its original position.

Review Questions

1. What are the two basic classifications of timers?
2. Explain the operation of an on-delay relay.
3. Explain the operation of an off-delay relay.
4. What are instantaneous contacts?
5. How are pneumatic timers adjusted?
6. Name two methods used by electronic timers to obtain their time base.

Chapter 12

SEQUENCE CONTROL

Objectives

After studying this chapter the student will be able to:

›› State the purpose for starting motors in a predetermined sequence.

›› Read and interpret sequence control schematics.

›› Convert a sequence control schematic into a wiring diagram.

›› Connect a sequence control circuit.

Sequence control forces motors to start or stop in a predetermined order. One motor cannot start until some other motor is in operation. Sequence control is used by such machines as hydraulic presses that must have a high pressure pump operating before they can be used, or by air conditioning systems that require that the blower be in operation before the compressor starts. Sequence control can be achieved by several methods. One design that meets the requirements is shown in Figure 12–1. In this circuit, push button #1 must be pressed before power can be provided to push button #2. When motor starter #1 energizes, the normally open auxiliary contact 1M closes providing power to coil 1M and to push button #2. Motor starter #2 can now be started by pressing push button #2. Once motor starter #2 energizes, auxiliary contact 2M closes and provides power to coil 2M and push button #3. If the STOP button should be pressed or any overload contact opens, power will be interrupted to all starters.

A Second Circuit for Sequence Control

A second method of providing sequence control is shown in Figure 12–2. Because the motor connections are the same as the previous circuit, only the control part of the schematic is shown. In this circuit, normally open auxiliary contacts located on motor starters 1M and 2M are used to ensure that the three motors start in the proper sequence. A normally open 1M auxiliary contact connected in series with starter coil 2M prevents motor #2 from starting before motor #1, and a normally open 2M auxiliary contact connected in series with coil 3M prevents motor #3 from starting before motor #2. If the STOP button is pressed or if any overload contact opens, power will be interrupted to all starters.

Sequence Control Circuit #3

A third circuit that is almost identical to the previous circuit is shown in Figure 12–3. This circuit also employs the use of normally open auxiliary contacts to prevent motor #2 from starting before motor #1, and motor #3 cannot start before motor #2. These normally open auxiliary contacts that control the starting sequence are often called *permissive* contacts because they permit action to take place. The main difference between the two circuits is that in the circuit shown in Figure 12–2 the

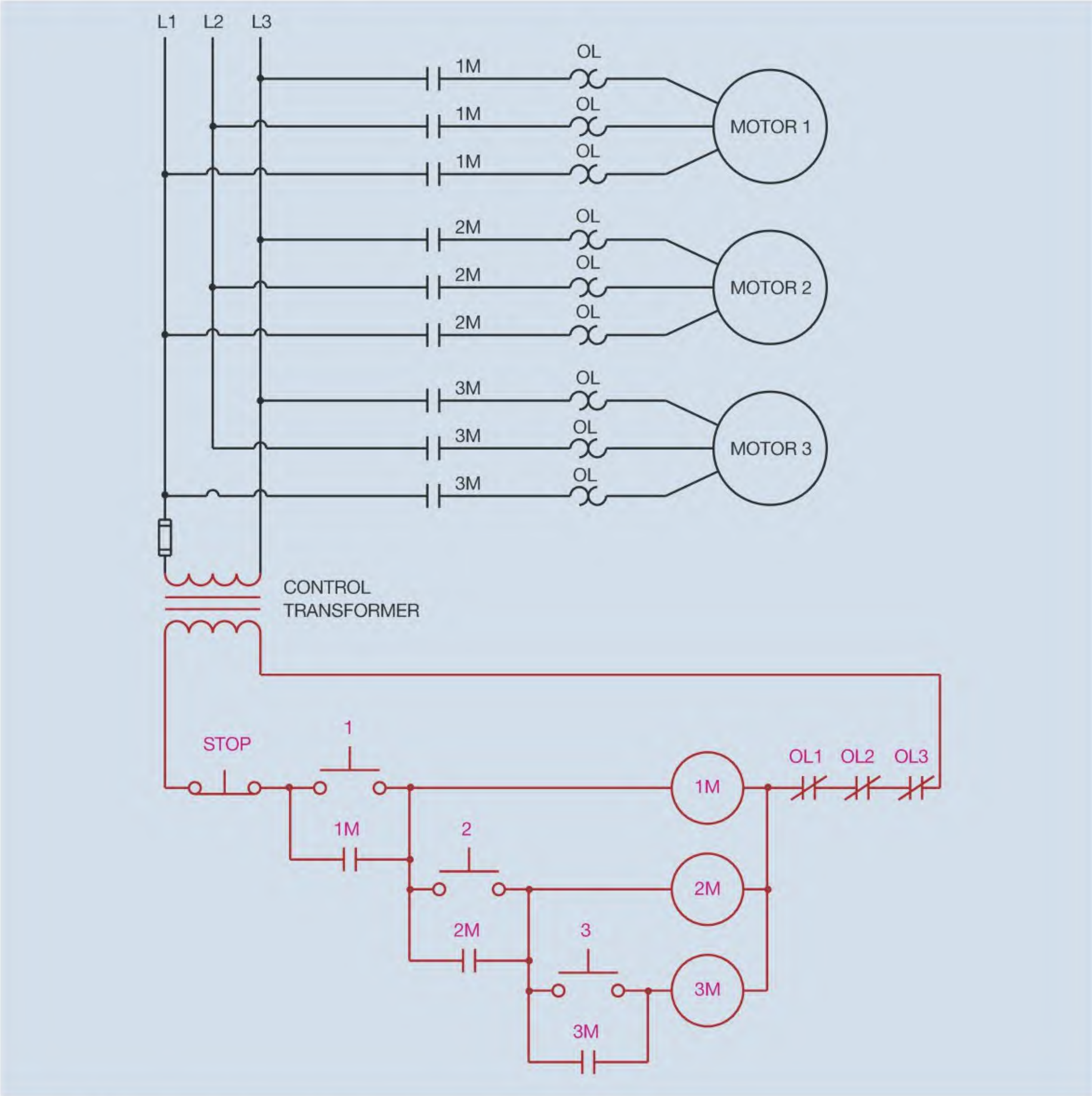


Figure 12–1 One example of a circuit that provides sequence control.

STOP push button interrupts the power to all the motor starters. The circuit in Figure 12–3 depends on the normally open auxiliary contacts reopening to stop motors #2 and #3.

Automatic Sequence Control

Circuits that permit the automatic starting of motors in sequence are common. A number of methods can be employed to determine when the next motor should start. Some sense motor current. When the current of a motor drops to a predetermined level, it permits the next motor to start. Other circuits sense the speed of one motor before permitting the next one to start. One of the most common methods is time delay. The circuit shown in Figure 12–4 permits three motors to start in sequence. Motor #1 starts immediately when the START button is pressed. Motor #2 starts 5 seconds after motor

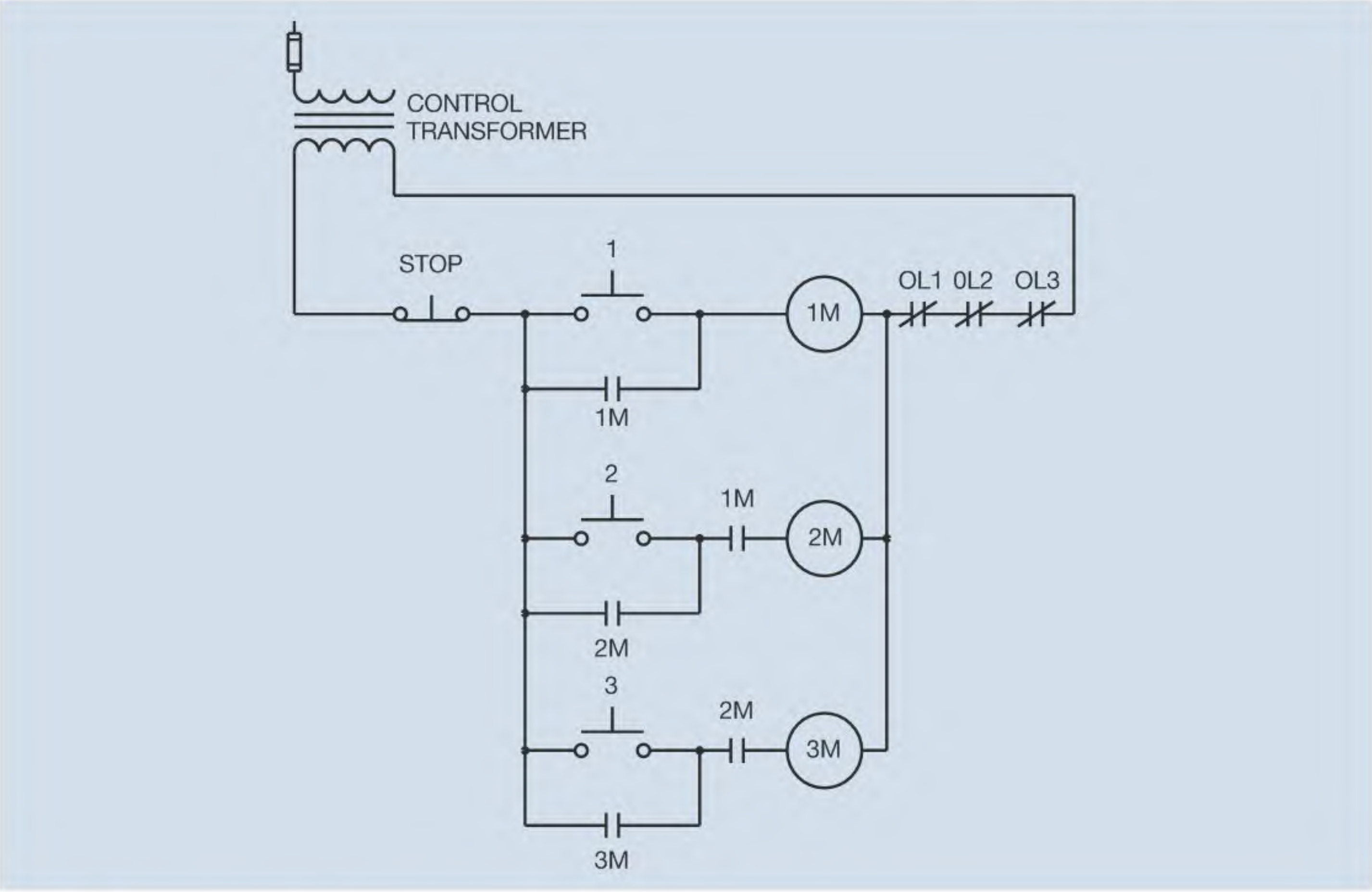


Figure 12–2 A second circuit for sequence control.

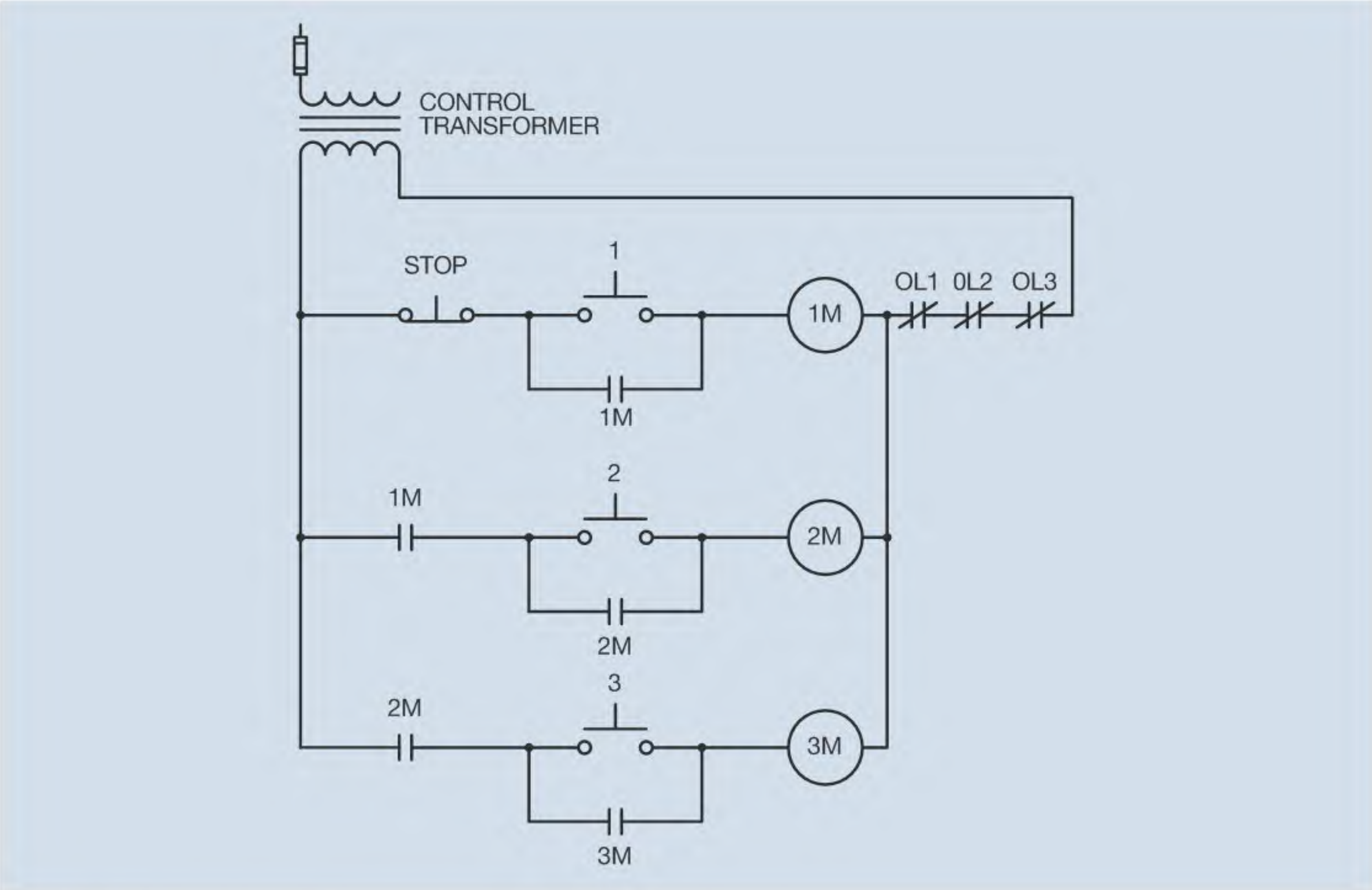


Figure 12–3 A third circuit for sequence control.

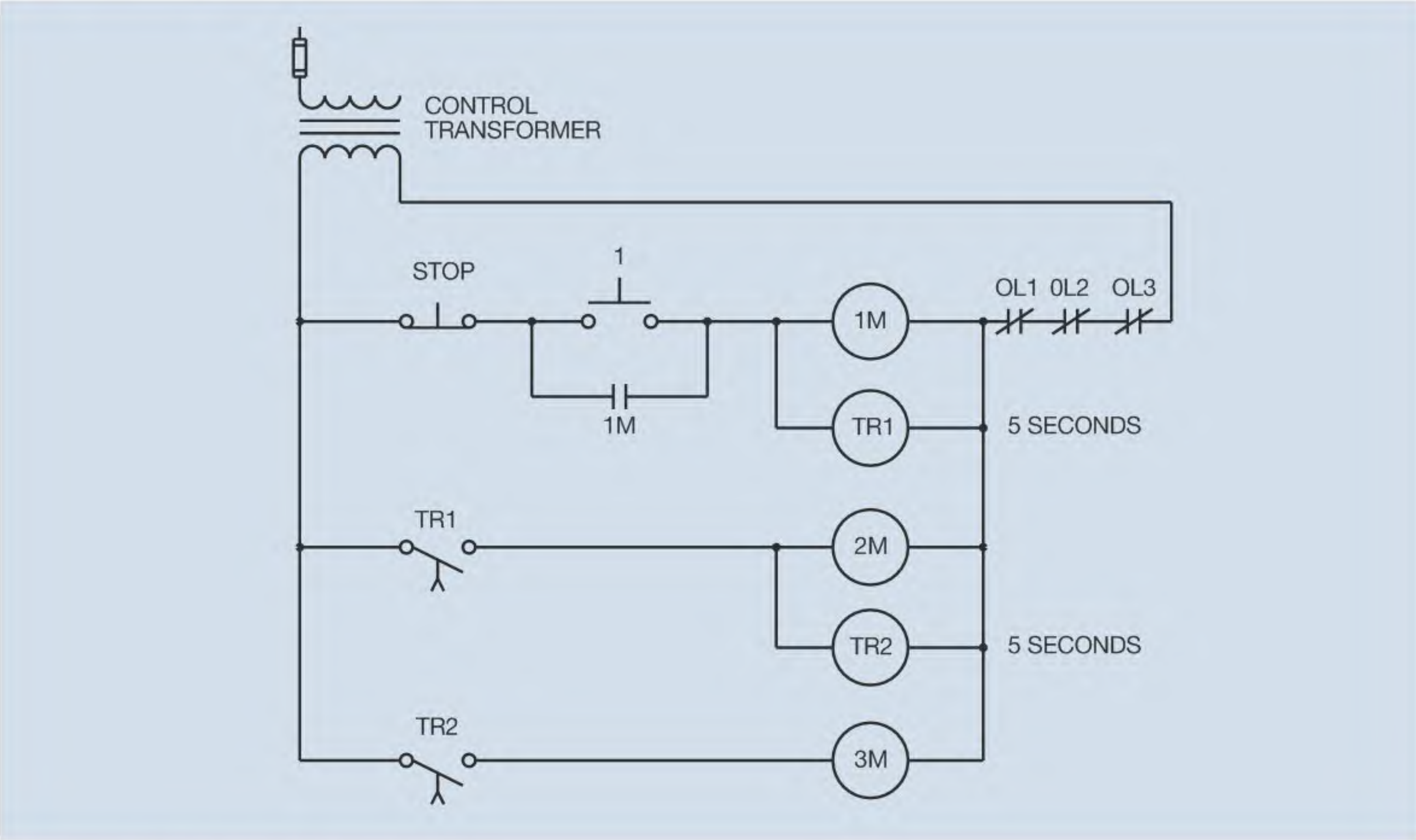


Figure 12–4 Timed starting for three motors.

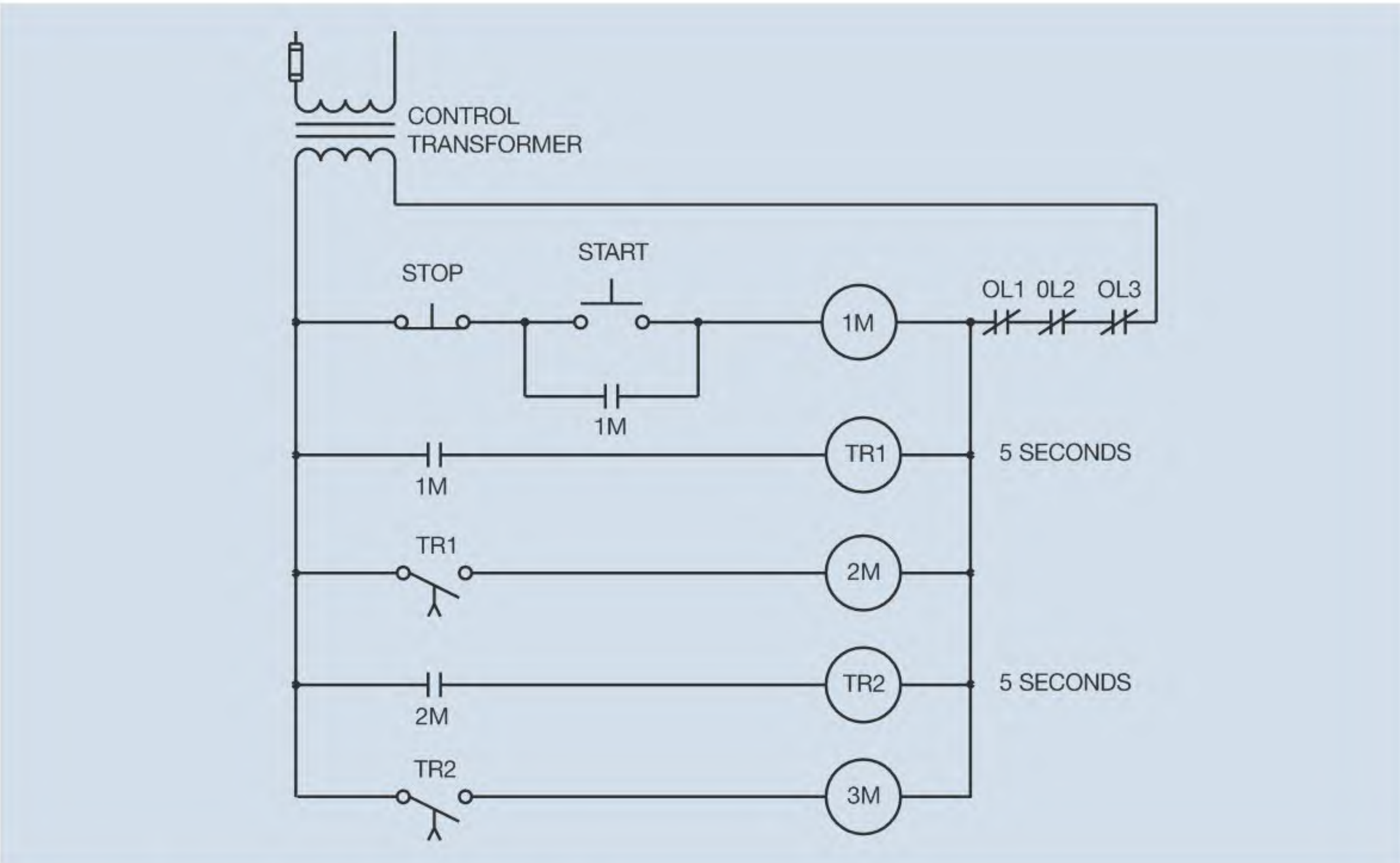


Figure 12–5 Circuit is modified to eliminate parallel coils.

#1 starts, and motor #3 starts 5 seconds after motor #2 starts. Timer coil TR1 is connected in parallel with 1M starter coil. Because they are connected in parallel, they will energize at the same time. After a delay of 5 seconds, TR1 contact closes and energizes coils 2M and TR2. Motor #2 starts immediately, but timed contact TR2 will delay closing for 5 seconds. After the delay period, starter coil 3M will energize and start motor #3. When the STOP button is pushed, all motors stop at virtually the same time.

Although the circuit logic in Figure 12–4 is correct, most ladder diagrams do not show coils connected in parallel. A modification of the circuit is shown in Figure 12–5. In this circuit, auxiliary contacts on the motor starters are used to control the action of the timed relays. Note that the logic of the circuit is identical to that of the circuit in Figure 12–4.

Stopping the Motors in Sequence

Some circuit requirements may demand that the motors turn off in sequence instead of turning on in sequence. This circuit requires the use of off-delay timers. Also, a control relay with four contacts is needed. The circuit shown in Figure 12–6 permits the motors to start in sequence from #1 to #3 when the START button is pressed. Although they start in sequence, the action will be so fast that it will appear they all start at approximately the same time. When the STOP button is pressed, however, they will stop in sequence from #3 to #1 with a time delay of 5 seconds between each motor. Motor #3 will stop immediately. Five seconds later motor #2 will stop, and 5 seconds after motor #2 stops, motor #1 will stop. An overload on any motor will stop all motors immediately.

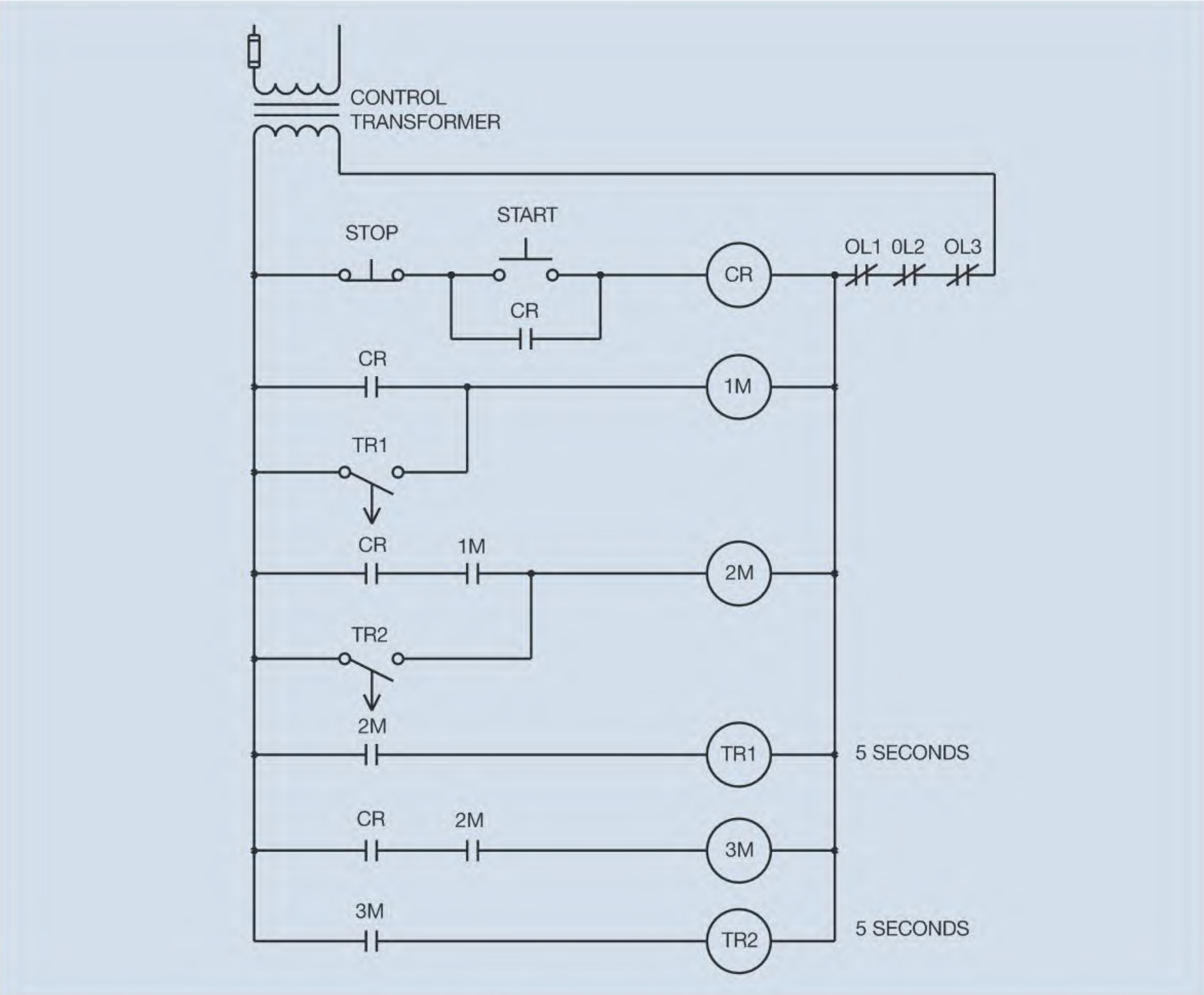


Figure 12–6 Motors start in sequence from 1 to 3 and stop in sequence from 3 to 1 with a delay of 5 seconds between the stopping of each motor.

