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Fundamentals of Motor Control
Basic principles and language of AC motor control.



SQUARE D
GROUPE SCHNEIDER

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INTRODUCTION

The intent of this manual is to familiarize the reader with the terms and concepts that are fundamental to understanding motor control equipment and its applications. The manual is not intended to serve as an engineering text; the material covered is general in nature. Study the definitions, symbols, diagrams and illustrations to get a sound background in the language and basic principles associated with motor control products.

NOTE

To help in understanding the language of motor control, cross-references are provided.

As a supplement to this manual, a separate set of questions on the material is available. These questions are meant to reinforce the basic principles covered and can also serve to direct the reader to specific areas which may warrant additional review.

Scope

Since over 90% of all motors in use run on alternating current (AC), direct current (DC) motors and their control are not discussed. Wound rotor motors and AC commutator motors have only limited applications, so they are also not included. The squirrel cage induction motor (see AC SQUIRREL CAGE MOTOR on page 4), however, is the most widely used motor. Therefore, its control is the subject of this manual. High voltages (2400, 4800 and higher) require additional controls as compared to 600 volt equipment, and although the basic principles are unchanged, these additional requirements are not covered here.

Within this scope, the manual addresses the following topics:

- Selection of motor control equipment and its basic terminology (Chapter 1)
- NEMA enclosure structures for motor control equipment (Chapter 2)
- Overcurrent and overload protection of motors (Chapter 3)
- Manual and magnetic starters (Chapter 4)
- Wiring diagrams (Chapter 5)
- Auxiliary contacts, control devices and control schemes (Chapter 6)
- Contactors, variations on starters, relays, timers and pilot devices (Chapter 7)

SELECTION OF MOTOR CONTROL

The motor, machine and motor controller are interrelated and must be considered as a package when choosing a specific device for a particular application. In general, six basic factors influence the selection of a controller:

- Electrical Service
- Motor
- Operating characteristics of controller
- Environment
- National codes and standards
- IEC (International Electrotechnical Commission)

Electrical Service	Establish whether the service is DC or AC. If AC, determine the voltage and the number of phases and frequency.
Motor	The motor should be matched to the electrical service and correctly sized for the machine load (horsepower rating). Other considerations include motor speed (see Motor Speed on page 4) and torque (see Torque on page 5). To select proper protection for the motor, its full load current rating (see Full Load Current on page 4), service factor (see Motor Service Factor on page 6) and time rating (see Time (Duty) Rating on page 5) must be known.
Operating Characteristics Of Controller	<p>The fundamental job of a motor controller is to start and stop the motor and to protect the motor, machine and operator.</p> <p>The controller might also provide supplementary functions which could include:</p> <ul style="list-style-type: none"><input type="checkbox"/> Reversing<input type="checkbox"/> Jogging or inching (see Jogging (Inching) on page 6)<input type="checkbox"/> Plugging (see Plugging on page 6)<input type="checkbox"/> Operation at several speeds<input type="checkbox"/> Operation at reduced levels of current and motor torque (see Torque on page 5)
Environment	<p>Controller enclosures (see ENCLOSURES on page 7) serve to provide protection for operating personnel by preventing accidental contact with live parts. In certain applications, the controller itself must be protected from a variety of environmental conditions which might include:</p> <ul style="list-style-type: none"><input type="checkbox"/> Water, rain, snow or sleet<input type="checkbox"/> Dirt or non-combustible dust<input type="checkbox"/> Cutting oils, coolants or lubricants <p>Both personnel and property require protection in environments made hazardous by the presence of explosive gases or combustible dusts.</p>
National Codes and Standards	<p>Motor control equipment is designed to meet the provisions of the National Electrical Code (NEC). Code sections applying to industrial control devices are Article 430 on motors and motor controllers and Article 500 on hazardous locations.</p> <p>The National Electrical Code deals with the installation of equipment and is primarily concerned with safety (the prevention of injury and fire hazard to persons and property arising from the use of electricity). It is adopted on a local basis, sometimes incorporating minor changes or interpretations. National Electrical Code rules and provisions are enforced by governmental bodies exercising legal jurisdiction over electrical installations and used by insurance inspectors. Therefore, minimum safety standards are assured.</p> <p>The 1970 Occupational Safety and Health Act, as amended in 1972, requires that each employer furnish employment free from recognized hazards likely to cause serious harm. Provisions of the act are strictly enforced by inspection.</p>

Standards established by the National Electrical Manufacturers Association (NEMA) assist users in the proper selection of control equipment. NEMA standards provide practical information concerning construction, test, performance and manufacture of motor control devices such as starters, relays and contactors (see CONTACTORS on page 41).