Circuit Operation

When the START push button is pressed, control relay CR energizes and causes all CR contacts to close (Figure 12–7). Motor starter 2M cannot energize because of the normally open 1M contact connected in series with coil 2M, and motor starter 3M cannot energize because of the normally open 2M contact connected in series with coil 3M. Motor starter 1M does energize, starting motor #1 and closing all 1M contacts (Figure 12–8).

The 1M contact connected in series with coil 2M closes and energizes coil 2M (Figure 12–9). This causes motor #2 to start and all 2M contacts to close. Off-delay timer TR1 energizes and immediately closes the TR1 contact connected in parallel with the CR contact connected in series with coil 1M.

When the 2M contact connected in series with coil 3M closes, starter coil 3M energizes and starts motor #3. The 3M auxiliary contact connected in series with off-delay timer coil TR2 closes and energizes the timer

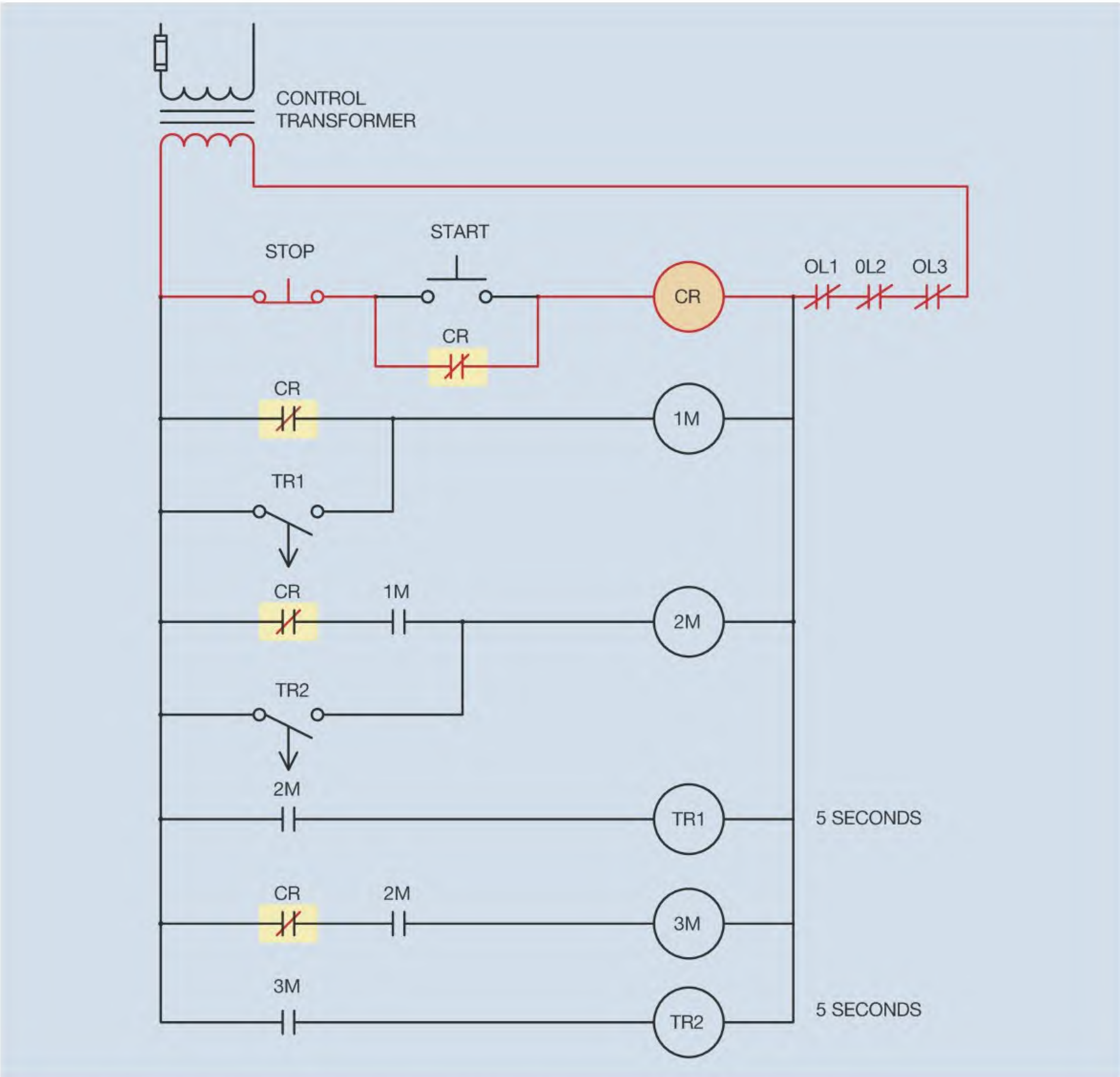


Figure 12–7 Control relay CR energizes and closes all CR contacts.

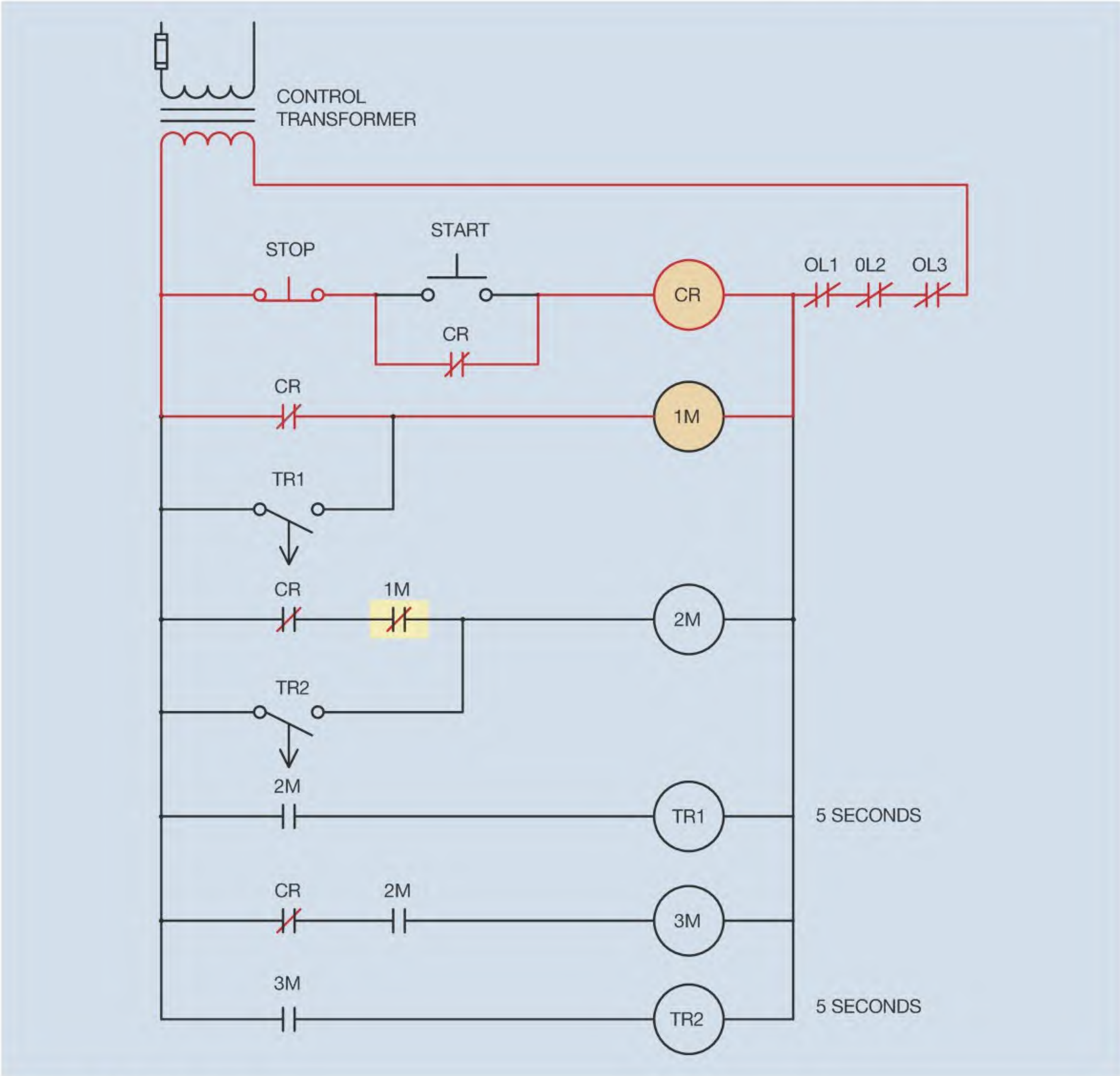


Figure 12–8 Motor #1 starts.

causing timed contacts TR2 to close immediately (Figure 12–10). Although this process seems long when discussed in step-by-step order, it actually takes place almost instantly.

When the STOP button is pressed, all CR contacts open immediately (Figure 12–11 on page 162). Motor #1 continues to run because the now closed TR1 contact maintains a circuit to the coil of 1M starter. Motor #2 continues to run because of the now closed TR2 contact. Motor #3, however, stops immediately when the CR contact connected in series with coil 3M opens. This causes the 3M auxiliary contact connected in series with TR2 coil to open and de-energizes the timer. Because TR2 is an off-delay timer, the timing process starts when the coil is de-energized. TR2 contact remains closed for a period of 5 seconds before it opens.

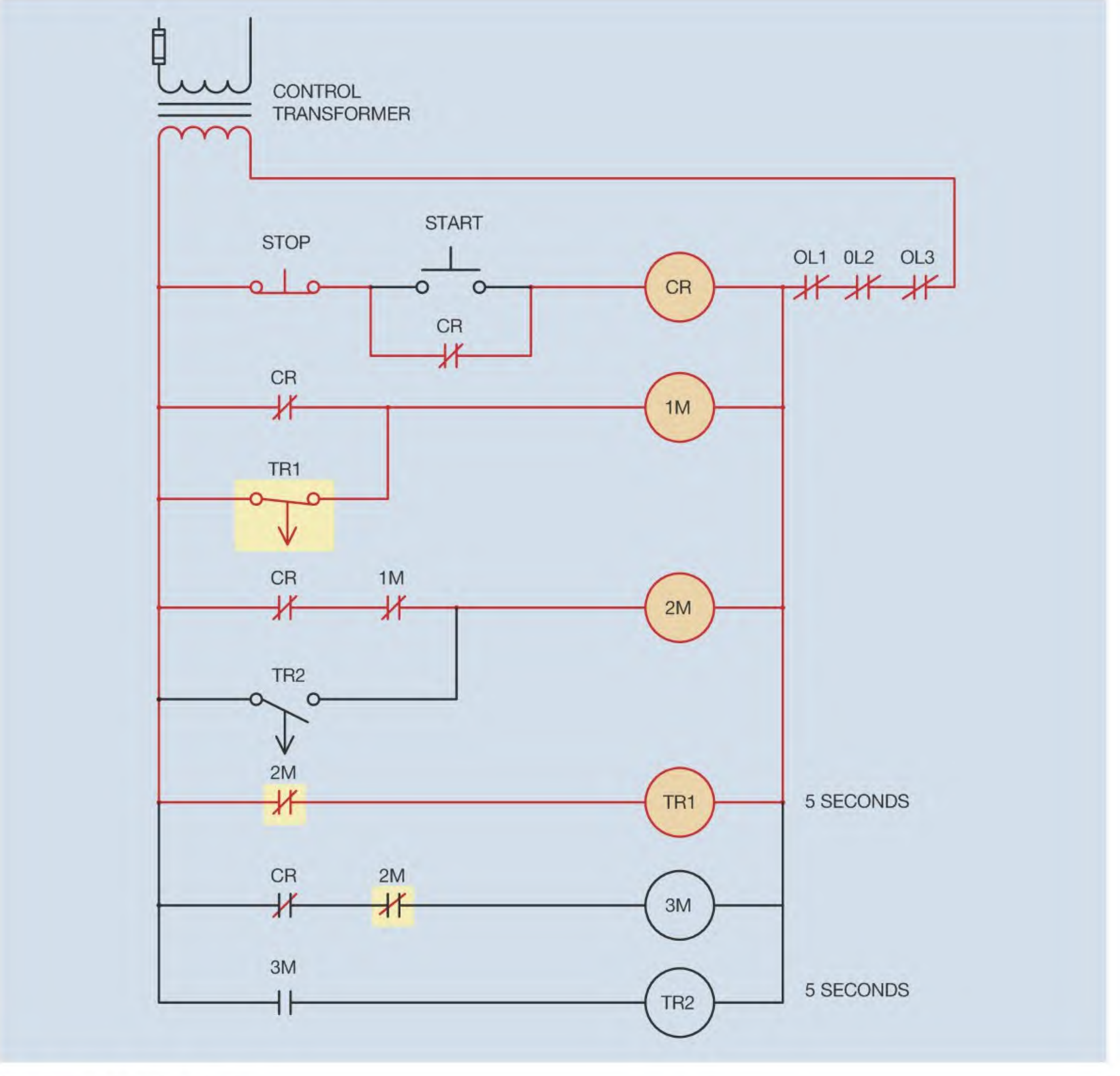


Figure 12–9 Motor #2 starts.

When TR2 contact opens, coil 2M de-energizes and stops motor #2. When the 2M auxiliary contacts open, TR1 coil de-energizes and starts the time delay for contact TR1 (Figure 12–12 on page 163). After a delay of 5 seconds, timed contact TR1 opens and de-energizes coil 1M, stopping motor #1 and opening the 1M auxiliary contact connected in series with coil 2M. The circuit is now back in its normal de-energized state as shown in Figure 12–6.

Timed Starting and Stopping of Three Motors

The addition of two timers makes it possible to start the motors in sequence from #1 to #3 with a time delay between the starting of each motor as well as stopping the motors in sequence from #3 to #1 with a time delay between the stopping of each motor. The circuit shown in Figure 12–13 on page 164 makes this amendment.

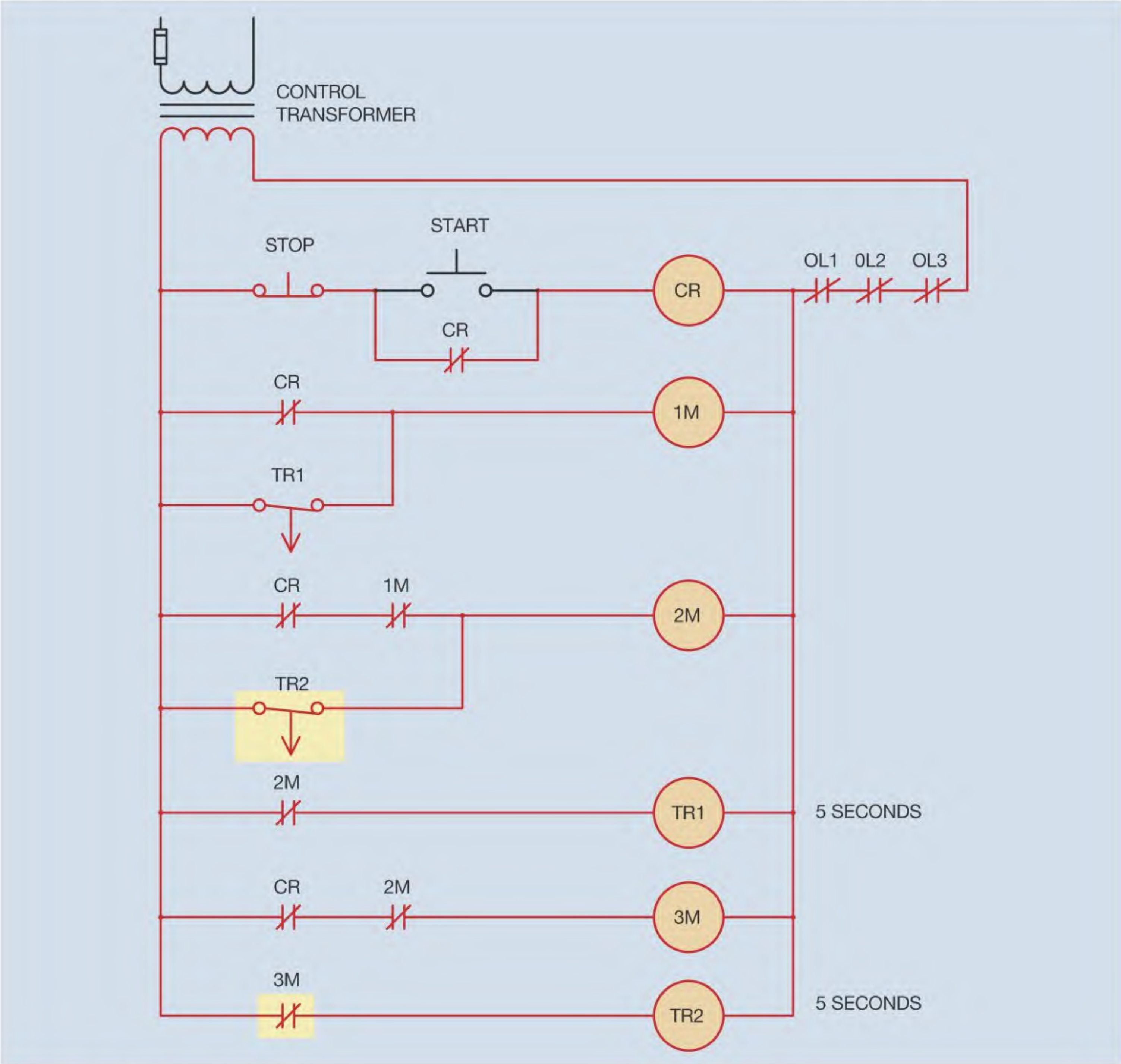


Figure 12–10 Motor #3 starts.

When the START button is pressed, all CR contacts close. Motor #1 starts immediately when starter 1M energizes. The 1M auxiliary contact closes and energizes on-delay timer TR3. After 5 seconds, starter 2M energizes and starts motor #2. The 2M auxiliary contact connected in series with off-delay timer TR1 closes causing timed contact TR1 to close immediately. The second 2M auxiliary contact connected in series with on-delay timer TR4 closes and starts the timing process. After 5 seconds, timed contact TR4 closes and energizes starter coil 3M starting motor #3. The 3M auxiliary contact connected in series with off-delay timer TR2 closes and energizes the timer. Timed contact TR2 closes immediately. All motors are now running.

When the STOP button is pressed, all CR contacts open immediately. This de-energizes starter 3M stopping

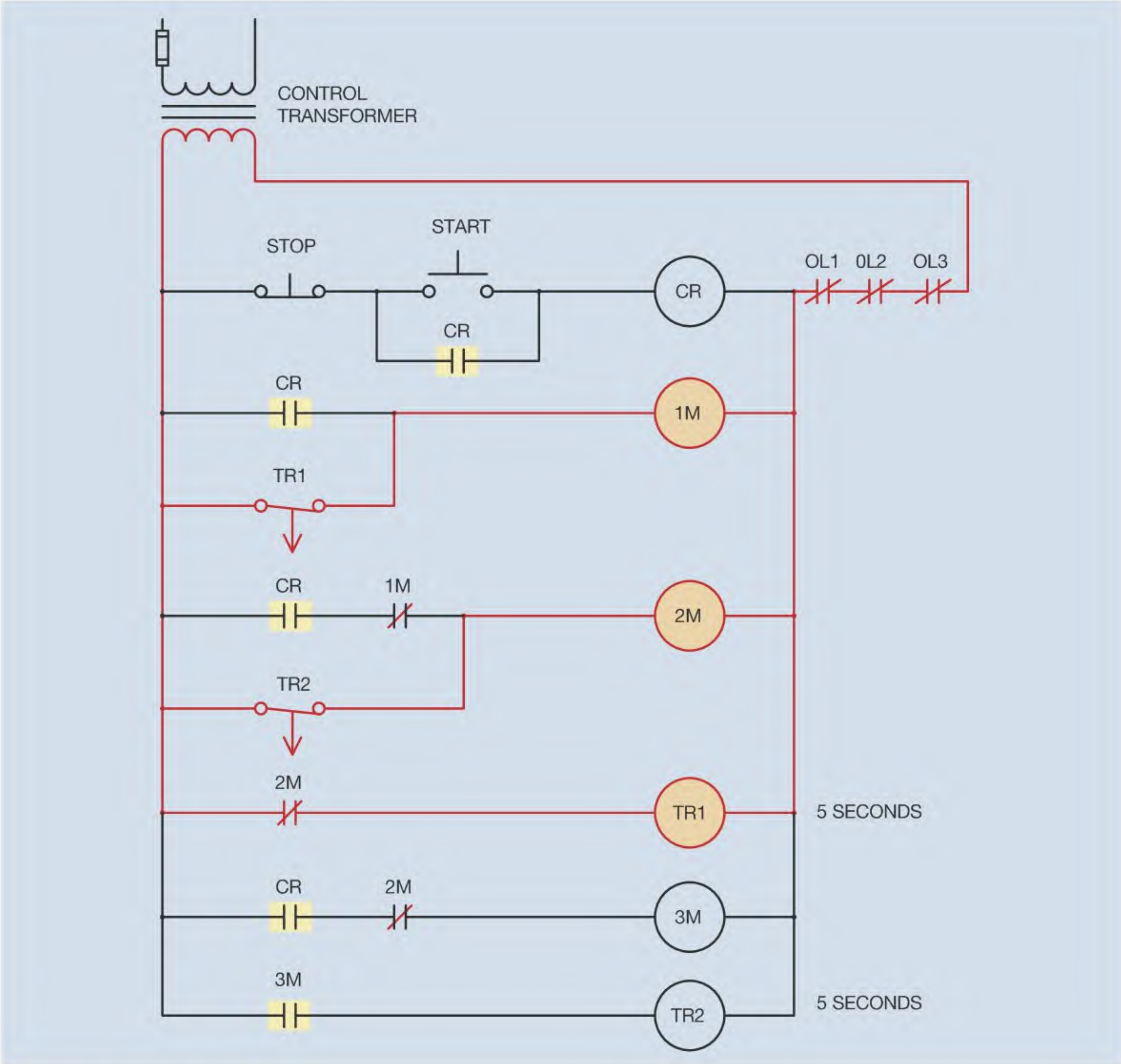


Figure 12–11 Motor #3 stops.

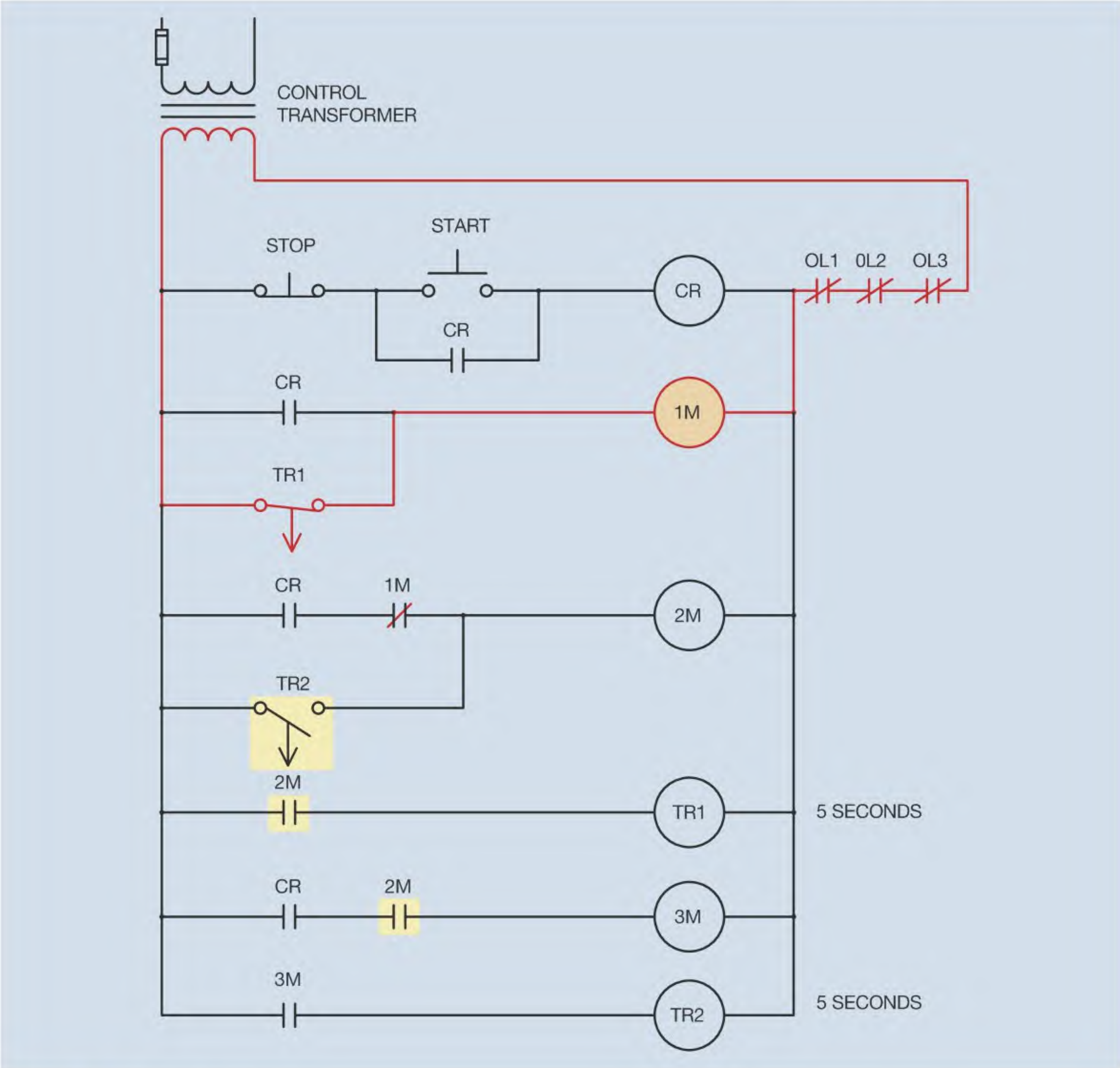


Figure 12–12 Motor #2 stops.

motor #3 and de-energizing off-delay timer coil TR2. After a delay of 5 seconds, timed contact TR2 opens and de-energizes starter 2M. This causes motor #2 to stop, off-delay timer TR1 to de-energize, and on-delay timer TR4 to de-energize. TR4 contact reopens immediately. After a delay of 5 seconds, timed contact TR1 opens and de-energizes starter coil 1M. This causes motor #1 to stop and on-delay timer TR3 to de-energize. Contact TR3 reopens immediately and the circuit is back in its original de-energized state.

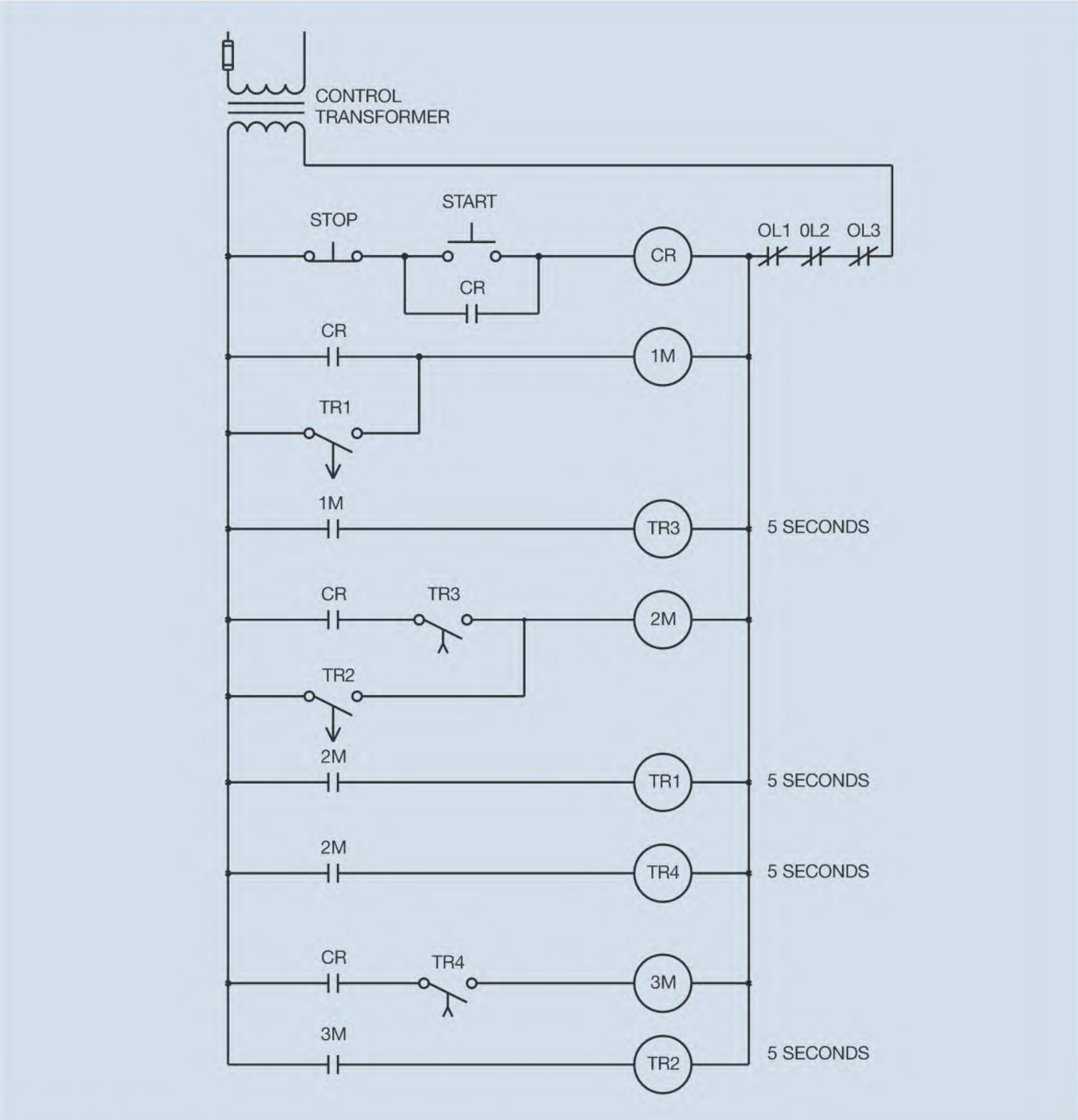


Figure 12–13 Motors start and stop in sequence with a time delay between starting and stopping.

Review Questions

1. What is the purpose of sequence control?
2. Refer to the schematic diagram in Figure 12–14. Assume that the 1M contact located between wire numbers 29 and 30 had been connected normally closed instead of normally open. How would this circuit operate?
3. Assume that all three motors shown in Figure 12–14 are running. Now assume that the STOP button is pressed and motors #1 and #2 stop running, but motor #3 continues to operate. Which of the following could cause this problem?
   a. STOP button is shorted.
   b. The 2M contact between wire numbers 31 and 32 is hung closed.

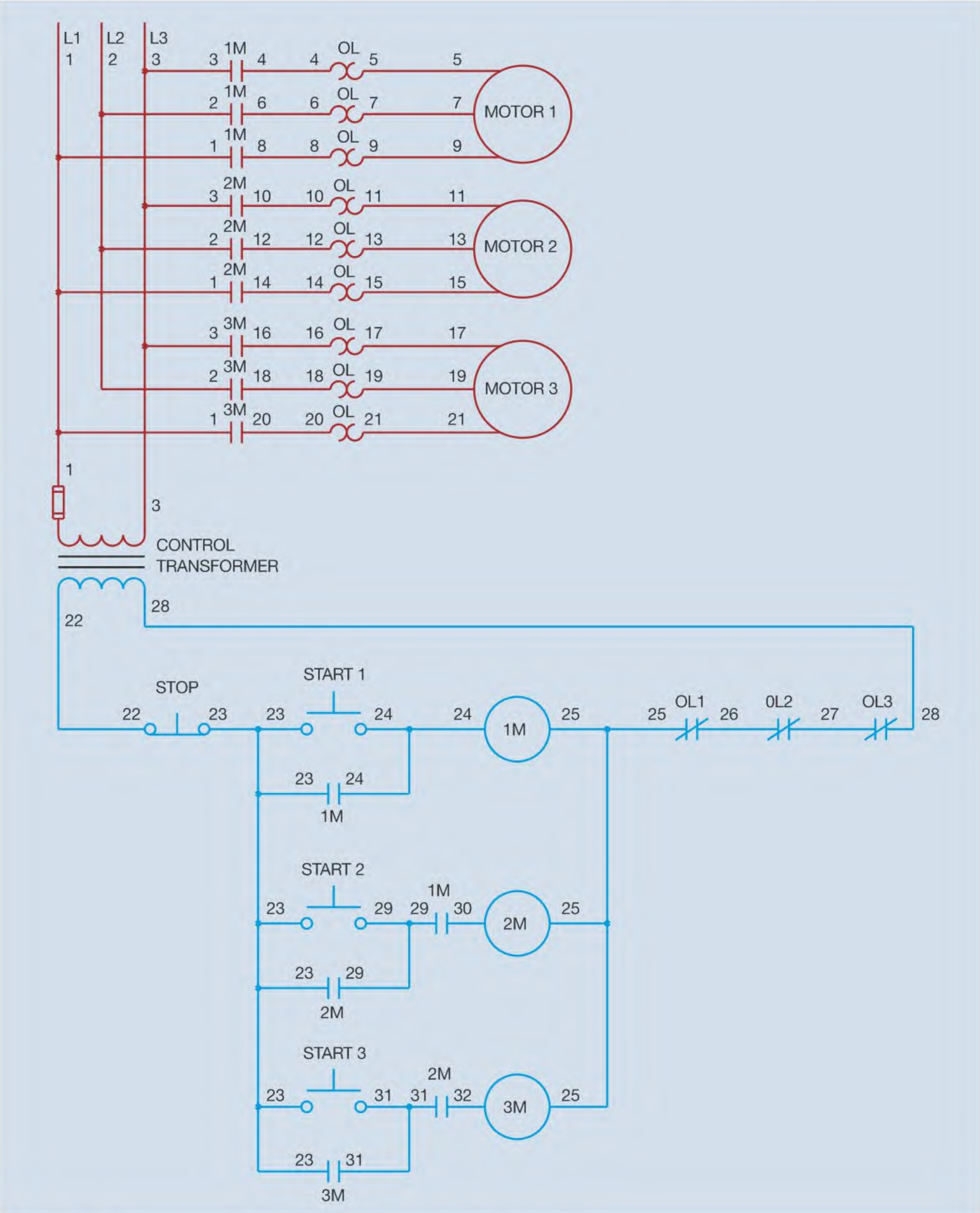


Figure 12–14 Sequence control schematic with wire numbers. Basic control circuits.

c. The 3M load contacts are welded shut.
d. The normally open 3M contact between wire numbers 23 and 31 is hung closed.

4. Referring to Figure 12–14, assume that the normally open 2M contact located between wire numbers 23 and 29 is welded closed. Also assume that none of the motors are running. What would happen if:
   a. The number 2 push button was to be pressed before the number 1 push button?
   b. The number 1 push button was to be pressed first?

5. In the control circuit shown in Figure 12–2, if an overload occurs on any motor, all three motors will stop running. Using a separate sheet of paper, redesign the circuit so that the motors must still start in sequence from #1 to #3, but an overload on any motor will stop only that motor. If an overload should occur on motor #1, for example, motors #2 and #3 would continue to operate.

Section 3

SENSING DEVICES

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Chapter 13

PRESSURE SWITCHES AND SENSORS

Objectives

After studying this chapter the student will be able to:

- Describe the operation of high pressure switches.
- Describe the operation of low pressure switches.
- Make connection of a high pressure switch.
- Make connection of a low pressure switch.
- Discuss differential setting of pressure switches.
- Discuss pressure sensors that convert pressure to current for instrumentation purposes.

Pressure switches are found throughout the industry in applications where it is necessary to sense the pressure of pneumatic or hydraulic systems. Pressure switches are available that can sense pressure changes of less than 1 psi (pounds per square inch) or pressures over 15,000 psi. A diaphragm-operated switch can sense small pressure changes at low pressure (Figure 13–1).

A metal bellows type switch can sense pressures up to 2,000 psi. The metal bellows type pressure switch employs a metal bellows that expands with pressure (Figure 13–2). Although this switch can be used to sense a much higher pressure than the diaphragm type, it is not as sensitive in that it takes a greater change in pressure to cause the bellows to expand enough to activate a switch. A piston type pressure switch can be used for pressures up to 15,000 psi (Figure 13–3).

Regardless of the method used to sense pressure, all pressure switches activate a set of contacts. The contacts may be either single pole or double pole depending on the application, and will be designed with some type of snap action mechanism. Contacts cannot be permitted to slowly close or open. This would produce a bad connection and cause burning of the contacts as well as low

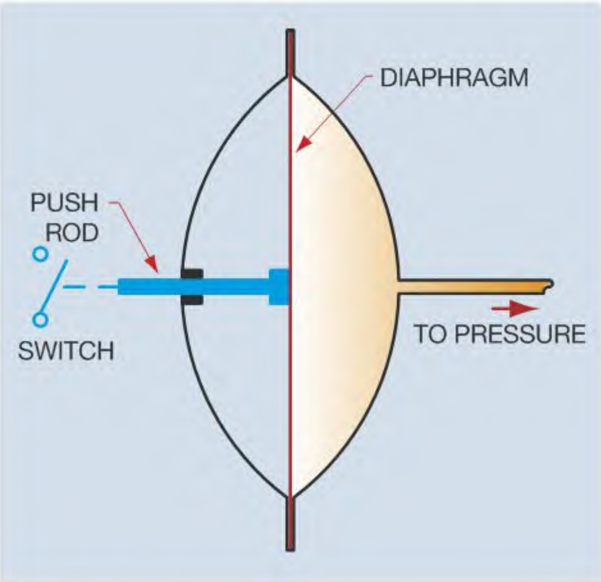


Figure 13–1 A diaphragm type pressure switch can sense small pressure changes at a low pressure.

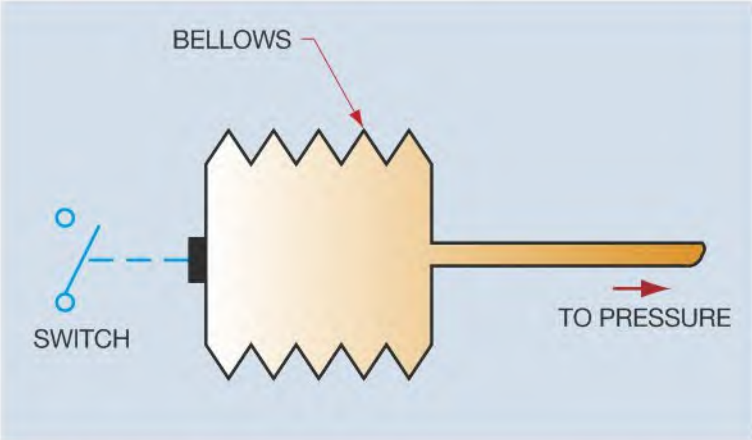


Figure 13–2 A metal bellows type pressure switch can be used for pressures up to 2000 psi.

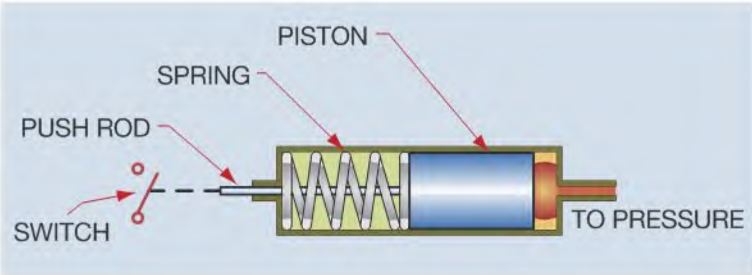


Figure 13–3 Piston type pressure switches can be used for pressures up to 15,000 psi.

Figure 13–4 Line voltage pressure switch.

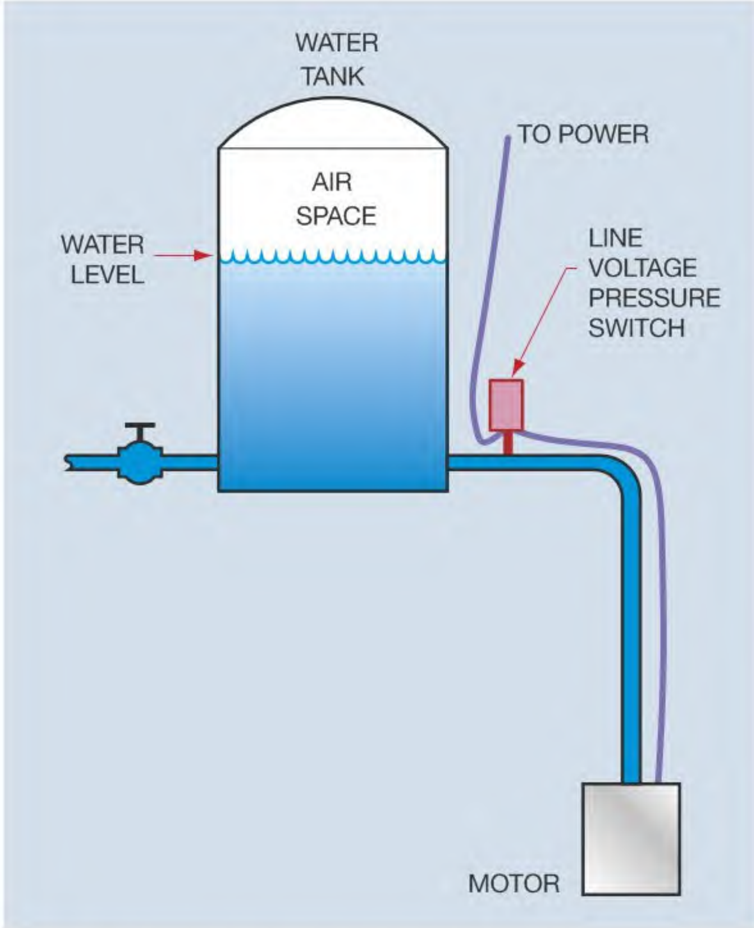


Figure 13–5 A line voltage pressure switch controls the operation of a pump motor.

voltage problems to the equipment they control. Some pressure switches are equipped with contacts large enough to connect a motor directly to the power line, and others are intended to control the operation of a relay coil. A line voltage type pressure switch is shown in Figure 13–4. Pressure switches of this type are often used to control the operation of well pumps and air compressors (Figure 13–5).

Differential Pressure

Differential pressure is the difference in pressure between cut-in or turn-on pressure and the cut-out or turn-off pressure. Most pressure switches provide a means for setting the pressure differential. In the example shown in Figure 13–5, a line voltage pressure switch controls the motor of a well pump. Typically, a pressure switch of this type would be set to cut in at about 30 psi and cut out at about 50 psi. The 20 pounds of differential pressure is necessary to prevent overworking the pump motor. Without differential pressure, the pump motor would continually turn on and off, which is what happens when a tank becomes waterlogged. An air space must be maintained in the tank to permit the pressure switch to function. The air space is necessary because air can be compressed, but a liquid cannot. If the tank becomes waterlogged the pressure switch would turn on and off immediately each time a very small amount of water was removed from the tank. Pressure switch symbols are shown in Figure 13–6.

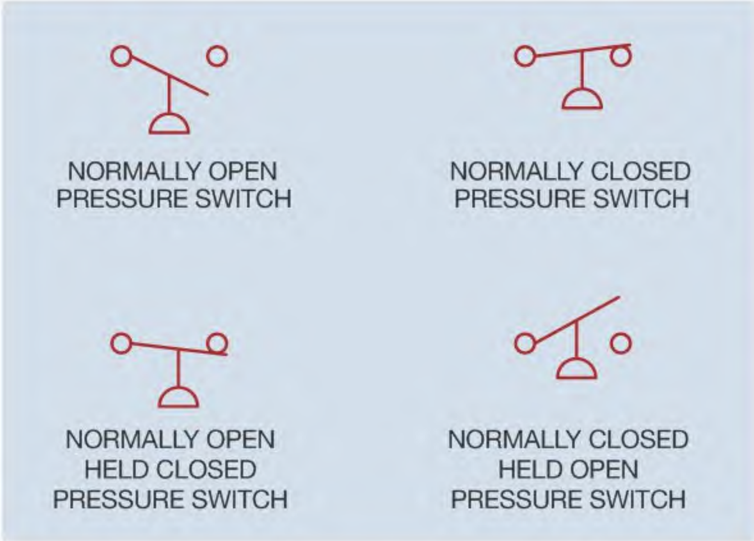


Figure 13–6 Pressure switch symbols.

Typical Application

Pressure switches are used in many common industrial applications. The circuit shown in Figure 13–7 employs a pressure switch to disconnect a motor and turn on two warning lights in the event of a high-pressure condition. The pressure switch contains both normally open and normally closed contacts. The normally closed part of the pressure switch is connected to a control relay labeled PSCR 2 (pressure switch control relay #2), and the normally open part of the switch is connected to a control relay labeled PSCR 1. In order for the control circuit to perform its desired function, the pressure switch must contain five different contacts, three normally closed and two normally open. Because pressure switches do not contain contacts in this arrangement,

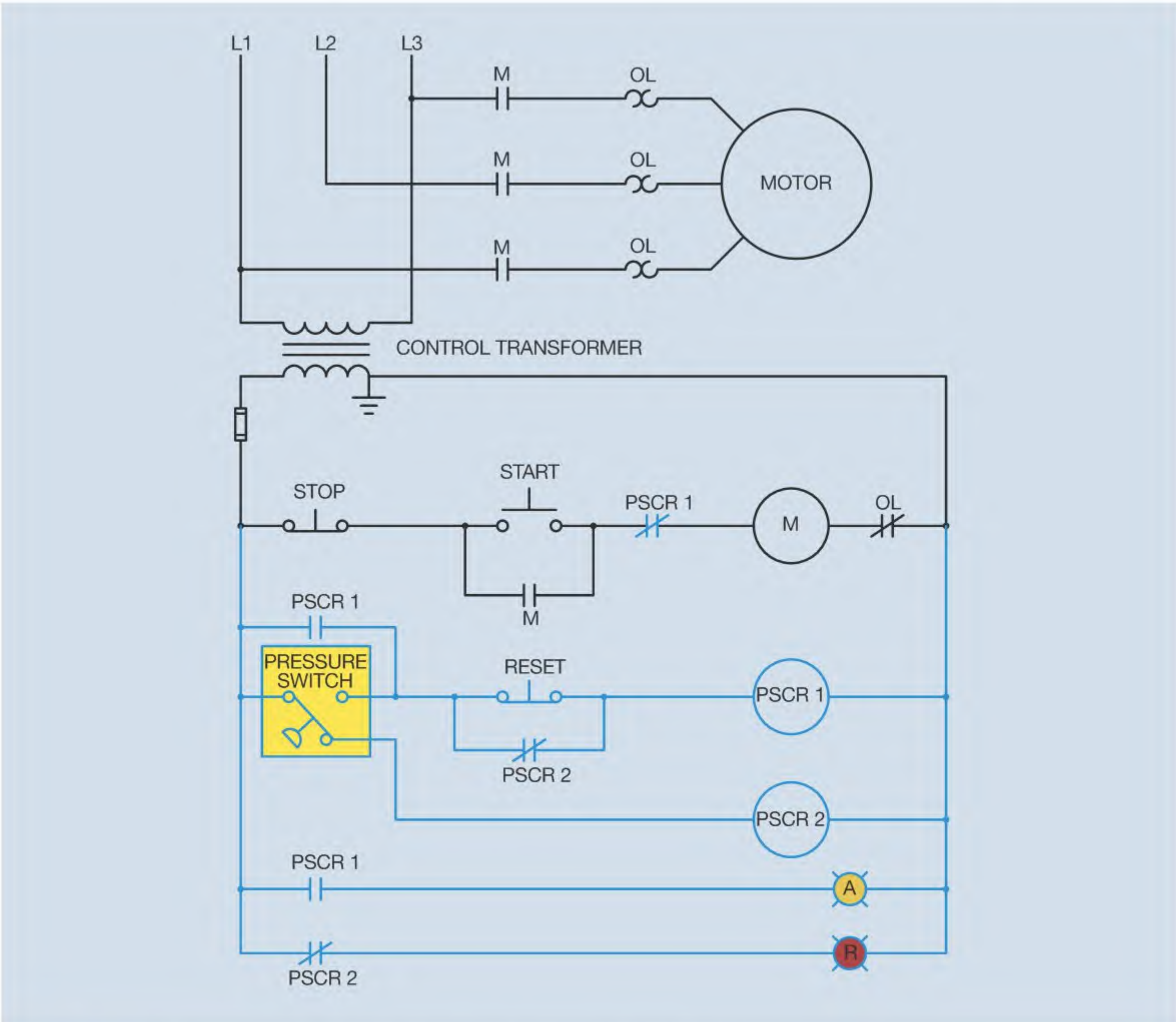


Figure 13–7 High pressure turns off the motor and turns on a warning light.

it is common practice to permit sensing devices such as pressure switches, limit switches, float switches, and others to operate control relays that do contain the necessary contacts.

Circuit Operation

When the pressure is below the value that will cause the pressure switch to activate, the normally closed part of the switch will provide continuous power to the coil of PSCR 2 control relay. Both PSCR 2 normally closed contacts will, therefore, be open anytime that the pressure is below that necessary to activate the pressure switch.

If the pressure should increase to a value that causes the pressure switch to activate, the switch contacts will change from the closed to the open position. When the contacts change position, power is no longer supplied to the coil of PSCR 2 relay coil and both PSCR 2 contacts close. One PSCR 2 contact is connected in parallel with the reset button. This now closed contact will prevent the reset button from working as long as the pressure is in a high condition. The second PSCR 2 contact now supplies power to a red warning light that indicates a high-pressure condition.

When the pressure switch activates, the normally open contact provides power to the coil of PSCR 1 relay coil, causing all PSCR 1 contacts to change position. The normally closed PSCR 1 contact connected in series with M starter opens and de-energizes the starter causing the motor to stop. One normally open PSCR 1 contact connected in parallel with the pressure switch closes to provide a path around the switch when the pressure returns to a low-enough level to permit the pressure switch to return to its normal position. A second normally open PSCR 1 contact closes to turn on an amber warning light to indicate that the motor has been stopped due to a high-pressure condition.

As long as the high-pressure condition continues, the red warning light will remain on and the circuit cannot be reset. Once the pressure has returned to a safe level, the red warning light will turn off, but the amber warning light will remain on until the reset button is pressed. The motor cannot be restarted until the circuit has been reset.

Connecting the Circuit

The PSCR 1 control relay must contain at least three separate contacts, two normally open and one normally closed. Because an 11 pin control relay contains three sets of both normally open and normally closed contacts, an 11 pin control relay will be used for the PSCR 1 relay in this example. The PSCR 2 control relay contains two normally closed contacts. An 8 pin control relay contains two sets of both normally open and normally closed contacts. An 8 pin control relay will be used for the PSCR 2 relay in this example. Both 11 pin and 8 pin control relays are shown in Figure 13–8. Both the 8 pin and 11 pin control relays are designed to plug into relay sockets (Figure 13–9). When connecting relays of this type, wires are connected to the socket, not the relay itself. Because the socket, not the relay, is connected in the circuit, a relay can be replaced very quickly in the event that it fails. The pin diagram for both 8 pin and 11 pin relays of this type is shown in Figure 13–10. The circuit shown in Figure 13–7 is shown in Figure 13–11 with the addition of wire numbers. There are several criteria

Figure 13–8 8 pin and 11 pin control relays.

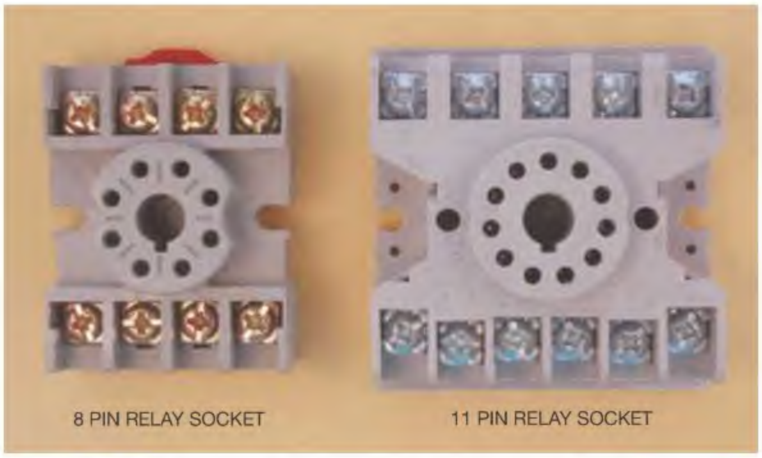


Figure 13–9 8 pin and 11 pin control relay sockets.