One of the organizations that actually tests for conformity to national codes and standards is Underwriters Laboratories (UL). Equipment tested and approved by UL is listed in an annual publication which is kept current by means of periodic supplements reflecting the latest additions and deletions.

International Electrotechnical Commission (IEC)

The International Electrotechnical Commission (IEC), founded in 1906, is responsible for international standardization in the electrical and electronics fields. The IEC is presently composed of 41 National Committees, including the United States, that represent about 80% of the world's population. For motor control, the IEC issues recommendations on electrical terms, ratings, test methods and dimensional requirements.

MOTOR CONTROLLER

A motor controller will include some or all of the following functions: starting, stopping, overcurrent protection (see OVERCURRENT PROTECTION on page 11), overload protection (see Overload Protection on page 12), reversing, changing speed, jogging (see Jogging (Inching) on page 6), plugging (see Plugging on page 6), sequence control (see Sequence (Interlocked) Control on page 6) and pilot light indication. The controller can be simple or complex. It can provide the control for a single motor, a group of motors or auxiliary equipment such as brakes, clutches, solenoids, heaters and signals. Both the small fractional horsepower manual starter and the special control panel in Figure 1-1 below qualify as motor controllers.

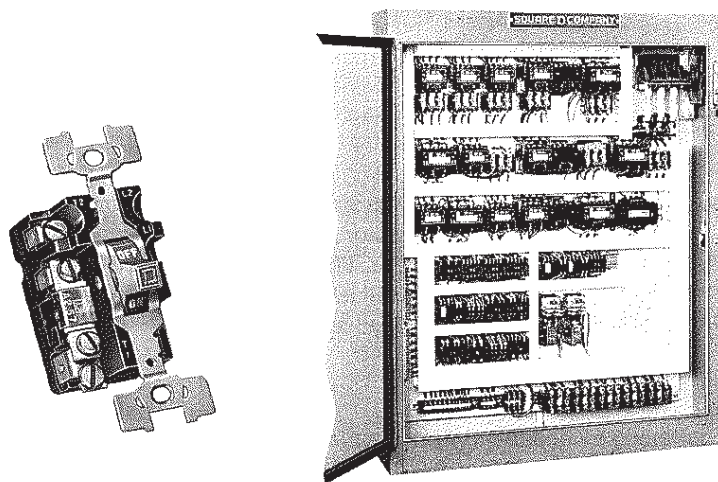


Figure 1-1 Manual Starter (left) and Control Panel (right)

Starter

The terms “starter” and “controller” mean practically the same thing. Strictly speaking, a starter is the simplest form of controller and is capable of starting and stopping the motor and providing it with overload protection (see Overload Protection on page 12).

AC SQUIRREL CAGE MOTOR

The workhorse of industry is the AC squirrel cage motor (Figure 1-2). Of the thousands of motors in general use today, the vast majority are the squirrel cage type. Squirrel cage motors are simple in construction and operation.

The squirrel cage motor gets its name because of its rotor construction which resembles a squirrel cage and has no wire winding.

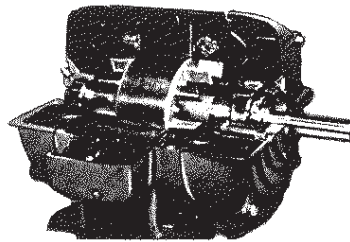


Figure 1-2 Squirrel Cage Motor

Full Load Current

Full load current (FLC) is the current required by the motor to produce rated torque (see Torque on page 5) at rated speed (see Motor Speed below).

Locked Rotor Current

During the acceleration period at the moment of start up, a motor draws a high current called the inrush current. The inrush current that occurs when the motor is initially connected directly to the power source or “line” (full voltage start) is called the locked rotor or stalled rotor current. The locked rotor current varies with motor design and can be from four to ten times the motor full load current (see Full Load Current above). The majority of motors have a locked rotor current of about six times full load current, and therefore this multiplier is generally used. The “six times” value is often expressed as 600% of full load current.