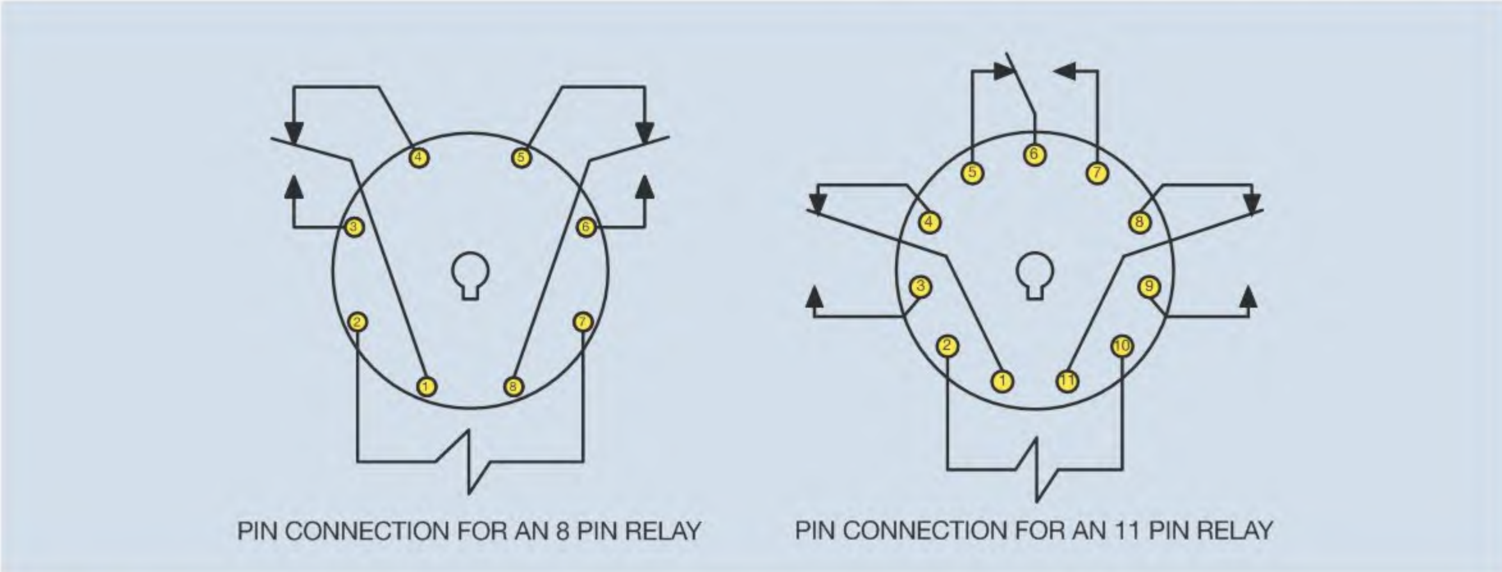


Figure 13–10 Pin connection diagrams for 8 and 11 pin relays.

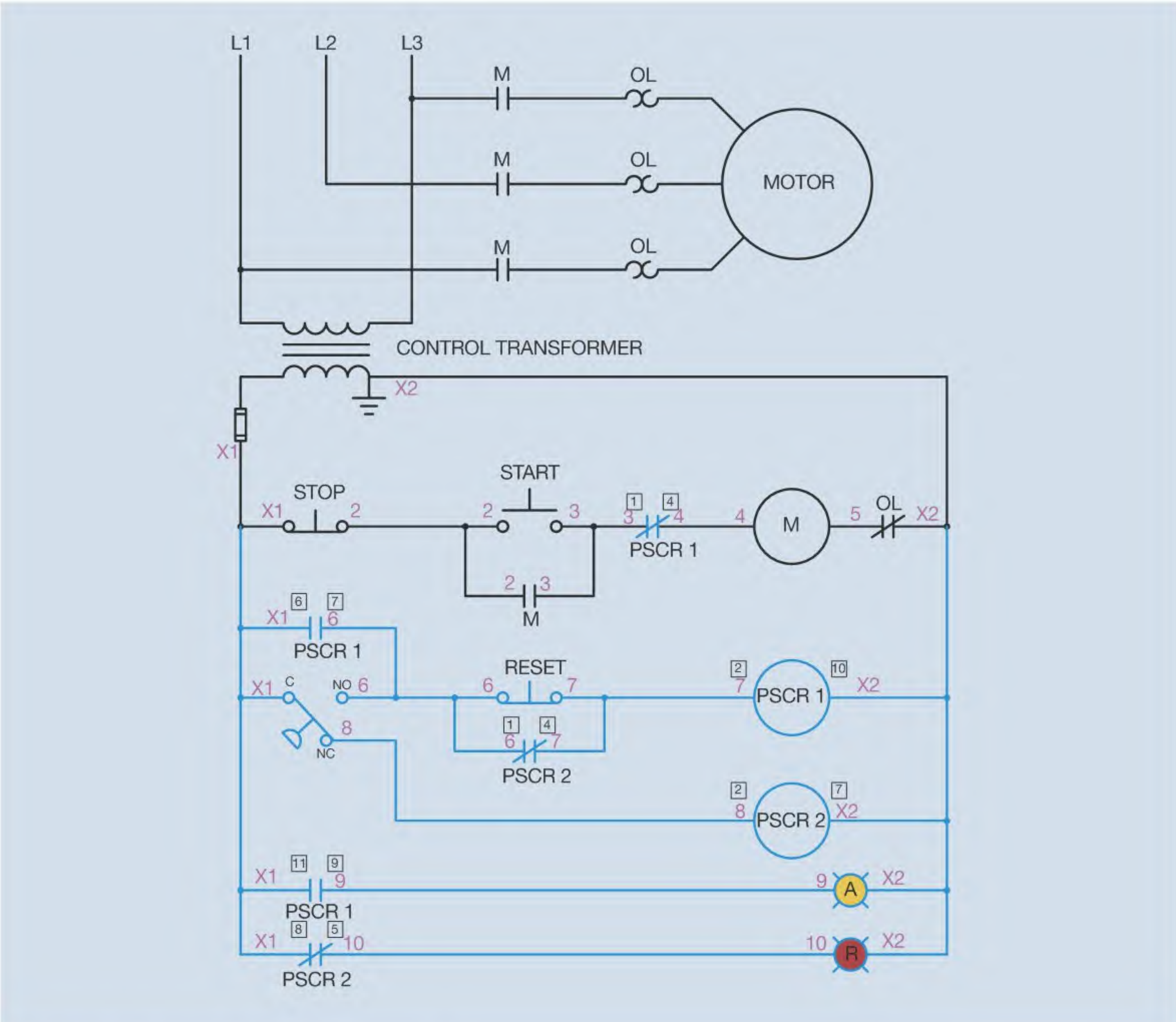


Figure 13–11 Control circuit with wire numbers.

concerning this particular connection that should be understood:

1. Only the control wiring will be numbered. The main power wiring does not contain wire numbers. This is a very common practice in industrial schematics.

2. It is assumed that the fuse connected to the secondary of the transformer is integral with the transformer. Therefore, wire numbers will begin at the fuse output.

3. When connecting relays of this type, it is common practice to place pin numbers beside the components. To prevent confusing pin numbers with wire numbers, the pin numbers are placed inside a circle or square. The schematic shows that a normally closed PSCR 1 contact is connected in series with the coil of M starter. The pin diagram in Figure 13-10 indicates that a normally closed contact is located between pins 1 and 4. The schematic also shows two normally open PSCR 1 contacts. The pin diagram indicates that pins 6 and 7 and pins 11 and 9 are connected to normally open contacts. The coil of PSCR 1 relay is connected to pins 2 and 10. The schematic indicates that two normally closed contacts are controlled by PSCR 2 control relay. The pin diagram for an 8 pin control relay shows that one of the normally closed contacts is located between pins 1 and 4 and a second normally closed contact is located between pins 8 and 5. The coil of PSCR 2 relay is connected to pins 2 and 7.

4. Many control schematics use X1 as the number for one side of the control transformer and X2 for the other. The schematic in Figure 13-11 will be numbered in the manner described by the preceding criteria.

The components with corresponding wire numbers are shown in Figure 13-12, and the circuit with wire

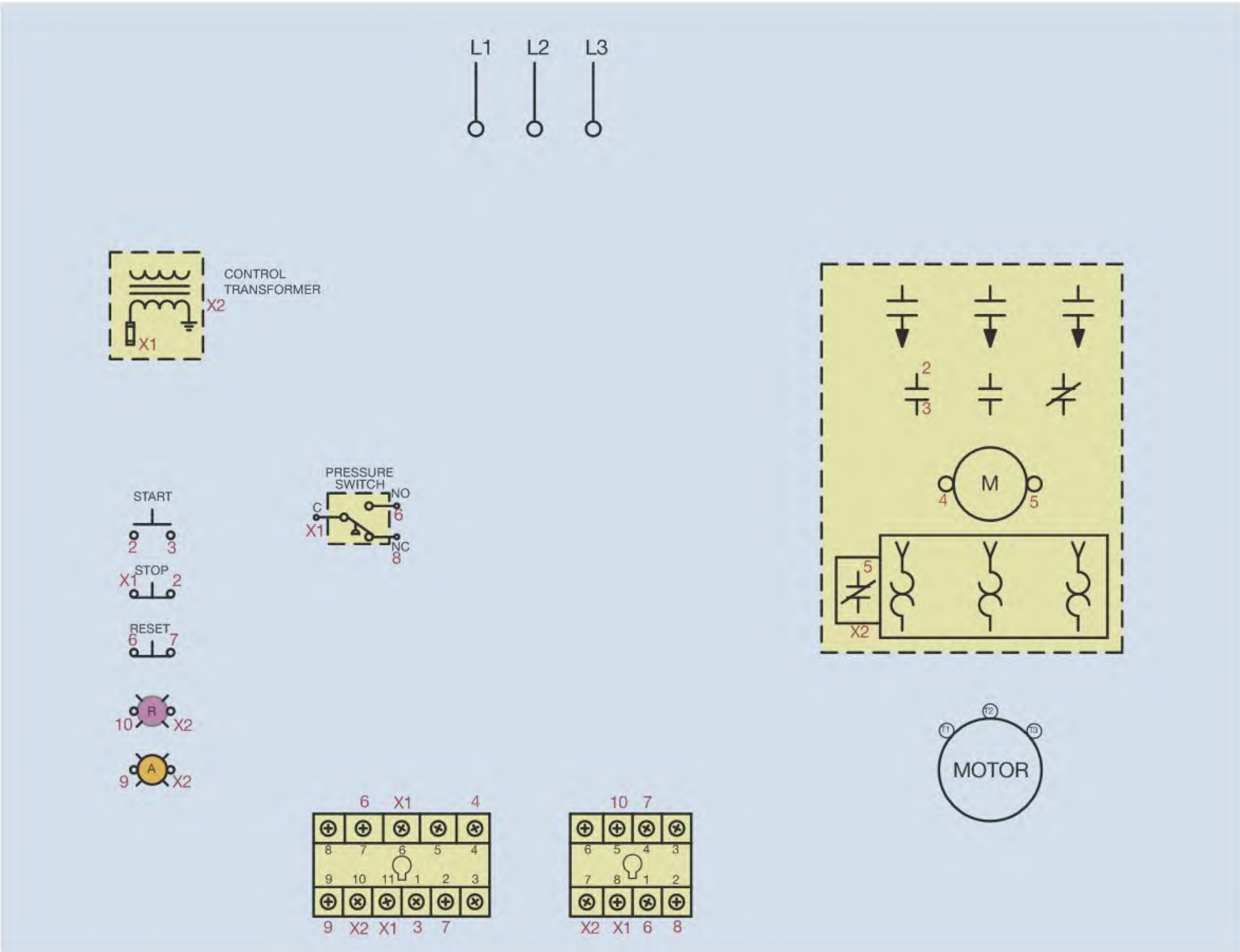


Figure 13–12 Components with corresponding wire numbers.

connections is shown in Figure 13-13. The wire connections are made by connecting all components with the same wire number together.

Pressure Sensors

Pressure switches are not the only pressure sensing devices that an electrician is likely to encounter on the job. This is especially true in an industrial environment. It is often necessary to not only know if the pressure has reached a certain level but also to know the amount of pressure. Although sensors of this type are generally considered to be in the instrumentation field, an electrician should be familiar with some of the various types and how they operate.

Pressure sensors are designed to produce an output voltage or current that is dependent on the amount of pressure being sensed. Piezoresistive sensors are very popular because of their small size, reliability, and accuracy (Figure 13–14). These sensors are available in ranges from 0–1 psi (pounds per square inch) and 0–30 psi. The sensing element is a silicon diaphragm integrated with an integrated circuit chip. The chip contains four implanted piezoresistors connected to form a bridge circuit (Figure 13–15). When pressure is applied to the diaphragm, the resistance of piezoresistors changes proportionally to the applied pressure, which changes the balance of the bridge. The voltage across V0 changes in

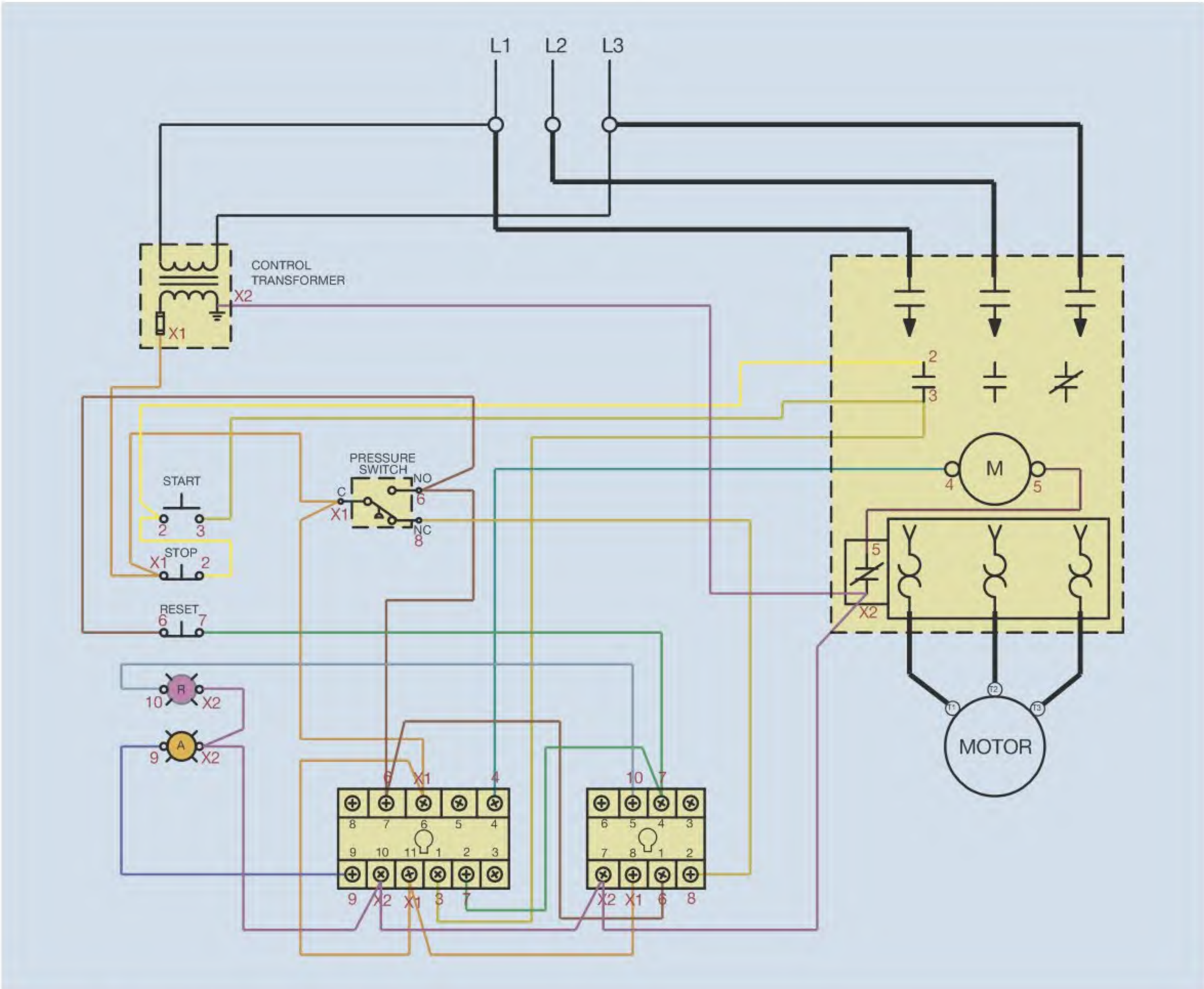
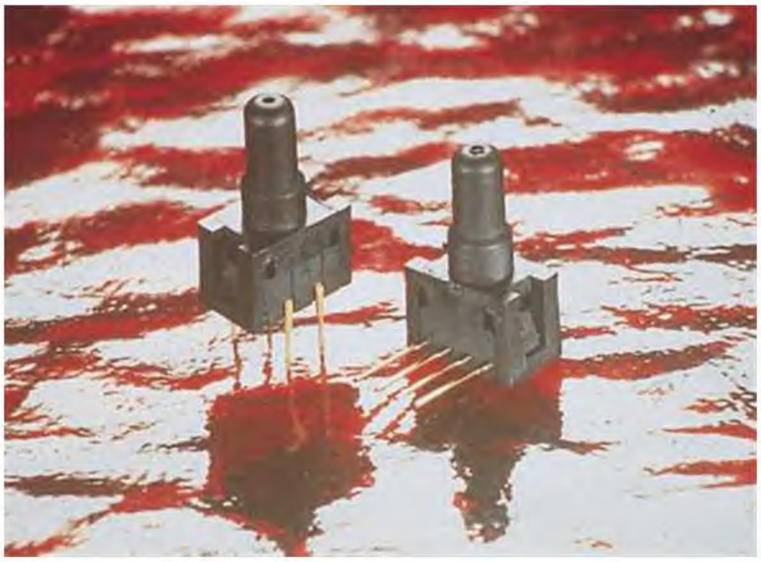


Figure 13–13 Circuit with wire connections.



Courtesy of Honeywell International Inc.

Figure 13–14 Piezoresistive pressure sensor.

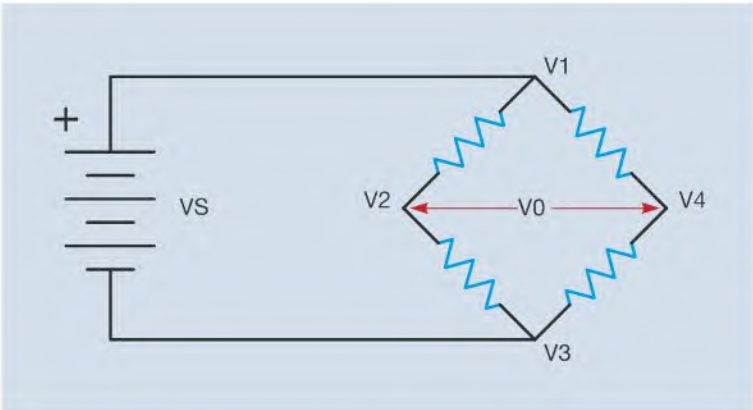


Figure 13–15 Piezoresistive bridge.

proportion to the applied pressure (V0 = V4 − V2 [when referenced to V3]). Typical millivolt outputs and pressures are shown below:

1 psi = 44 mV
5 psi = 115 mV
15 psi = 225 mV
30 psi = 315 mV

Another type of piezoresistive sensor is shown in Figure 13–16. This particular sensor can be used to sense absolute, gauge, or differential pressure. Units are available that can be used to sense vacuum. Sensors of this type can be obtained to sense pressure ranges of 0–1, 0–2, 0–5, 0–15, 0–30, and 0–(−15[vacuum]). The sensor contains an internal operational amplifier and can provide an output voltage proportional to the pressure. Typical supply voltage for this unit is 8 VDC. The *regulated* voltage output for this unit is 1–6 volts. Assume, for example, that the sensor is intended to sense a pressure

Courtesy of Honeywell International Inc.

Figure 13–16 Differential pressure sensor.

range of 0–15 psi. At 0 psi the sensor would produce an output voltage of 1 volt. At 15 psi the sensor would produce an output voltage of 6 volts.

Sensors can also be obtained that have a ratiometric output. The term *ratiometric* means that the output voltage will be proportional to the supply voltage. Assume that the supply voltage increases by 50 percent to 12 VDC. The output voltage would increase by 50 percent also. The sensor would now produce a voltage of 1.5 volts at 0 psi and 9 volts at 15 psi.

Other sensors can be obtained that produce a current output of 4 to 20 mA, instead of a regulated voltage output (Figure 13–17). One type of pressure to current sensor, which can be used to sense pressures as high as 250 psi, is shown in Figure 13–18. This sensor

Courtesy of Honeywell International Inc.

Figure 13–17 Pressure to current sensor for low pressures.

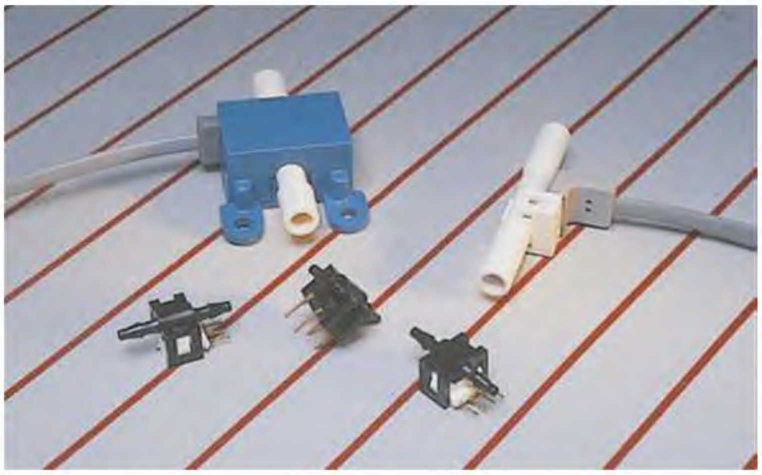
Courtesy of Honeywell International Inc.

Figure 13–18 Pressure to current sensor for high pressure.

can also be used as a set point detector to provide a normally open or normally closed output. Sensors that produce a proportional output current instead of voltage have fewer problems with induced noise from surrounding magnetic fields, and with voltage drops due to long wire runs.

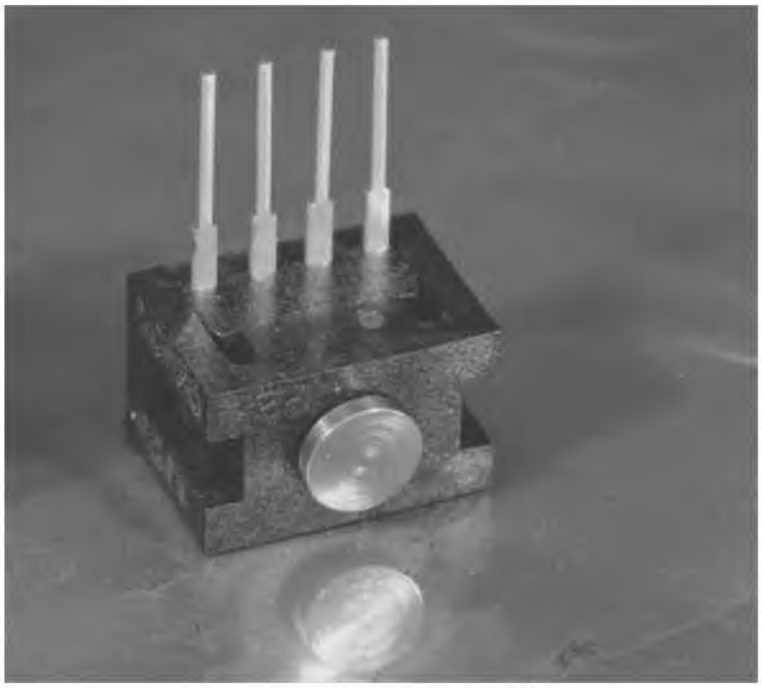
A flow-through pressure sensor is shown in Figure 13–19. This type of sensor can be placed in line with an existing system. In-line pressure sensors make it easy to add a pressure sensor to an existing system.

Another device that is basically a pressure sensor is the force sensor (Figure 13–20). This sensor uses silicon piezoresistive elements to determine the amount of pressure to the sensing element.



Courtesy of Honeywell International Inc.

Figure 13–19 Flow-through pressure sensor.



Courtesy of Honeywell International Inc.

Figure 13–20 Force sensor.

Review Questions

1. What type of pressure switch is generally used to sense small changes in low pressure systems?
2. A pressure switch is set to cut in at a pressure of 375 psi and cut out at 450 psi. What is the pressure differential for this switch?
3. A pressure switch is to be installed on a system with pressures that can range from 1500 psi to 1800 psi. What type of pressure switch should be used?
4. A pressure switch is to be installed in a circuit that requires it to have three normally open contacts and one normally closed contact. The switch actually has one normally open contact. What must be done to permit this pressure switch to operate in this circuit?
5. What is a piezoresistor?
6. Refer to the circuit shown in Figure 13–7. If the pressure should become high enough for the pressure switch to close and stop the motor, is it possible to restart the motor before the pressure drops to a safe level?
7. Refer to the circuit shown in Figure 13–7. Assume that the motor is running and an overload occurs and causes the overload contact to open and disconnect coil M to stop the motor. What effect does the opening of the overload contact have on the pressure switch circuit?

Chapter 14

FLOAT SWITCHES AND LIQUID LEVER SENSORS

Objectives

After studying this chapter the student will be able to:

» Describe the operation of a float switch.

» Draw schematic symbols for float switches.

» Describe methods of sensing the level of a liquid.

Float switches are used to control the action of a pump in accord with the level of a liquid in a tank or sump. The operation of the float switch is controlled by the upward or downward movement of a float in a tank of liquid. There are several styles of float switches. One employs the use of a rod with a float mounted on one end. Adjustable stops on the rod determine the amount of movement that must take place before a set of contacts is opened or closed (Figure 14–1).

Another common type of float switch is chain operated (Figure 14–2). A float is attached to one end of a chain and a counterweight is connected to the other. The float weighs more than the counterweight, which permits it to control the movement of the chain as the liquid level rises or falls. Some float switches contain large contacts that can be used to connect the motor directly to the line. The contacts may be normally open or normally closed depending on contact arrangement and may not be submerged. Float switches can be used to pump water from a tank or sump, or to fill a tank depending on the requirements of the circuit.

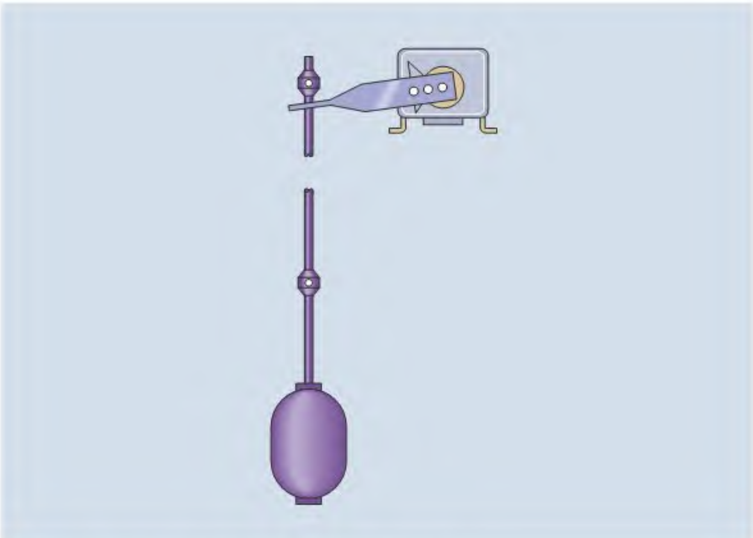


Figure 14–1 Rod-operated float switch.

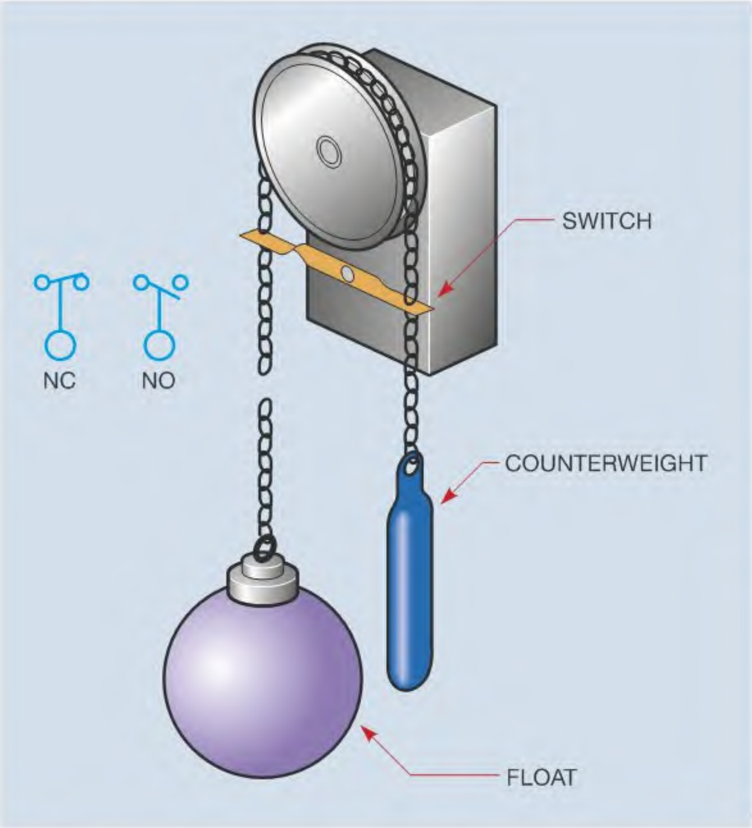


Figure 14–2 Chain-operated float switch with float switch symbols.

Mercury Bulb Float Switch

Another float switch that has become increasingly popular is the mercury bulb type of float switch. This type of float switch does not depend on a float rod or chain to operate. The mercury bulb switch appears to be a rubber bulb connected to a conductor. A set of mercury contacts is located inside the bulb. When the liquid level is below the position of the bulb, it is suspended in a vertical position (Figure 14–3A). When the liquid level rises to the position of the bulb, it changes to a horizontal position (Figure 14–3B). This change of position changes the state of the contacts in the mercury switch.

Because the mercury bulb float switch does not have a differential setting as does the rod or chain type of float switch, it is necessary to use more than one mercury bulb float switch to control a pump motor. The differential level of the liquid is determined by suspending mercury bulb switches at different heights in the tank. Figure 14–4 illustrates the use of four mercury bulb type switches used to operate two pump motors and provide a high liquid level alarm. The control circuit is shown in Figure 14–5. Float switch FS1 detects the lowest point of liquid level in the tank and is used to turn both pump motors off. Float switch FS2 starts the

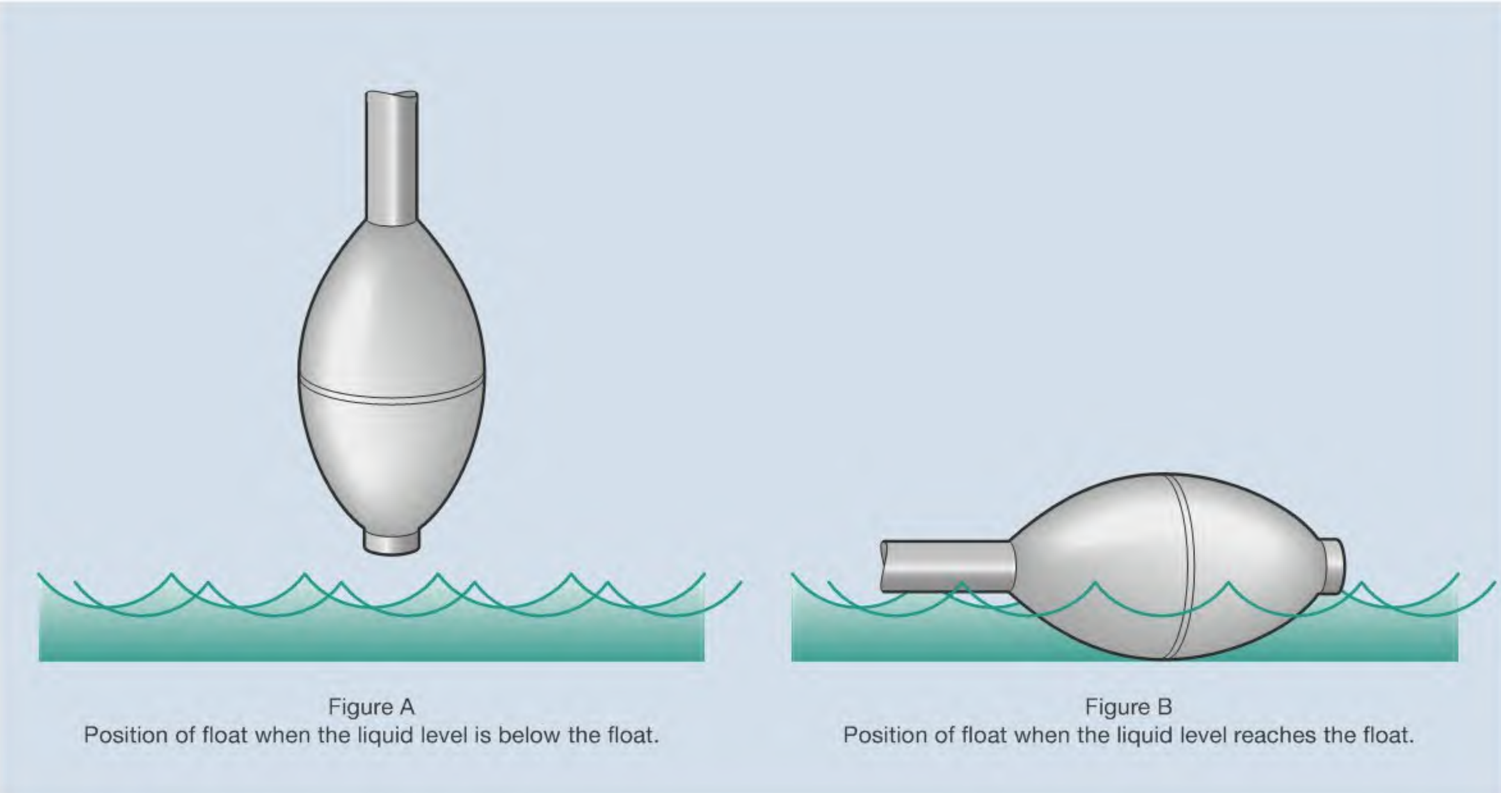


Figure 14–3 Mercury bulb type float switch.

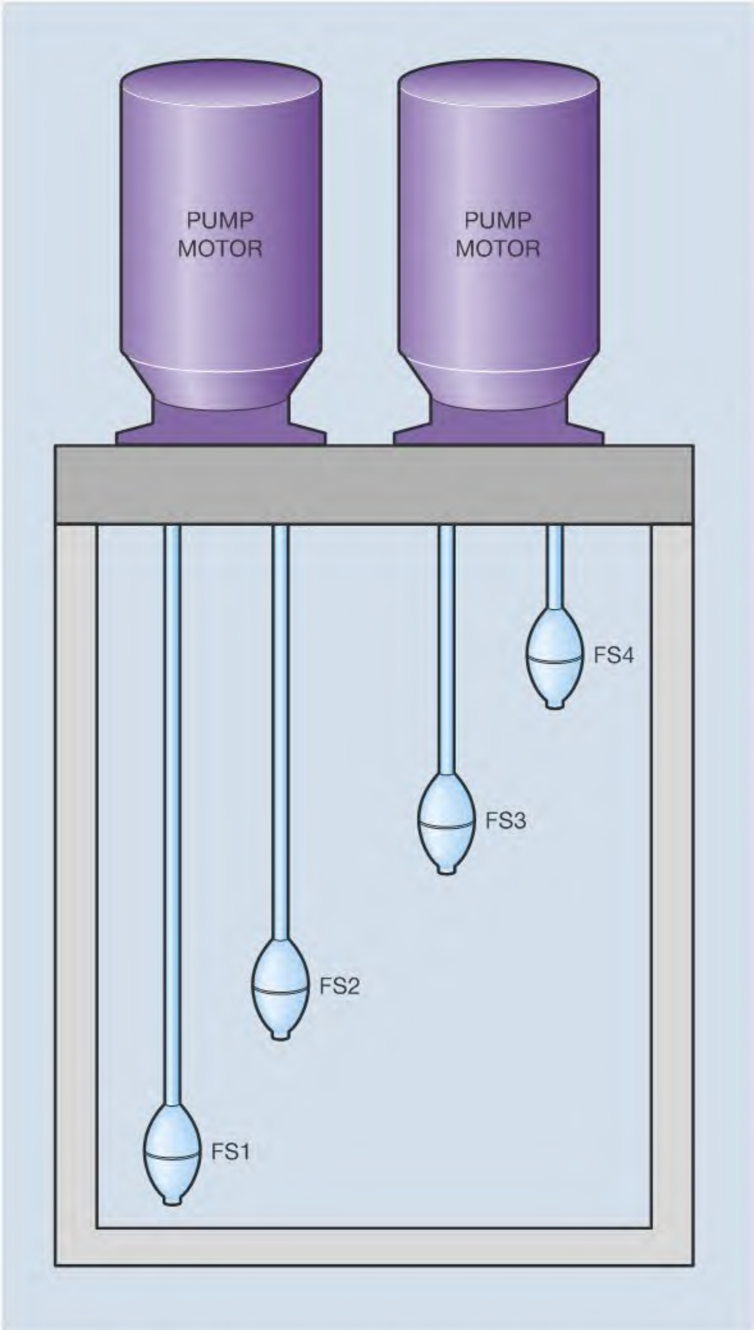


Figure 14–4 Float level is set by the length of the conductor.

first pump when the liquid level reaches that height. If pump #1 is unable to control the level of the tank, float switch FS3 will start pump motor #2 if the liquid level should rise to that height. Float switch FS4 operates a warning light and buzzer to warn that the tank is about to overflow. A reset button can be used to turn off the buzzer, but the warning light remains on until the water level drops below the level of float switch FS4.

The Bubbler System

Another method often used to sense liquid level is the bubbler system. This method does not employ the use of float switches. The liquid level is sensed by pressure switches (Figure 14–6). A great advantage of this system is that the pressure switches are located outside the tank, which makes it unnecessary to open the tank to service the system.

The bubbler system is connected to an air line, which is teed to a manifold and another line that extends down into the tank. A hand valve is used to adjust the maximum air flow. The bubbler system operates on the principle that as the liquid level increases in the tank, it requires more air pressure to blow air through the line in the tank. For example, consider a pipe with an inside area of 1 square inch (1 in^2). Each inch in length would represent a volume of 1 cubic inch (1 $in^2 \times 1$ in = 1 in^3). A cubic inch of water weighs 0.0361 pounds. If a pipe with an inside area of 1 square inch were inside a tank of water 10 feet deep, the weight of the water inside the pipe would be 4.332 pounds.

$$10\ ft \times 12\ in^3\ per\ foot = 120\ in^3$$
$$120\ in^3 \times 0.0361 = 4.332\ lb$$

It would require 4.332 pounds of air pressure to remove the water from inside the pipe. If the water inside the tank were to drop to a depth of 7 feet, it would require 3.032 pounds of air pressure to keep the pipe clear of water.

The bubbler system can be employed to measure the depth of virtually any liquid. The pressure needed would depend on the weight of the liquid. Gasoline, for example, weighs an average of 6.073 pounds per gallon, #2 diesel fuel weighs an average of 7.15 pounds per gallon, and water weighs an average of 8.35 pounds per gallon.

Because the pressure required to bubble air through the pipe is directly proportional to the height of the liquid, the pressure switches provide an accurate measure of the liquid level. The pressure switches shown in Figure 14–6 could be used to control the two pump circuit previously discussed by replacing the float switches with pressure switches in the circuit shown in Figure 14–5.

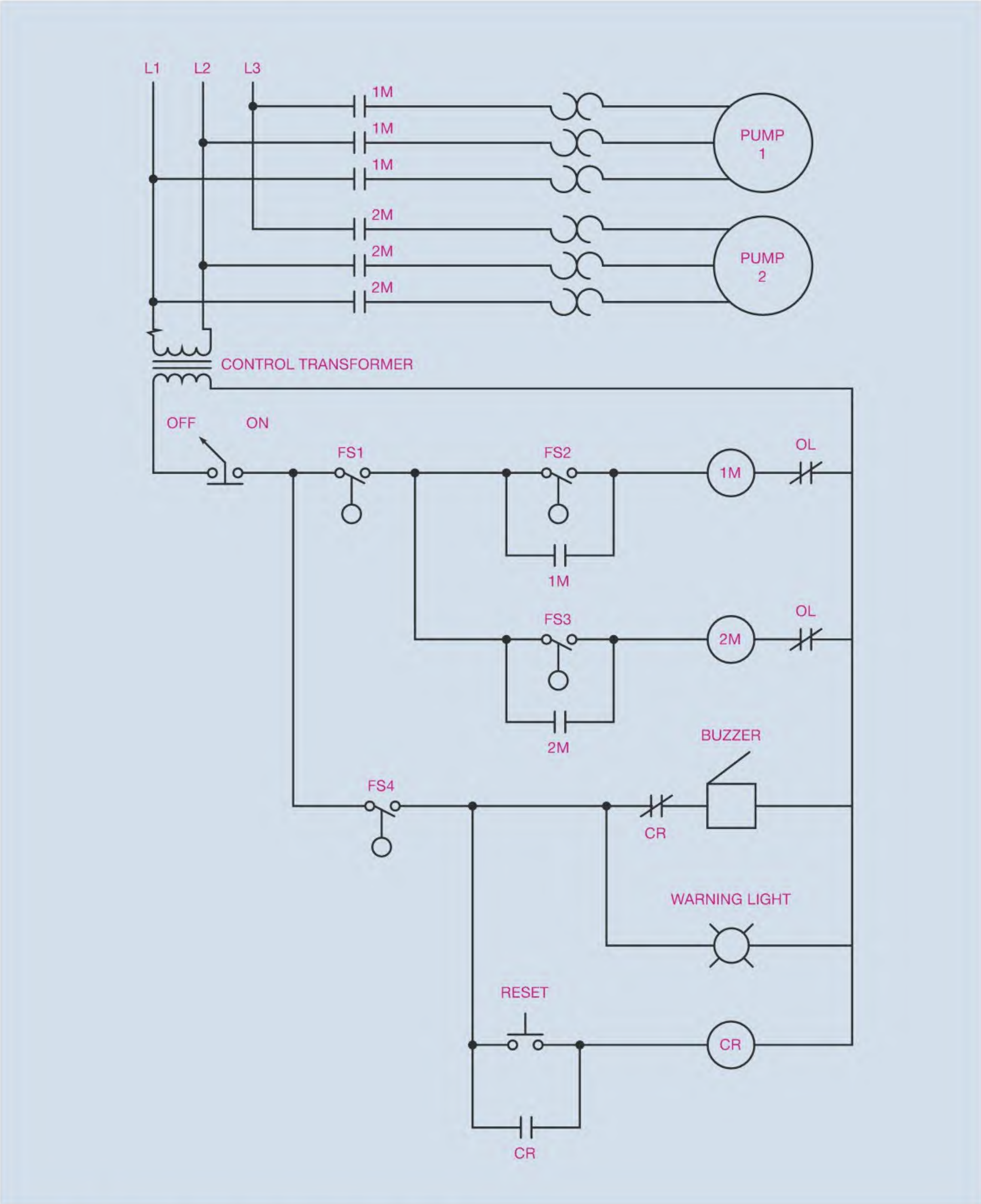


Figure 14–5 Two pump control with high liquid level warning.

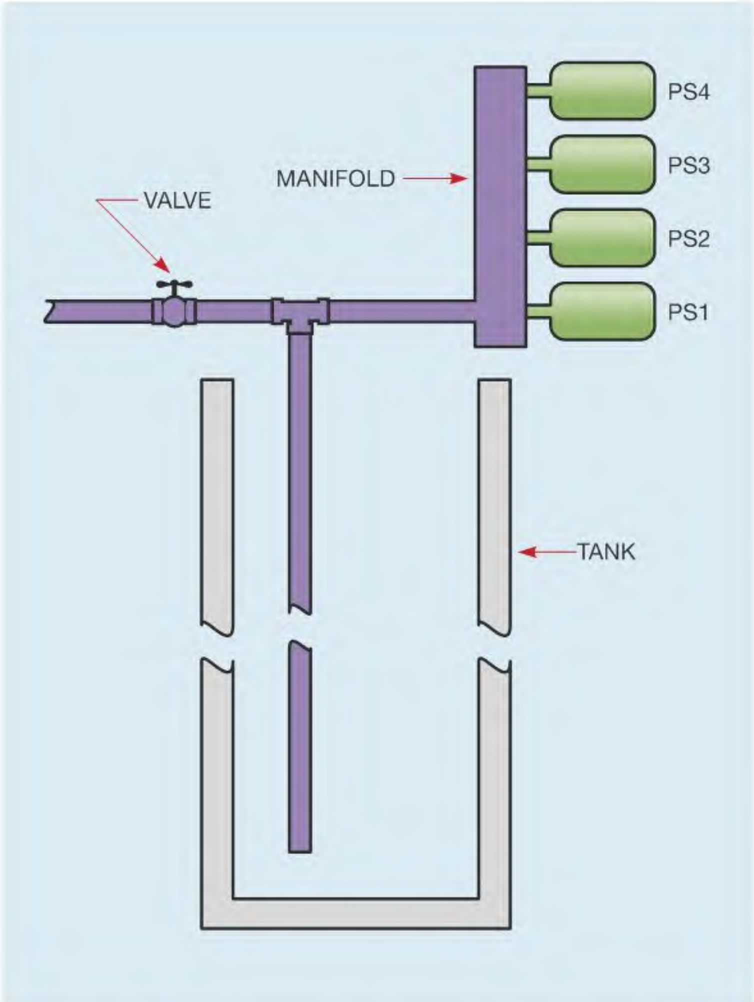


Figure 14–6 Bubbler system for detecting liquid level.

Figure 14–7 Operation of the radar gauge.

Microwave Level Gauge

The microwave level gauge operates by emitting a high frequency signal of approximately 24 GHz into a tank and then measuring the frequency difference of the return signal that bounces off the product (Figure 14–7). A great advantage of the microwave level gauge is that no mechanical object touches or is inserted into the product. The gauge is ideal for measuring the level of turbulent, aerated, solids-laden, viscous, corrosive fluids. It also works well with pastes and slurries. A cut-away view of a microwave level gauge is shown in Figure 14–8.

The gauge shown in Figure 14–9 has a primary 4–20 mA analog signal. The gauge can accept one RTD (resistance temperature detector) input signal. The gauge can be configured to display the level, calculated volume, or standard volume. A microwave level gauge with meter is shown in Figure 14–9.

Figure 14–8 Cut-away view of a microwave level gauge.

Courtesy © 1988 Rosemount Inc., used by permission

Figure 14–9 Microwave level gauge with meter.

Review Questions

1. When using a rod type float switch, how is the amount float movement required to open or close the contacts adjusted?
2. What type of float switch does not have a differential setting?
3. What is the advantage of the bubbler type system for sensing liquid level?
4. Refer to the circuit in Figure 14–5. What is the purpose of control relay CR in this circuit?
5. Assume that a pipe has an inside diameter of 1 square inch. How much air pressure would be required to bubble air through 25 feet of water?

Chapter 15

FLOW SWITCHES

Objectives

After studying this chapter the student will be able to:

- Describe the operation of flow switches.
- Connect a flow switch in a circuit.
- Draw the NEMA symbols that represent a flow switch in a schematic diagram.

Flow switches are used to detect the movement of air or liquid through a duct or pipe. Air flow switches are often called *sail switches* because the sensor mechanism resembles a sail (Figure 15–1). The air flow switch is constructed from a snap action micro switch. A metal arm is attached to the micro switch. A piece of thin metal or plastic is connected to the metal arm. The thin piece of metal or plastic has a large surface area and offers resistance to the flow of air. When a large amount of air flow passes across the sail, enough force is produced to cause the metal arm to operate the contacts of the switch.

Air flow switches are often used in air conditioning and refrigeration circuits to give a positive indication that the evaporator or condenser fan is operating before the compressor is permitted to start. A circuit of this type is shown in Figure 15–2. When the thermostat contact closes, control relay CR energizes and closes all CR contacts. This energizes both the condenser fan motor (CFM) relay

Courtesy of Honeywell International, Inc.

Figure 15–1 Air flow switch.

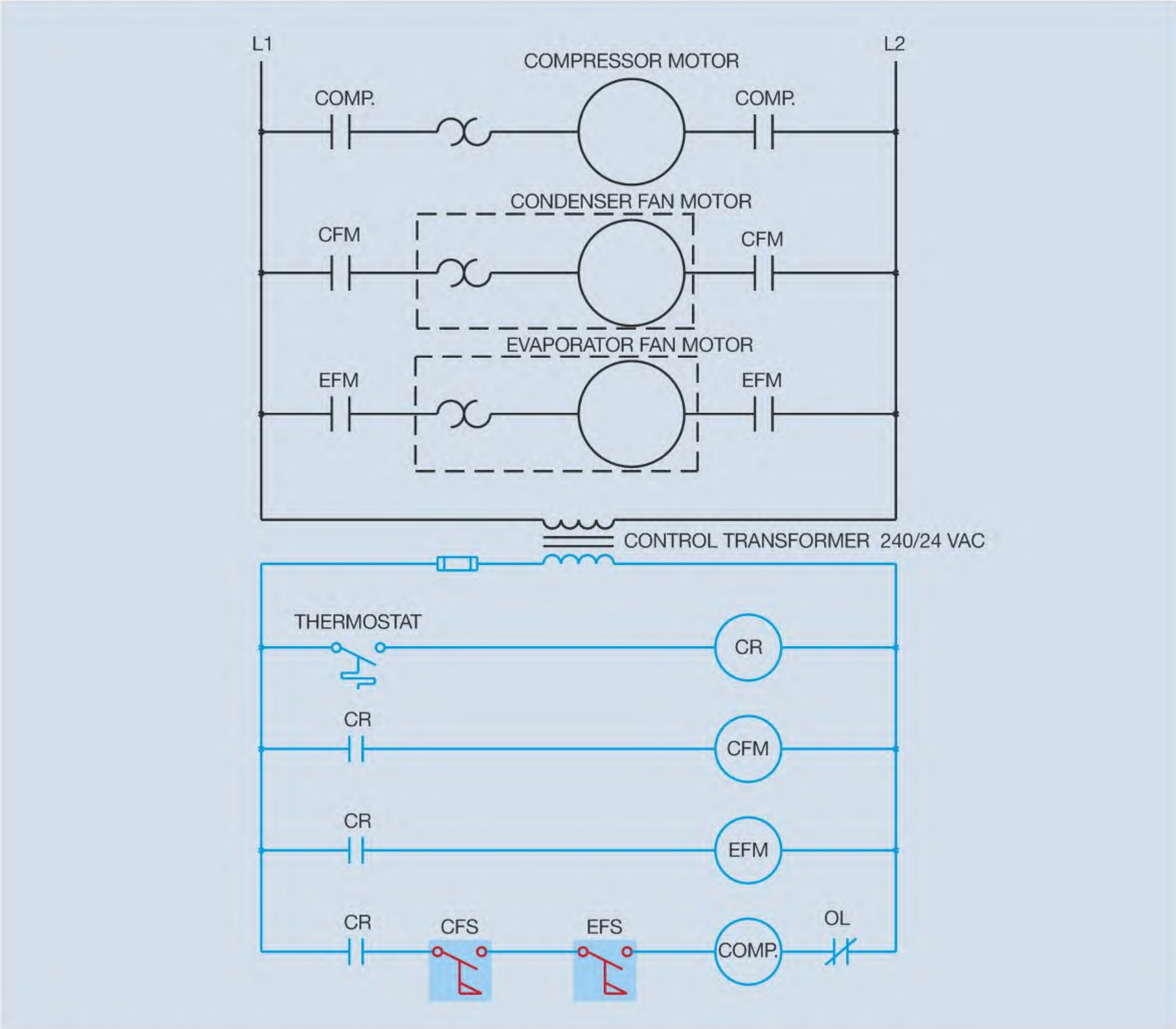


Figure 15–2 Air flow switches indicate a positive movement of air before the compressor can start.

and the evaporator fan motor (EFM) relay. The compressor relay (COMP.) cannot start because of the two normally open air flow switches. If both the condenser fan and evaporator fan start, air movement causes both air flow switches to close and complete a circuit to the compressor relay.

Notice in this circuit that a normally closed overload contact is shown in series with the compressor contactor only. Also notice that a dashed line has been drawn around the condenser fan motor and overload symbol, and around the evaporator fan motor and overload symbol. This indicates that the overload for these motors is located on the motor itself and is not part of the control circuit.

Liquid flow switches are equipped with a paddle that inserts into the pipe (Figure 15–3). A flow switch can be installed by placing a tee in the line as shown in Figure 15–4. When liquid moves through the line, force is exerted against the paddle causing the contacts to change position.

Regardless of the type of flow switch used, they generally contain a single pole double throw micro switch (Figure 15–5). Flow switches are used to control low current loads, such as contactor or relay coils or pilot

Courtesy of Flow Network/Kobold Instruments

Figure 15–3 Liquid flow switch.

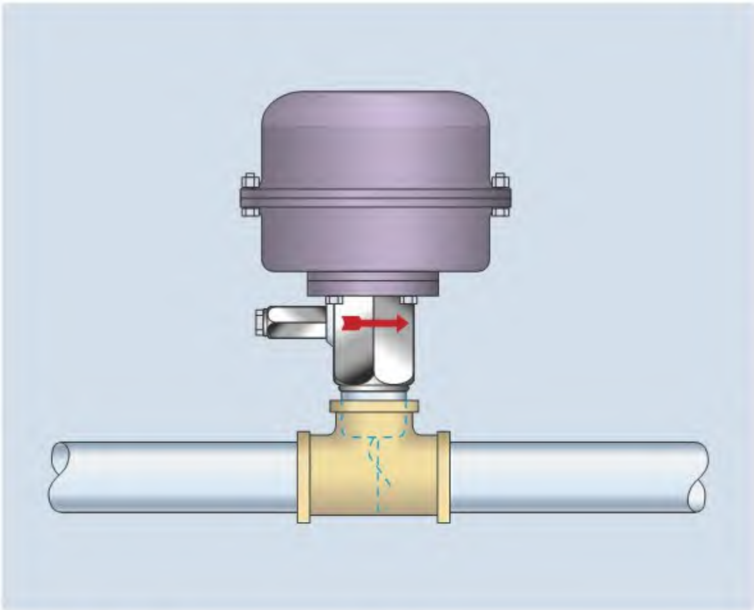


Figure 15–4 Flow switch installed in a tee.

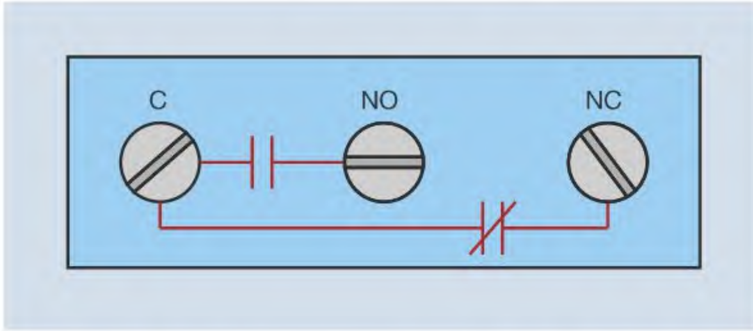


Figure 15–5 Connections of a single pole double throw micro switch.

lights. A circuit that employs both the normally open and normally closed contact of a flow switch is shown in Figure 15–6. The circuit is designed to control the operation of an air compressor. A pressure switch controls the operation of the compressor. In this circuit, a normally open push button is used as a reset button. The control relay must be energized before power can be supplied to the rest of the control circuit. When the pressure switch contact closes, power is supplied to the lube oil pump relay. The flow switch detects the flow of lubricating oil before the compressor is permitted to start. Note that a red warning light indicates when there is no flow of oil. To connect the flow switch in this circuit, power from the control relay contact must be connected to the common terminal of the flow switch so that power can be supplied to both the normally open and normally closed contacts (Figure 15–7). The normally open section of the switch connects to the coil of the compressor contactor, and the normally closed section connects to the red pilot light.

Regardless of whether a flow switch is intended to detect the movement of air or liquid, the NEMA symbol for both is the same. Standard NEMA symbols for flow switches are shown in Figure 15–8.

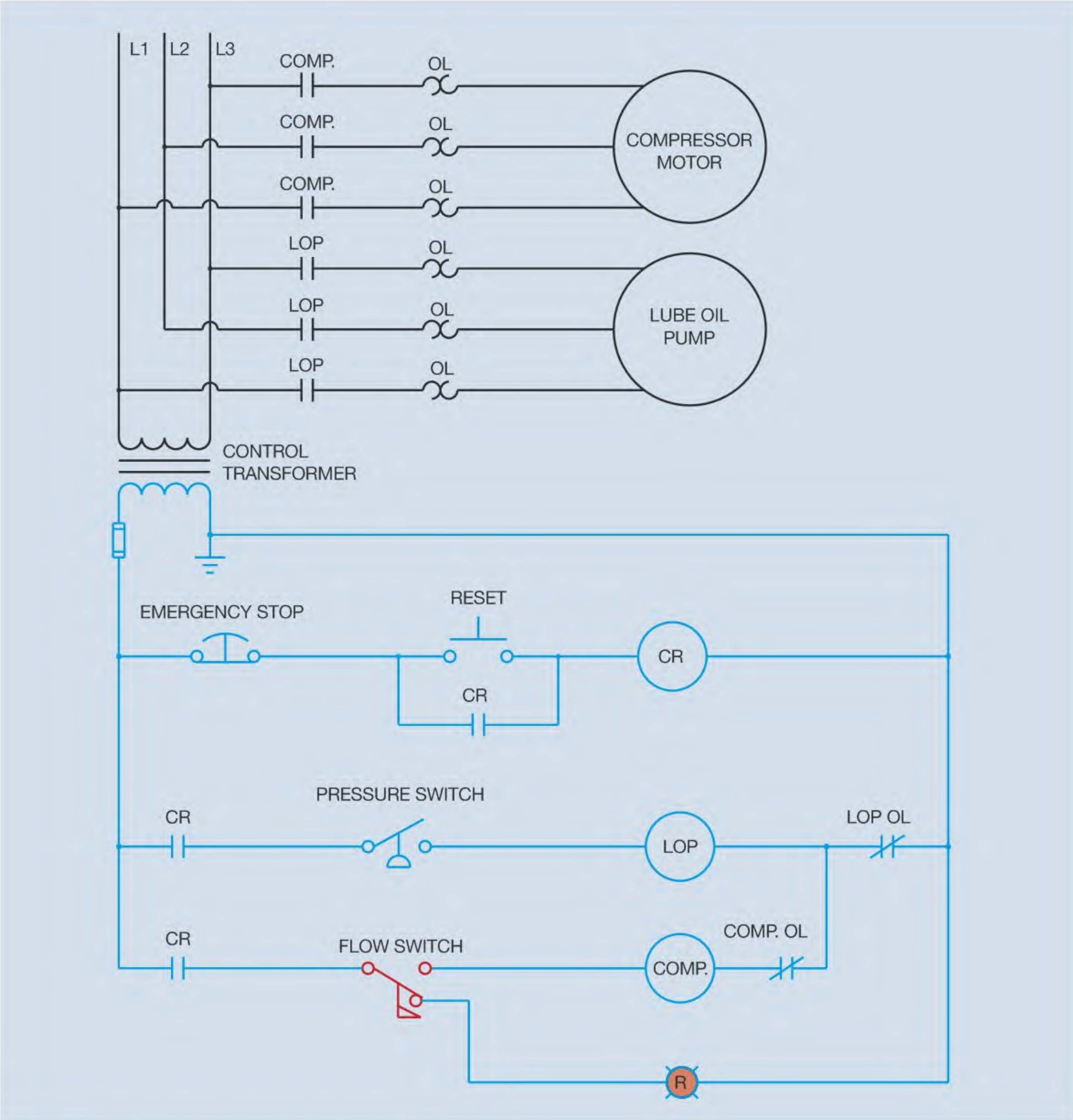


Figure 15–6 A red warning light indicates there is no oil flow.

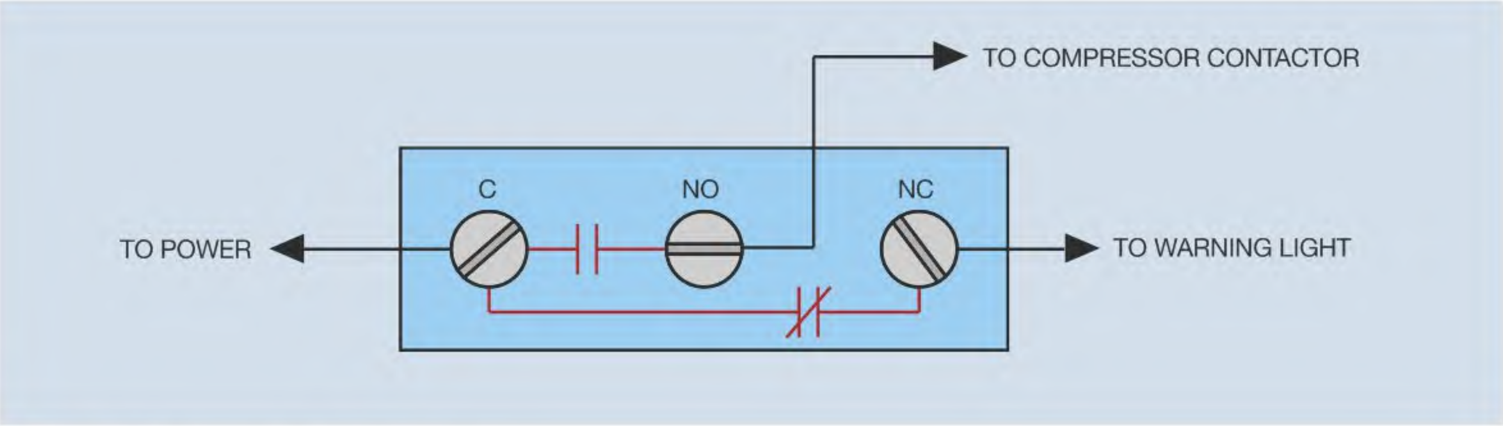


Figure 15–7 Connecting the flow switch.

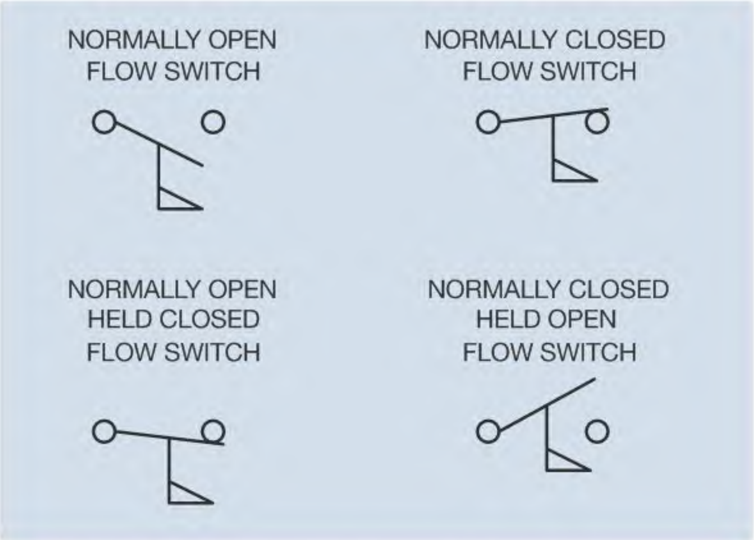


Figure 15–8 NEMA standard flow switch symbols.

Review Questions

1. What is the common name for an air flow switch?
2. What type of switch is contained on most flow switches?
3. Refer to the circuit shown in Figure 15–2. Why is there an overload contact symbol shown in series with the compressor contactor but not the condenser fan contactor or evaporator fan contactor?
4. Refer to the circuit shown in Figure 15–6. The STOP button is shown to be an emergency STOP button. What does the symbol used for the STOP button actually represent?
5. Refer to the circuit shown in Figure 15–6. If an overload should occur on the compressor motor and the overload contact open, would it affect the operation of the lube oil pump?
6. Refer to the circuit shown in Figure 15–6. If the circuit is in operation and an overload should occur on the lube oil pump and the overload contact open, would it affect the operation of the compressor?
7. Refer to the circuit shown in Figure 15–6. The pressure switch is:
   a. normally open
   b. normally closed
   c. normally open held closed
   d. normally closed held open

Chapter 16

LIMIT SWITCHES

Objectives

After studying this chapter the student will be able to:

- Discuss the operation of a limit switch.
- Connect a limit switch in a circuit.
- Recognize limit switch symbols in a ladder diagram.
- Discuss the different types of limit switches.

Limit switches are used to detect when an object is present or absent from a particular location. They can be activated by the motion of a machine or by the presence or absence of a particular object. Limit switches contain some type of bumper arm that is impacted by an object. The type of bumper arm used is determined by the application of the limit switch. When the bumper arm is impacted, it causes the contacts to change position. Figure 16–1 illustrates the use of a limit switch used to detect the position of boxes on a conveyer line. This particular limit switch uses a long metal rod that is free to move in any direction when hit by an object. This type of bumper arm is generally called a wobble stick or wiggle stick. Limit switches with different types of bumper arms are shown in Figure 16–2. They vary in size and contact arrangement depending on the application. Some are constructed of heavy gauge metal and are intended to be struck by moving objects thousands of times. Others are small and designed to fit into constricted spaces. Some contain a single set of contacts and others

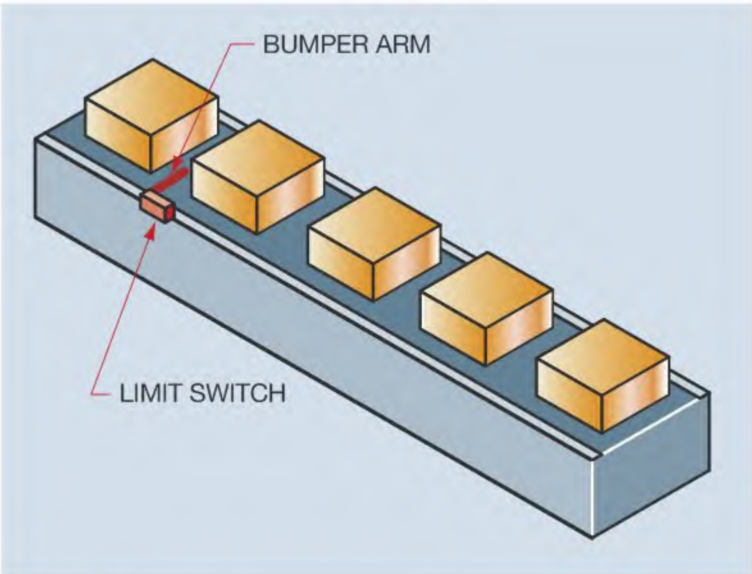


Figure 16–1 Limit switch detects position of boxes on a conveyer line.

Courtesy of Honeywell International Inc.

Figure 16–2 Limit switches.

Figure 16–3 Limit switch with cover removed to show multiple contacts.

contain multiple contacts as shown in Figure 16–3. Some limit switches are momentary contact (spring returned) and others are maintained contact.

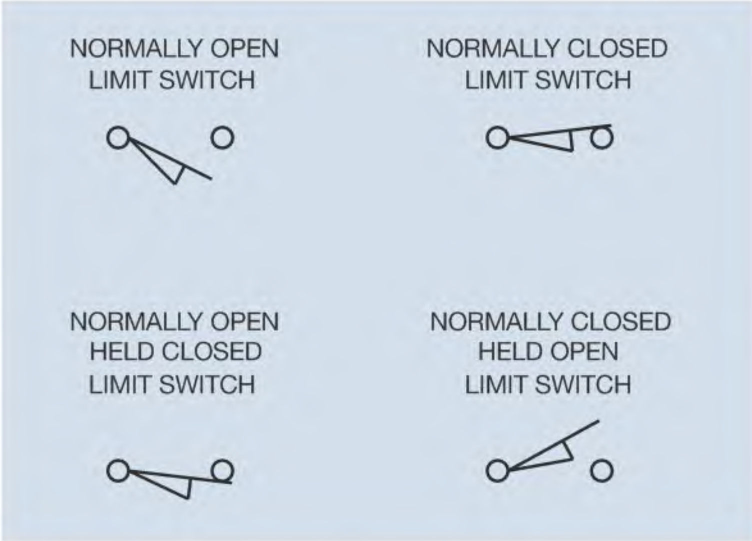


Figure 16–4 NEMA standard symbols for limit switches.

Generally, limit switches are used as pilot devices that control the coil of relays and motor starters in control circuits. The standard NEMA symbols used to indicate limit switches are shown in Figure 16–4. The wedge drawn under the switch symbol represents the bumper arm of the switch.

Micro Limit Switches

Another type of limit switch often used in different types of control circuits is the micro limit switch or *micro switch*. Micro switches are much smaller in size than the limit switches shown in Figure 16–2, which permits them to be used in small spaces that would never be accessible to the larger devices. Another characteristic of the micro switch is that the actuating plunger requires only a small amount of travel to cause the contacts to change position. The micro switch shown in Figure 16–5

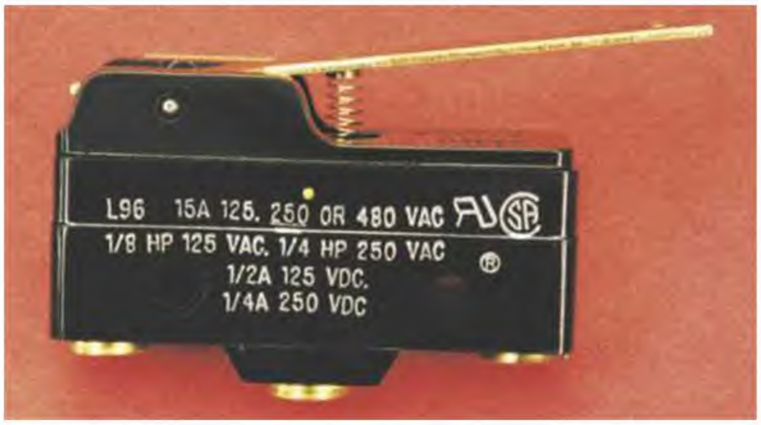


Figure 16–5 Micro limit switch.

has an activating plunger located at the top of the switch. This switch requires that the plunger be depressed approximately 0.015 inch or 0.38 mm. Switching the contact position with this small amount of movement is accomplished by spring loading the contacts as shown in Figure 16–6. A small amount of movement against the spring causes the movable contact to snap from one position to another.

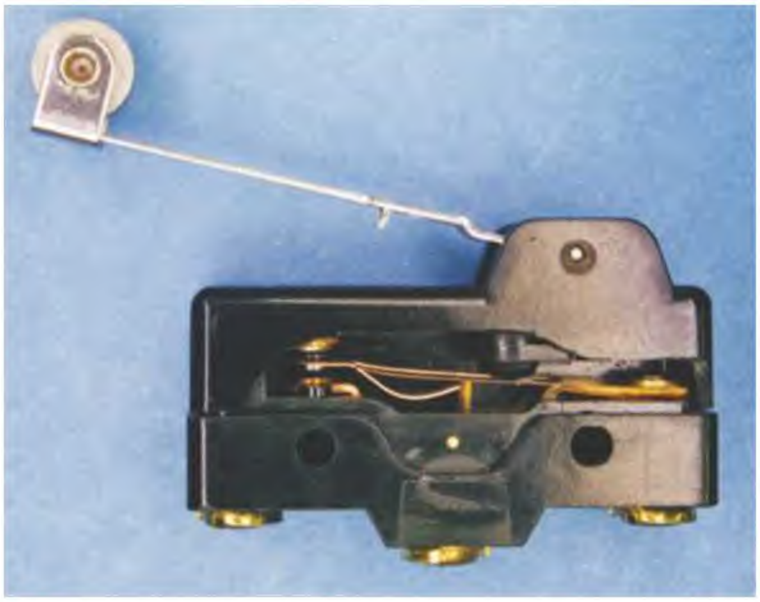
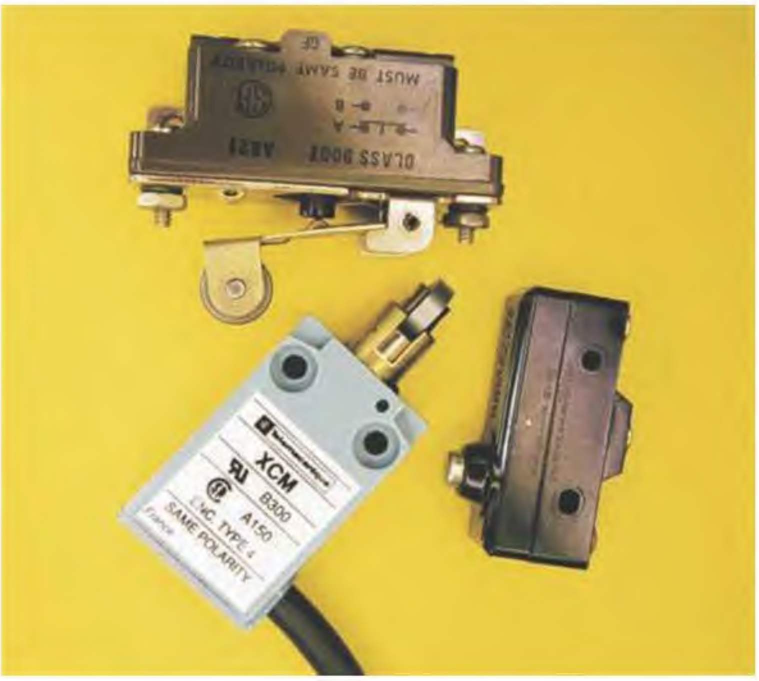


Figure 16–6 Spring-loaded contacts of a basic micro switch.

Electrical ratings for the contacts of the basic micro switch are generally in the range of 250 volts AC and 10 to 15 amps depending on the type of switch. The basic micro switch can be obtained with a variety of different activating arms as shown in Figure 16–7.

Subminiature Micro Switches

The *subminiature micro switch* employs a similar spring contact arrangement as the basic micro switch (Figure 16–8). The switch shown in Figure 16–8 contains a single normally open contact instead of a contact with a common terminal, a normally open contact terminal, and a normally closed contact terminal. The subminiature switches are approximately one-half to one-quarter the size of the basic switch, depending on the model. Due to their reduced size, the contact rating of subminiature switches ranges from about 1 ampere to about 7 amperes depending on the switch



Courtesy of Honeywell International Inc.

Figure 16–7 Micro switches can be obtained with different types of activating arms.

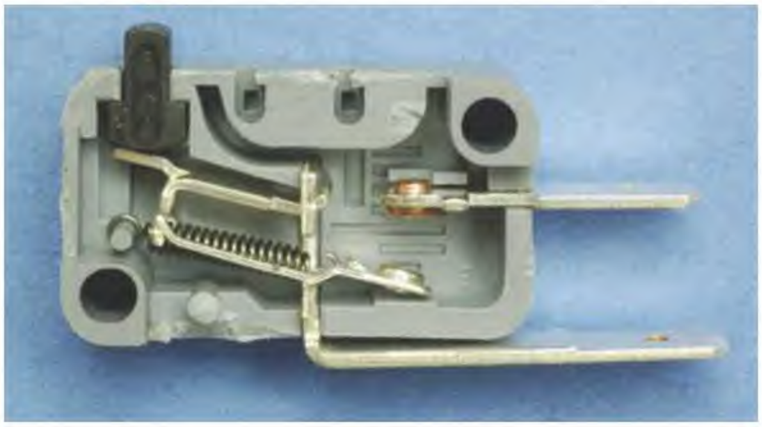


Figure 16–8 Subminiature micro switches employ a similar set of spring-loaded contacts.

Courtesy of Schneider Electric USA, Inc.

Figure 16–9 Subminiature micro switch with both a normally open and a normally closed contact.

type. A subminiature micro switch containing both a normally open and a normally closed contact is shown in Figure 16–9.

Limit Switch Application

Figure 16–10 illustrates a common use for limit switches. A platform is used to raise material from a bottom floor to an upper floor. A hydraulic cylinder is used to raise the platform. A limit switch located on the bottom floor detects when the platform is in that position, and a second limit switch on the upper floor detects when the platform has reached the upper floor. A hydraulic pump is used to raise the platform. When the platform is to travel from the upper floor to the lower floor, a solenoid valve opens and permits oil to return to a holding tank. It is not necessary to use the pump to lower the platform because the weight of the platform will return it to the lower floor.

The schematic for this control circuit is shown in Figure 16–11. The schematic shows both limit switches to be normally closed. When the platform is at the extent of travel in one direction, however, one of the limit switches will be open. If the platform is at the bottom floor, limit switch LS2 will be open. If the UP push button is pressed, a circuit will be completed to M starter causing the motor to start raising the platform. The M normally closed contact will open to prevent CR from

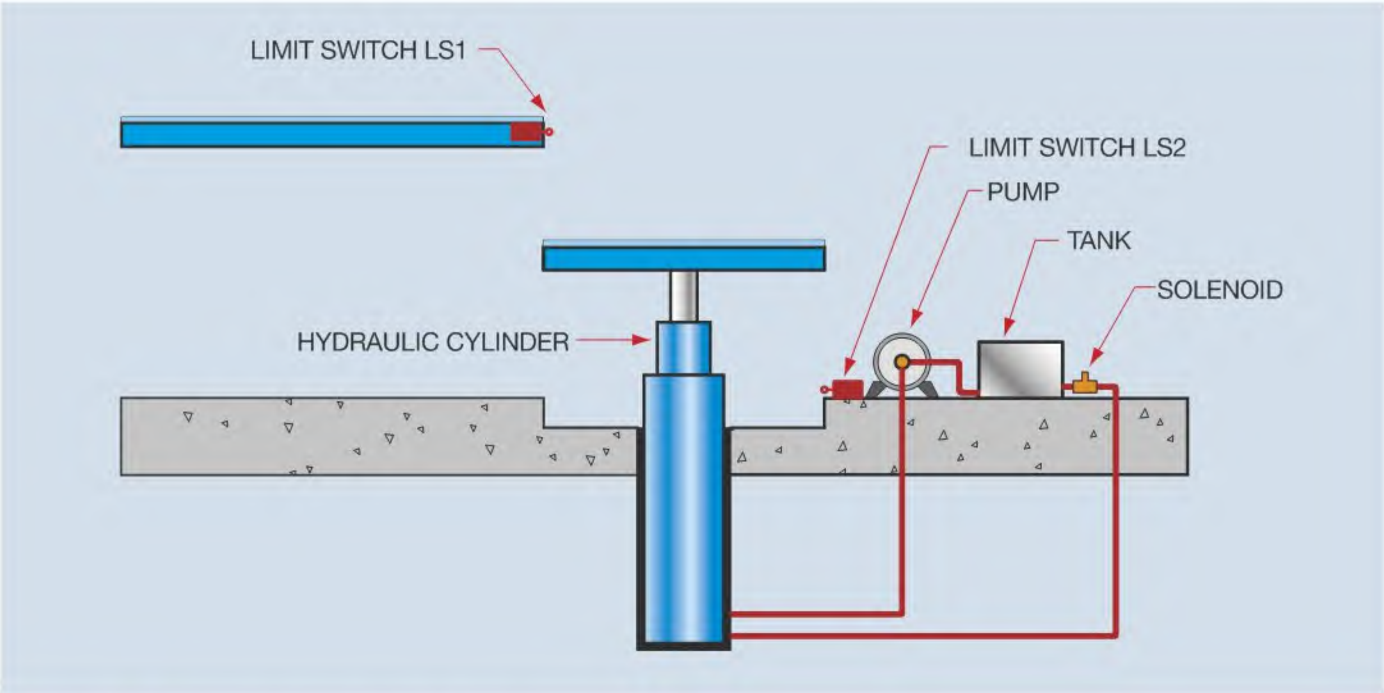


Figure 16–10 Platform rises between floors.

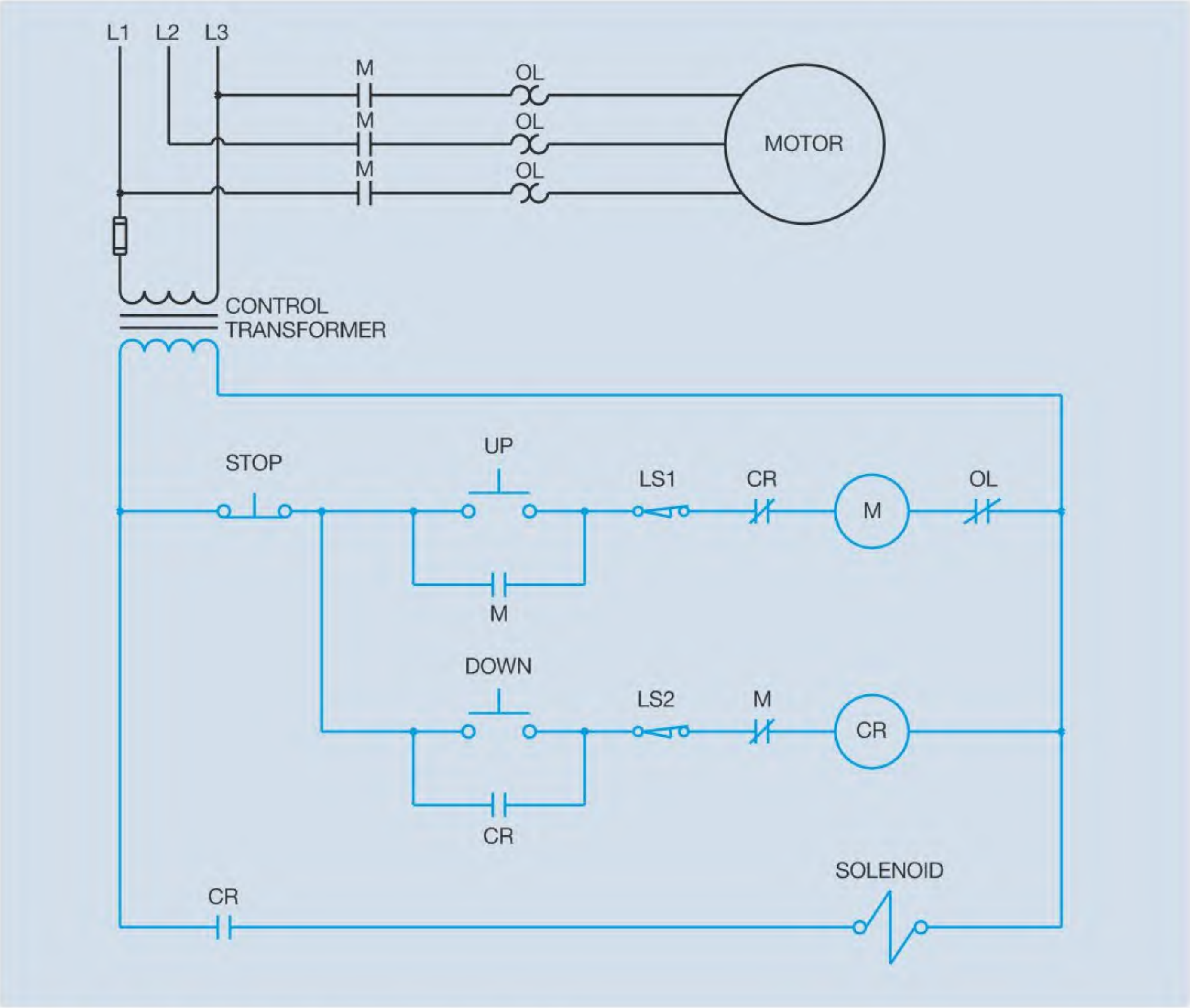


Figure 16–11 Control circuit to raise and lower platform.

being energized at the same time. When the platform begins to rise, limit switch LS2 will close. The platform continues upward until it reaches the top, causing limit switch LS1 to open. This de-energizes M contactor, causing the motor to stop and the normally closed auxiliary contact in series with CR coil to reclose.

When the DOWN push button is pressed, control relay CR energizes. The normally closed CR contact connected in series with M contactor opens to interlock the circuit, and the normally open CR contact connected in series with the solenoid coil closes. When the solenoid coil energizes, the platform starts downward, causing limit switch LS1 to reclose. When the platform reaches the bottom floor, limit switch LS2 opens and de-energizes coil CR.

Review Questions

1. What is the primary use of a limit switch?
2. Why are the contacts of a micro switch spring loaded?
3. Refer to the circuit shown in Figure 16–11. Assume that the platform is located on the bottom floor. When the UP push button is pressed the pump motor does not start. Which of the following could *not* cause this problem?
   a. The contacts of limit switch LS1 are open.
   b. The contacts of limit switch LS2 are open.
   c. Motor starter coil M is open.
   d. The overload contact is open.

4. Refer to the circuit shown in Figure 16–11. Assume that the platform is located on the lower floor. When the UP push button is pressed, the platform rises. When the platform reaches the upper floor, however, the pump does not turn off but continues to run until the overload relay opens the overload contacts. Which of the following could cause this problem?
   a. The solenoid valve opened when limit switch LS1 opened.
   b. The UP push button is shorted.
   c. Limit switch LS1 did not open its contacts.
   d. Limit switch LS2 contacts did not reclose when the platform began to rise.
5. Refer to the circuit shown in Figure 16–11. Assume that the platform is located at the upper floor. When the DOWN push button is pressed, the platform does not begin to lower. Which of the following could *not* cause the problem?
   a. Control relay coil CR is open.
   b. Limit switch LS1 contacts are open.
   c. Limit switch LS2 contacts are open.
   d. The solenoid coil is open.

Chapter 17

TEMPERATURE SENSING DEVICES

Objectives

After studying this chapter the student will be able to:

- Describe different methods for sensing temperature.
- Discuss different devices intended to be operated by a change of temperature.
- List several applications for temperature sensing devices.
- Read and draw the NEMA symbols for temperature switches.

There are many times when the ability to sense temperature is of great importance. The industrial electrician will encounter some devices designed to change a set of contacts with a change of temperature and other devices used to sense the amount of temperature. The method used depends a great deal on the applications of the circuit and the amount of temperature that must be sensed.

Expansion of Metal

A very common and reliable method for sensing temperature is by the expansion of metal. It has long been known that metal expands when heated. The amount of expansion is proportional to two factors:

1. The type of metal used.
2. The amount of temperature.

Consider the metal bar shown in Figure 17–1. When the bar is heated, its length expands. When the metal is permitted to cool, it will contract. Although the amount of movement due to contractions and expansion is small, a simple mechanical principle can be used to increase the amount of movement (Figure 17–2).

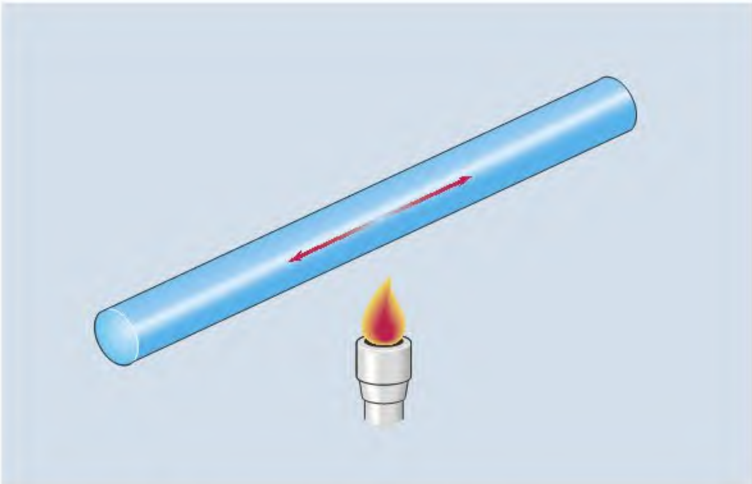


Figure 17–1 Metal expands when heated.

The metal bar is mechanically held at one end. This permits the amount of expansion to be in one direction only. When the metal is heated and the bar expands, it pushes against the mechanical arm. A small movement of the bar causes a great amount of movement in the mechanical arm. This increased movement in the arm can be used to indicate the temperature of the bar by attaching a pointer and scale, or to operate a switch as shown. It should be understood that illustrations are used to convey a principle. In actual practice, the switch shown in Figure 17–2 would be spring loaded to provide a snap action for the contacts. Electrical contacts must never be permitted to open or close slowly. This produces poor contact pressure and will cause the contacts to burn or will cause erratic operation of the equipment they are intended to control.

Hot-Wire Starting Relay

A very common device that uses the principle of expanding metal to operate a set of contacts is the *hot-wire starting relay* found in the refrigeration industry. The hot-wire relay is so named because it uses a length of resistive wire connected in series with the motor to sense motor current. A diagram of this type of relay is shown in Figure 17–3.

When the thermostat contact closes, current can flow from line L1 to terminal L of the relay. Current then flows through the resistive wire, the movable arm, and the normally closed contacts to the run and start windings. When current flows through the resistive wire, its temperature increases. This increase of temperature causes the wire to expand in length. When the length increases, the movable arm is forced downward. This downward pressure produces tension on the springs of both contacts. The relay is so designed that the start contact will snap open first, disconnecting the motor start winding from the circuit. If the motor current is not excessive, the wire will never become hot enough to cause the overload contact to open. If the motor current should become too great, however, the temperature of the resistive wire will become high enough to cause the wire to expand to the point that it will cause the overload contact to snap open and disconnect the motor run winding from the circuit.

The Mercury Thermometer

Another very useful device that works on the principle of contraction and expansion of metal is the *mercury thermometer*. Mercury is a metal that remains in a liquid state at room temperature. If the mercury is confined in a glass tube as shown in Figure 17–4, it rises up the tube as it expands due to an increase in temperature. If the tube is calibrated correctly, it provides an accurate measurement for temperature.

The Bimetal Strip

The bimetal strip is another device that operates by the expansion of metal. It is probably the most common heat sensing device used in the production of

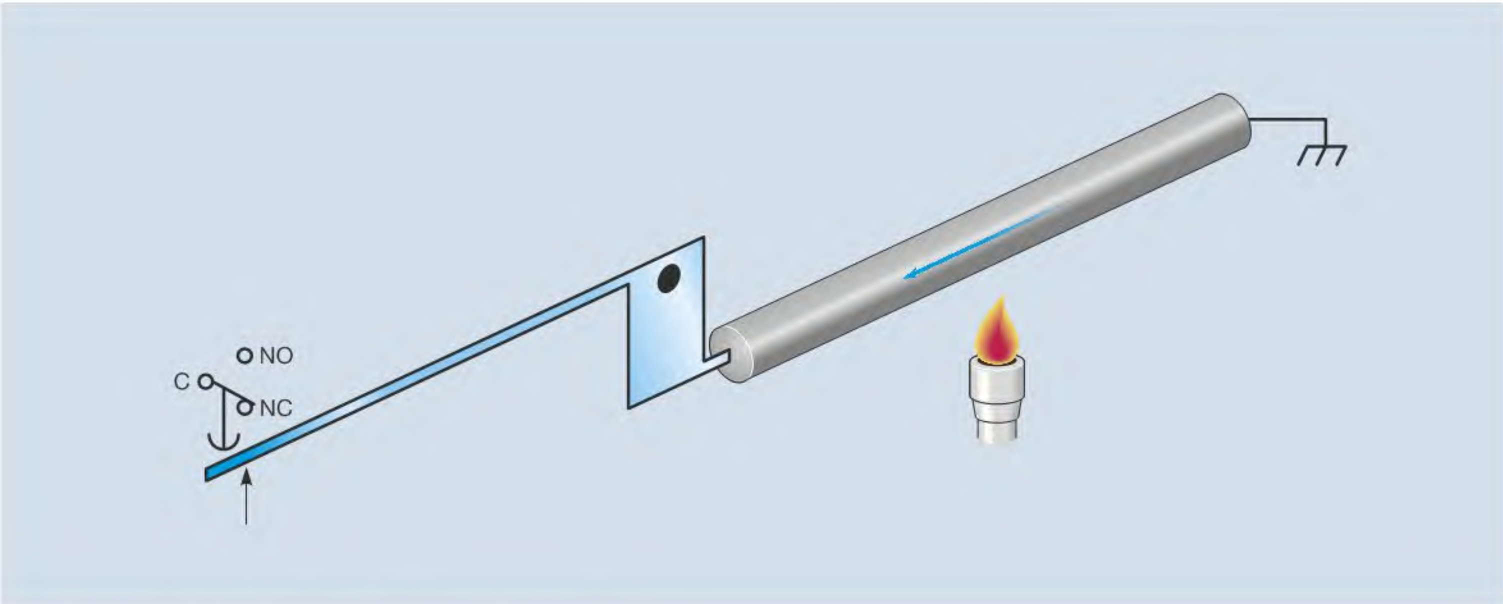


Figure 17–2 Expanding metal operates a set of contacts.

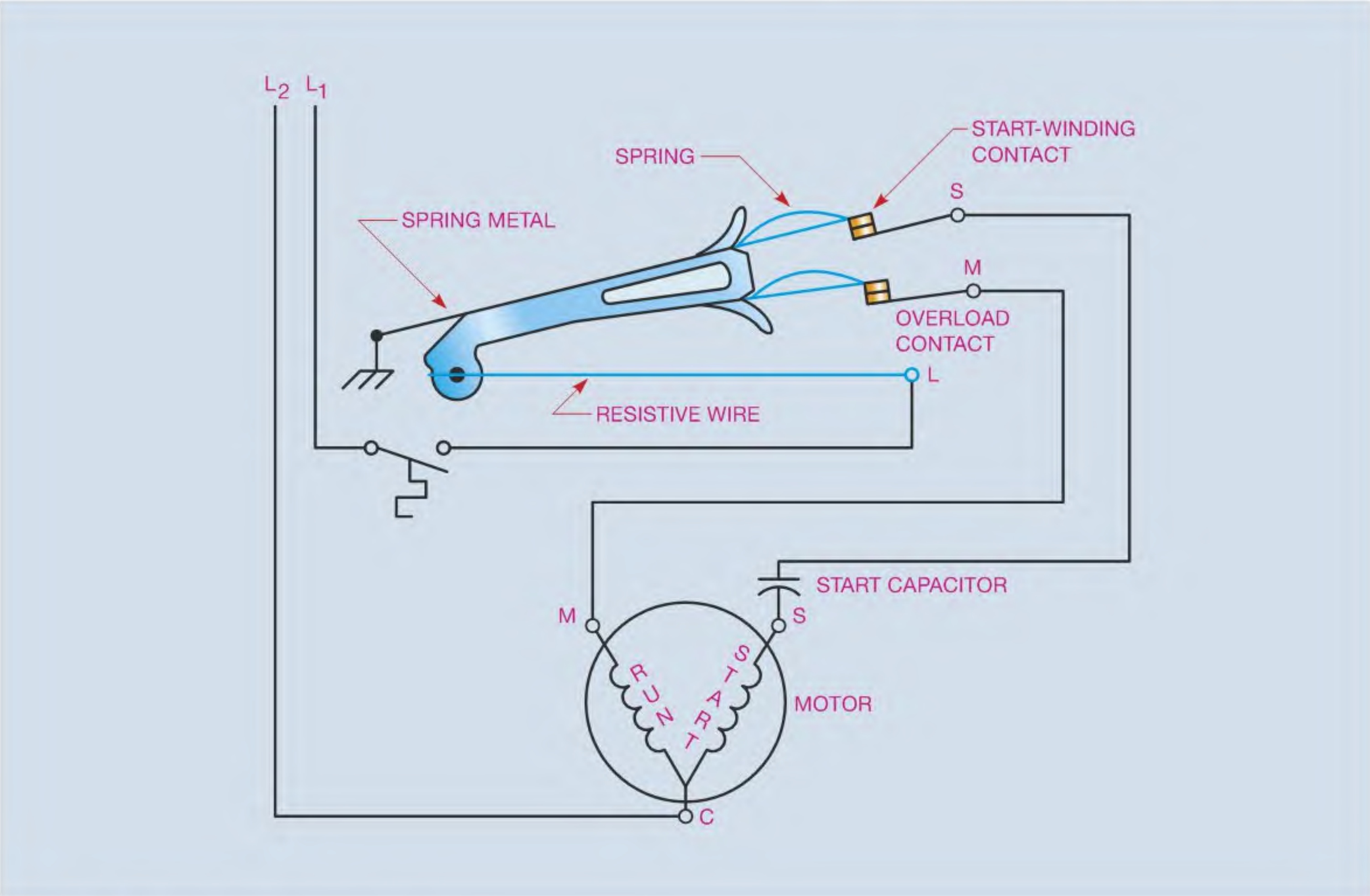


Figure 17–3 Hot-wire relay connection.

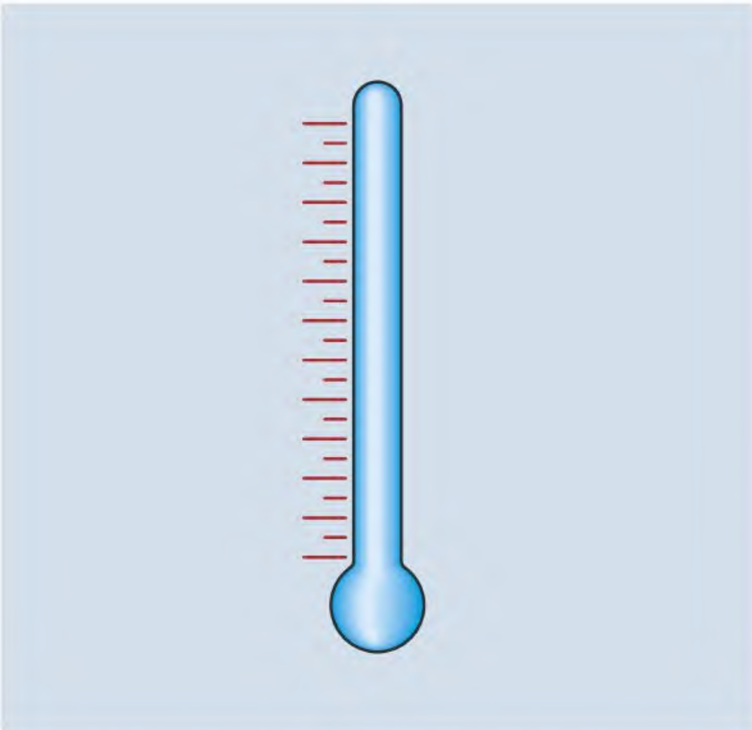


Figure 17–4 A mercury thermometer operates by the expansion of metal.

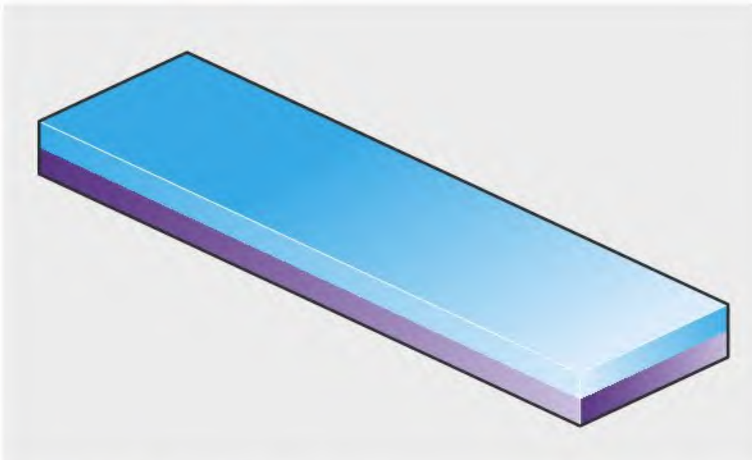


Figure 17–5 A bimetal strip.

room thermostats and thermometers. The bimetal strip is made by bonding two dissimilar types of metal together (Figure 17–5). Because these two metals are not alike, they have different expansion rates. This difference causes the strip to bend or warp when heated (Figure 17–6). A bimetal strip is often formed into a

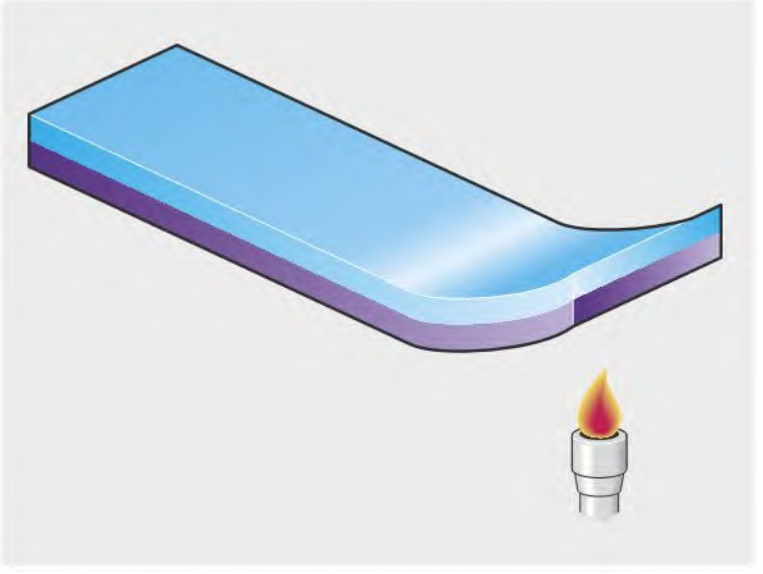


Figure 17–6 A bimetal strip warps with a change of temperature.

spiral shape as shown in Figure 17–7. The spiral permits a longer bimetal strip to be used in a small space. A long bimetal strip is desirable because it exhibits a greater amount of movement with a change of temperature.

If one end of the strip is mechanically held and a pointer is attached to the center of the spiral, a change in temperature will cause the pointer to rotate. If a calibrated scale is placed behind the pointer, it becomes a thermometer. If the center of the spiral is held in position and a contact is attached to the end of the bimetal strip, it becomes a thermostat. A small permanent magnet is used to provide a snap action for the contacts (Figure 17–8). When the moving contact reaches a point that is close to the stationary contact, the magnet attracts the metal strip and causes a sudden closing of the contacts. When the bimetal strip cools, it pulls away from the magnet. When the force of the bimetal strip becomes strong enough, it overcomes the force of the magnet and the contacts snap open.

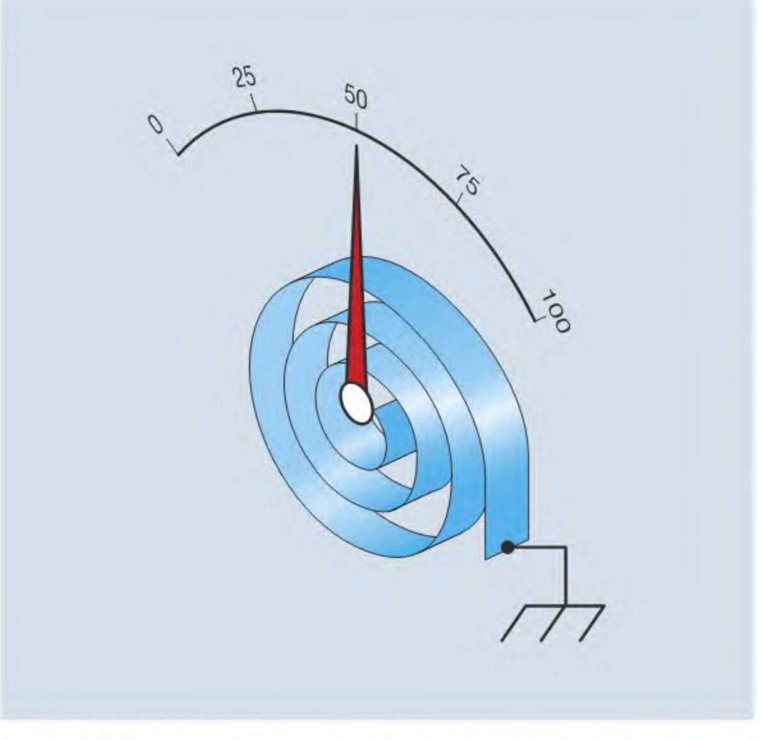


Figure 17–7 A bimetal strip used as a thermometer.

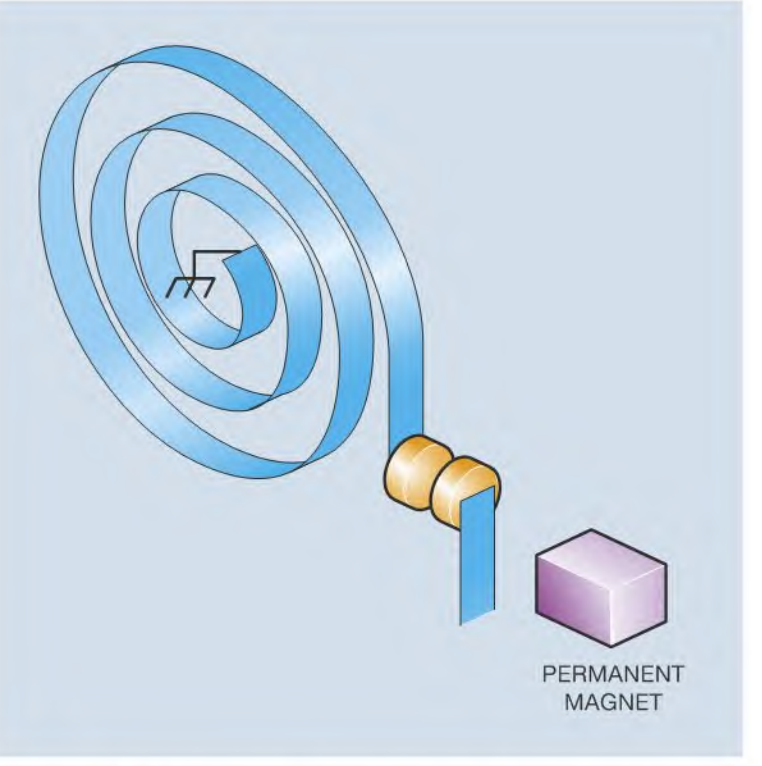


Figure 17–8 A bimetal strip used to operate a set of contacts.

Thermocouples

In 1822, a German scientist named Seebeck discovered that when two dissimilar metals are joined at one end, and that junction is heated, a voltage is produced (Figure 17–9). This is known as the *Seebeck effect*. The device produced by the joining of two dissimilar metals for the purpose of producing electricity with heat is called a *thermocouple*. The amount of voltage produced by a thermocouple is determined by:

1. The type of materials used to produce the thermocouple.
2. The temperature difference of the two junctions.

The chart in Figure 17–10 shows common types of thermocouples. The different metals used in the construction of thermocouples as well as their normal temperature ranges are shown.

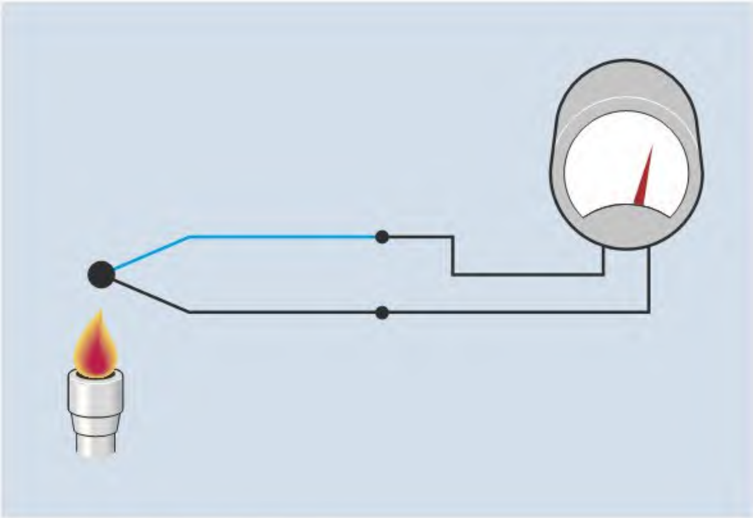


Figure 17–9 Thermocouple.

The amount of voltage produced by a thermocouple is small, generally in the order of millivolts (1 millivolt = 0.001 volt). The polarity of the voltage of some thermocouples is determined by the temperature. For example, a type "J" thermocouple produces 0 volts at about 32°F. At temperatures above 32°F, the iron wire is positive and the constantan wire is negative. At temperatures below 32°F, the iron wire becomes negative and the constantan wire becomes positive. At a temperature of +300°F, a type "J" thermocouple will produce a voltage of about +7.9 millivolts. At a temperature of −300°F, it will produce a voltage of about −7.9 millivolts.

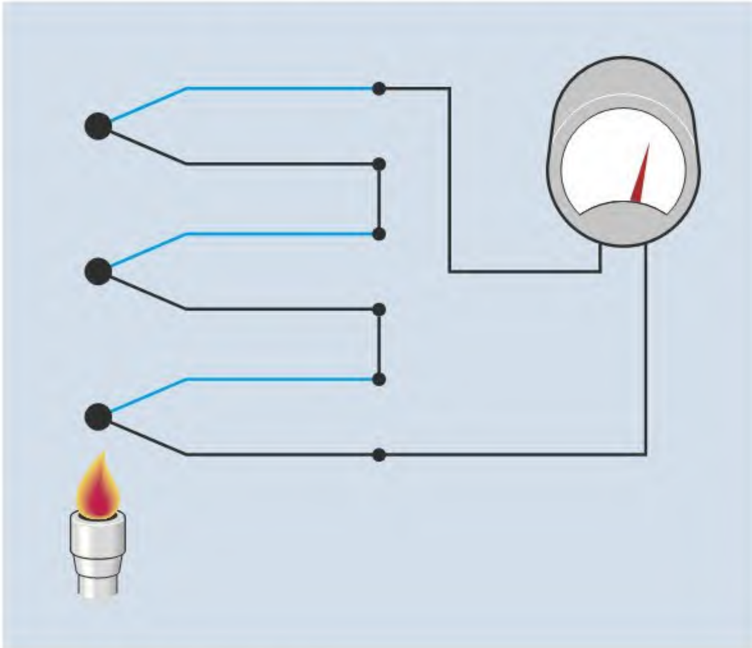


Figure 17–11 Thermopile.

Because thermocouples produce such low voltages, they are often connected in series as shown in Figure 17–11. This connection is referred to as a *thermopile*. Thermocouples and thermopiles are generally used

TYPE	MATERIAL		DEGREES F	DEGREES C
J	IRON	CONSTANTAN	–328 to +32 +32 to +1432	–200 to 0 0 to +778
K	CHROMEL	ALUMEL	–328 to +32 +32 to +2472	–200 to 0 0 to +1356
T	COPPER	CONSTANTAN	–328 to +32 +32 to +752	–200 to 0 0 to +400
E	CHROMEL	CONSTANTAN	–328 to +32 +32 to +1832	–200 to 0 0 to +1000
R	PLATINUM 13% RHODIUM	PLATINUM	+32 to +3232	0 to +1778
S	PLATINUM 10% RHODIUM	PLATINUM	+32 to +3232	0 to +1778
B	PLATINUM 30% RHODIUM	PLATINUM 6% RHODIUM	+992 to +3352	+533 to +1800

Figure 17–10 Thermocouple chart.

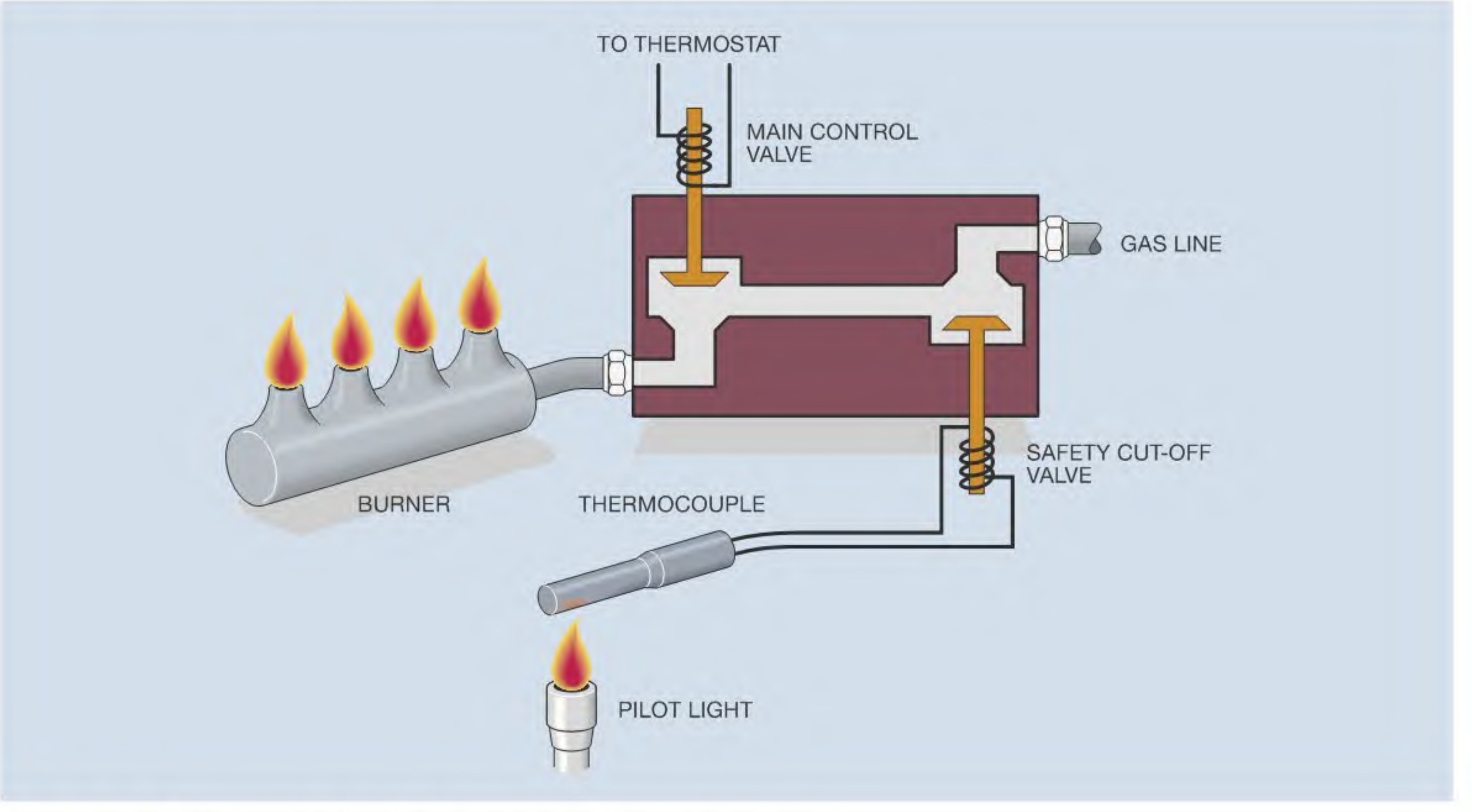


Figure 17–12 A thermocouple provides power to the safety cut-off valve.

for making temperature measurements and are sometimes used to detect the presence of a pilot light in appliances that operate with natural gas. The thermocouple is heated by the pilot light. The current produced by the thermocouple is used to produce a magnetic field that holds a gas valve open and permits gas to flow to the main burner. If the pilot light should go out, the thermocouple ceases to produce current and the valve closes (Figure 17–12).

Resistance Temperature Detectors

The *resistance temperature detector* (RTD) is made of platinum wire. The resistance of platinum changes greatly with temperature. When platinum is heated, its resistance increases at a very predictable rate; this makes the RTD an ideal device for measuring temperature very accurately. RTDs are used to measure temperatures that range from −328 to +1166 degrees Fahrenheit (−200° to +630 °C). RTDs are made in different styles to perform different functions. Figure 17–13 illustrates a typical RTD used as a probe. A very small coil of platinum wire is encased inside a copper tip. Copper is used to provide good thermal contact. This permits the probe to be very fast-acting. The chart in Figure 17–14 shows resistance versus temperature for a typical RTD probe. The temperature is given in degrees Celsius and the resistance is given in ohms. RTDs in several different case styles are shown in Figure 17–15.

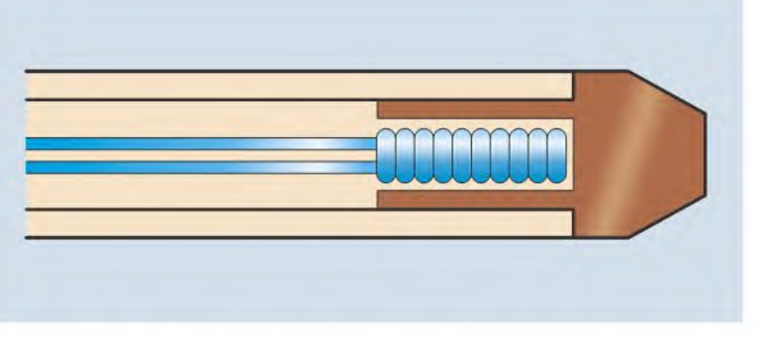


Figure 17–13 Resistance temperature detector.

Thermistors

The term *thermistor* is derived from the words "thermal resistor." **Thermistors** are actually thermally sensitive semiconductor devices. There are two basic types of thermistors: one type has a negative temperature coefficient (NTC) and the other has a positive temperature coefficient (PTC). A thermistor that has a negative

DEGREES C	RESISTANCE (Ω)
0	100
50	119.39
100	138.5
150	157.32
200	175.84
250	194.08
300	212.03
350	229.69
400	247.06
450	264.16
500	280.93
550	297.44
600	313.65

Figure 17–14 Temperature and resistance for a typical RTD.

Courtesy of Honeywell International Inc.

Figure 17–15 RTDs in different case styles.

temperature coefficient will decrease its resistance as the temperature increases. A thermistor that has a positive temperature coefficient will increase its resistance as the temperature increases. The NTC thermistor is the most widely used.

Thermistors are highly nonlinear devices. For this reason they are difficult to use for measuring temperature. Devices that measure temperature with a thermistor must be calibrated for the particular type of thermistor being used. If the thermistor is ever replaced, it has to be an exact replacement or the circuit will no longer operate correctly. Because of their nonlinear characteristics, thermistors are often used as *set point detectors* as opposed to actual temperature measurement. A set point detector is a device that activates some process or circuit when the temperature reaches a certain level. For example, assume a thermistor has been placed inside the stator winding of a motor. If the motor should become overheated, the windings could become severely damaged or destroyed. The thermistor can be used to detect the temperature of the windings. When the temperature reaches a certain point, the resistance value of the thermistor changes enough to cause the starter coil to drop out and disconnect the motor from the line. Thermistors can be operated in temperatures that range from about −100° to +300°F.

One common use for thermistors is in the solid-state starting relays used with small refrigeration compressors (Figure 17–16). Starting relays are used with hermetically sealed motors to disconnect the start windings from the circuit when the motor reaches about 75 percent of its full speed. Thermistors can be used for this application because they exhibit an extremely rapid change of resistance with a change of temperature. A schematic diagram showing the connection for a solid-state relay is shown in Figure 17–17.

When power is first applied to the circuit, the thermistor is cool and has a relatively low resistance. This permits current to flow through both the start and run windings of the motor. The temperature of the thermistor increases because of the current flowing through it. The increase of temperature causes the resistance to change from a very low value of 3 or 4 ohms to several thousand ohms. This increase of resistance is very sudden and has the effect of opening a set of contacts connected in series with the start winding. Although the start winding is never completely disconnected from the power line, the amount of current flow through it is very small, typically 0.03 to 0.05 amps, and does not affect the operation of the motor. This small amount of *leakage current* maintains the temperature of the thermistor and prevents it from returning to a low resistance. After power has been disconnected from the motor, a cool-down period of about 2 minutes should be allowed before restarting the motor. This cool-down period is needed for the thermistor to return to a low value of resistance.

Figure 17–16 Solid-state starting relay.

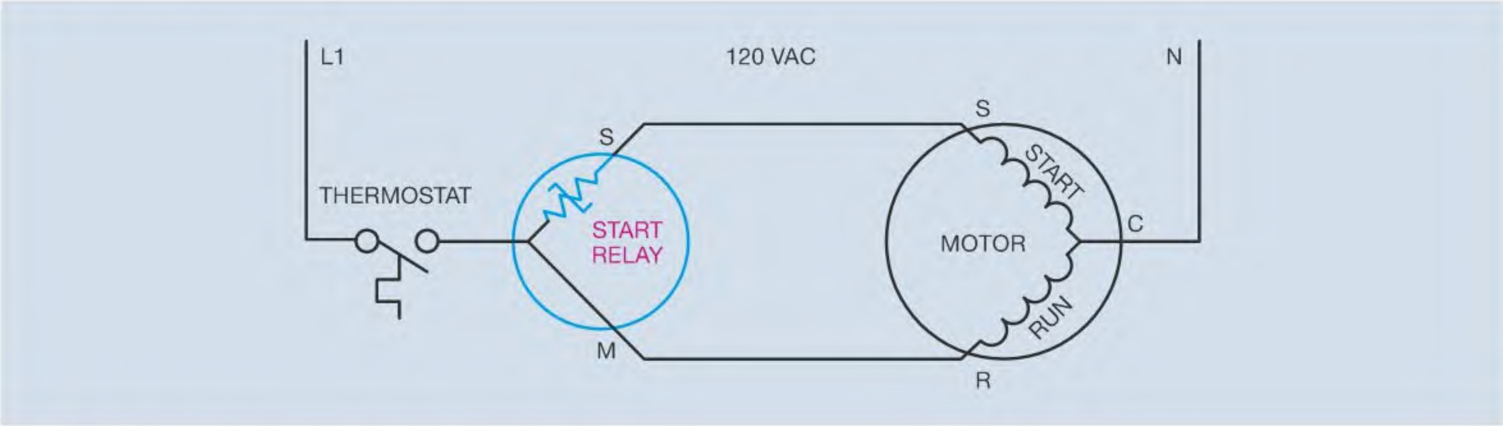


Figure 17–17 Connection of solid-state starting relay.

The PN Junction

Another device that has the ability to measure temperature is the PN junction or diode. The diode is becoming a very popular device for measuring temperature because it is accurate and linear.

When a silicon diode is used as a temperature sensor, a constant current is passed through the diode. Figure 17–18 illustrates this type of circuit. In this circuit, resistor R1 limits the current flow through the transistor and sensor diode. The value of R1 also determines the amount of current that flows through the diode. Diode D1 is a 5.1 volt zener used to produce a constant voltage drop between the base and emitter of the PNP transistor. Resistor R2 limits the amount of current flow through the zener diode and the base of the transistor. D1 is a common silicon diode. It is being used as the temperature sensor for the circuit. If a digital voltmeter is connected across the diode, a voltage drop between 0.8 and 0 volts can be seen. The amount of voltage drop is determined by the temperature of the diode.

Another circuit that can be used as a constant current generator is shown in Figure 17–19. In this circuit, a field effect transistor (FET) is used to produce a current generator. Resistor R1 determines the amount of current that will flow through the diode. Diode D1 is the temperature sensor.

If the diode is subjected to a lower temperature, say, by touching it with a piece of ice, the voltage drop across the diode increases. If the diode temperature is increased, the voltage drop decreases because the diode has a negative temperature coefficient. As its temperature increases, its voltage drop becomes less.

In Figure 17–20, two diodes connected in a series are used to construct an electronic thermostat. Two diodes are used to increase the amount of voltage drop as the temperature changes. A field effect transistor and resistor are used to provide a constant current to the two diodes used as the heat sensor. An operational amplifier is used

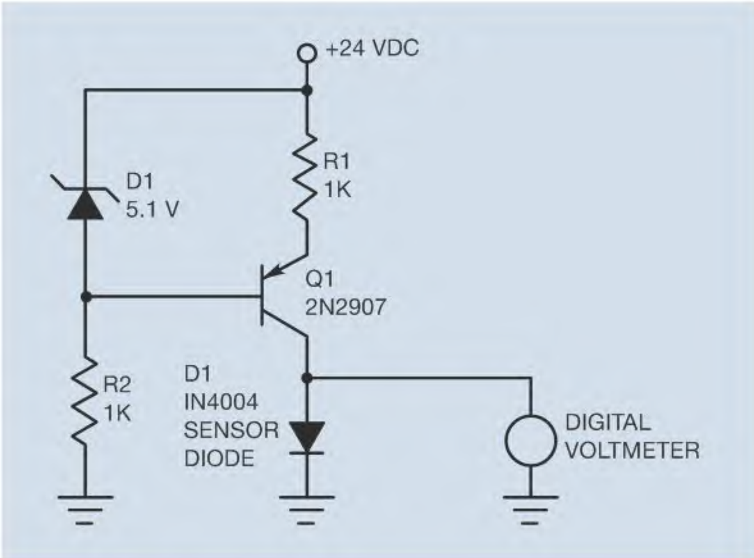


Figure 17–18 Constant current generator.

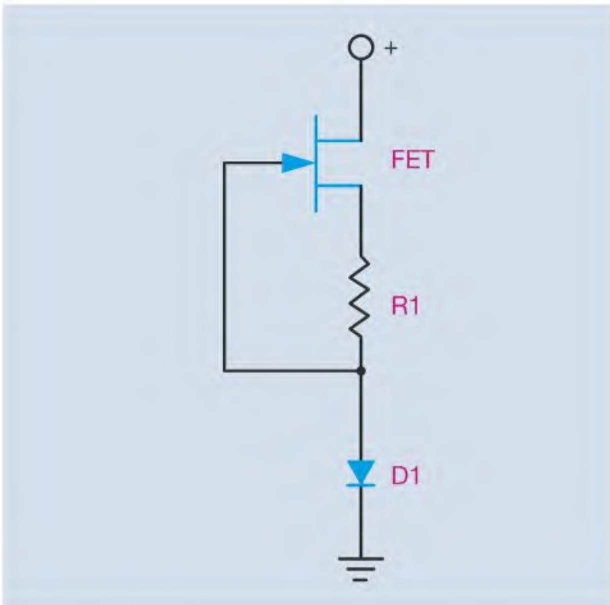


Figure 17–19 Field effect transistor used to produce a constant current generator.

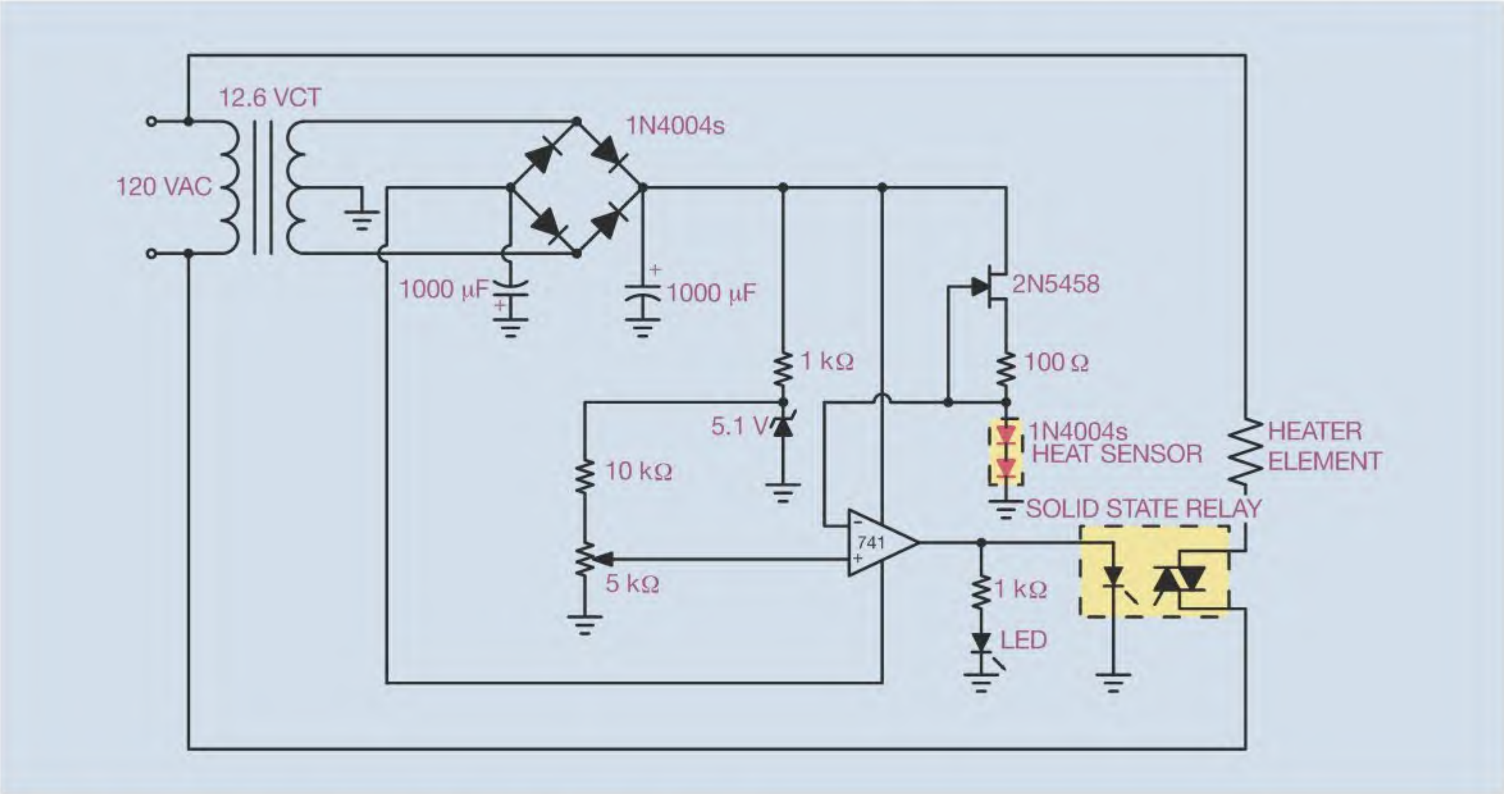


Figure 17–20 Solid-state thermostat using diodes as heat sensors.

to turn a solid-state relay on or off as the temperature changes. In the example shown, the circuit operates as a heating thermostat. The output of the amplifier turns on when the temperature decreases sufficiently. The circuit can be converted to a cooling thermostat by reversing the connections of the inverting and noninverting inputs of the amplifier.

Expansion Due to Pressure

Another common method of sensing a change of temperature is by the increase of pressure of some chemicals. Refrigerants confined in a sealed container, for example, will increase the pressure in the container with an increase of temperature. If a simple bellows is connected to a line containing refrigerant (Figure 17–21), the bellows will expand as the pressure inside the sealed system increases. When the surrounding air temperature decreases, the pressure inside the system decreases and the bellows contracts. When the air temperature increases, the pressure increases and the bellows expands. If the bellows controls a set of contacts, it becomes a bellows type thermostat. A bellows thermostat and the standard NEMA symbols used to represent a temperature operated switch are shown in Figure 17–22.

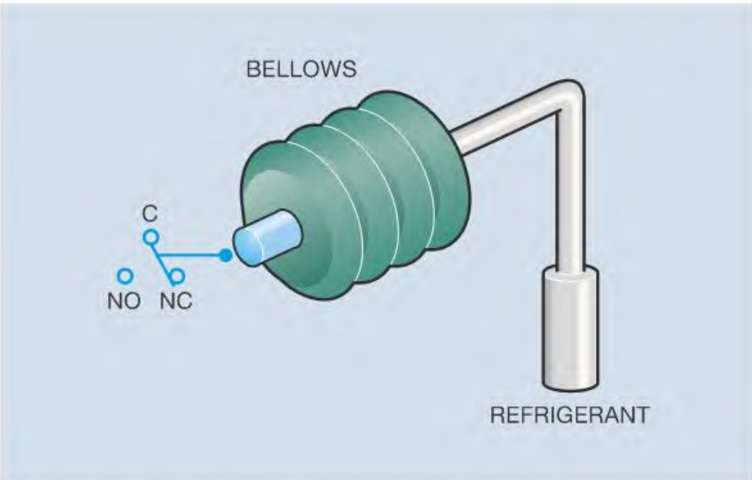


Figure 17–21 Bellows contracts and expands with a change of refrigerant pressure.

Figure 17–22 Industrial temperature switch.

Review Questions

1. Should a metal bar be heated or cooled to make it expand?
2. What type of metal remains in a liquid state at room temperature?
3. How is a bimetal strip made?
4. Why are bimetal strips often formed into a spiral shape?
5. Why should electrical contacts never be permitted to open or close slowly?
6. What two factors determine the amount of voltage produced by a thermocouple?
7. What is a thermopile?
8. What do the letters RTD stand for?
9. What type of wire is used to make an RTD?
10. What material is a thermistor made of?
11. Why is it difficult to measure temperature with a thermistor?
12. If the temperature of a NTC thermistor increases, will its resistance increase or decrease?
13. How can a silicon diode be made to measure temperature?
14. Assume that a silicon diode is being used as a temperature detector. If its temperature increases, will its voltage drop increase or decrease?
15. What type of chemical is used to cause a pressure change in a bellows type thermostat?

Chapter 18

HALL EFFECT SENSORS

Objectives

After studying this chapter the student will be able to:

- Describe the Hall effect.
- Discuss the principles of operation of a Hall generator.
- Discuss applications in which Hall generators can be used.

Principles of Operation

The Hall effect is a simple principle that is widely used in industry today. The Hall effect was discovered by Edward H. Hall at Johns Hopkins University in 1879. Hall originally used a piece of pure gold to produce the Hall effect, but today a piece of semiconductor material is used because semiconductor material works better and is less expensive to use. The device is often referred to as the Hall generator.

Figure 18–1 illustrates how the Hall effect is produced. A constant current power supply is connected to opposite sides of a piece of semiconductor material. A sensitive voltmeter is connected to the other two sides. If the current flows straight through the semiconductor material, no voltage is produced across the voltmeter connection.

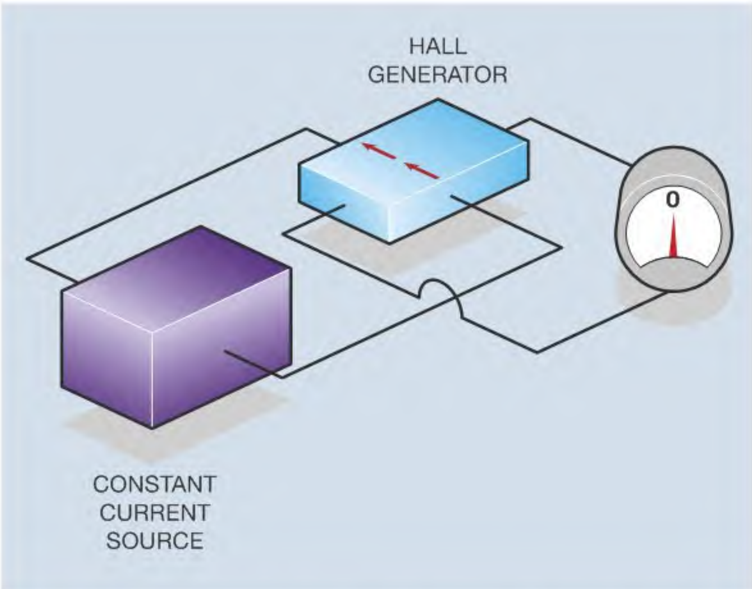


Figure 18–1 Constant current flows through a piece of semiconductor material.