Motor Speed

The speed of a squirrel cage motor depends on the number of magnetic poles of the motor's winding and the frequency (cycles per second, or hertz) of the applied voltage. The synchronous speed of a squirrel cage motor is the rotational speed of the magnetic field created in the stationary winding (the stator) of the motor and is defined as follows:

$$\text{Synchronous speed (rpm)} = \frac{2 \times \text{frequency (Hz per Minute)}}{\# \text{ of poles}}$$

The rotating part of a squirrel cage motor (the rotor) always spins at a slower speed than the rotating magnetic field (required for this type of motor design to develop torque - see Torque on page 5). Thus, when operating at full load on 60 Hz power,

a 2-pole squirrel cage motor rotates at about 3450 rpm (3600 synchronous speed), a 4-pole at about 1725 rpm (1800 synchronous speed) and a 6-pole at about 1150 rpm (1200 synchronous speed).

The synchronous speed described above is not to be confused with a special design of motor known as a "synchronous motor" where the rotor does in fact turn at synchronous speed.

Torque

Torque is the turning or twisting force of the motor and is usually measured in pound-feet (lb-ft). Except when the motor is accelerating up to speed, the torque is related to the motor horsepower (hp) by the formula:

$$\text{Torque in lb-ft} = \frac{\text{hp} \times 5252}{\text{rpm}}$$

The torque of a 25 hp motor running at 1725 rpm would be computed as follows:

$$\text{Torque} = \frac{25 \times 5252}{1725} = \text{approximately } 76 \text{ lb-ft}$$

If 90 lb-ft is required to drive a particular load, the above motor will be overloaded and will draw a current in excess of full load current (see Full Load Current on page 4).

Ambient Temperature

The temperature of the air where a piece of equipment is located is called the ambient temperature. Most controllers are of the enclosed type, and the ambient temperature is the temperature of the air outside the enclosure, not inside. Similarly, if a motor is said to be in an ambient temperature of 30° C (86° F), this is the temperature of the air outside the motor, not inside. According to NEMA standards, the ambient temperature for both motors and controllers may not exceed 40° C (104° F).

Temperature Rise

Current passing through the windings of a motor results in an increase in the motor temperature. The difference between the winding temperature of the motor when running and the ambient temperature is called the temperature rise.

The temperature rise produced at full load is not harmful provided the motor ambient temperature does not exceed 40° C (104° F).

Higher temperature caused by increased current or higher ambient temperatures produces a deteriorating effect on motor insulation and lubrication. An old rule of thumb states that for each increase of 10° C above the rated temperature, motor life is cut in half.

Time (Duty) Rating

Most motors have a continuous duty rating permitting indefinite operation at rated load. Intermittent duty ratings are based on a fixed operating time (5, 15, 30, 60 minutes) after which the motor must be allowed to cool.

Motor Service Factor

If the motor manufacturer has given a motor a service factor, it means that the motor can be allowed to develop more than its rated or nameplate horsepower without causing undue deterioration of the insulation. The service factor is a margin of safety. If, for example, a 10 hp motor has a service factor of 1.15, the motor can be allowed to develop 11.5 hp (horsepower times service factor). The service factor depends on the motor design.

Jogging (Inching)

Jogging describes the frequent starting and stopping of a motor for short periods of time. A motor would be jogged when a piece of driven equipment has to be positioned fairly closely, for example when positioning the table of a horizontal boring mill during setup. If jogging is to occur more frequently than five times per minute, NEMA standards require that the starter be derated.

A NEMA Type 1 starter has a normal duty rating of 7.5 hp at 230 V, polyphase. On jogging applications, this same starter has a maximum rating of 3 hp.

Plugging

When a motor running in one direction is momentarily reconnected to reverse the direction, it will be brought to rest very rapidly. This is referred to as plugging. If a motor is plugged more than five times per minute, derating of the controller is necessary due to the heating of the contacts.

Plugging can only be used if the driven machine and its load will not be damaged by the reversal of the motor.

Sequence (Interlocked) Control

Many processes require a number of separate motors which must be started and stopped in a definite sequence, as in a system of conveyors. When starting up, the delivery conveyor must start first with the other conveyors starting in sequence to avoid a pileup of material. When shutting down, the reverse sequence must be followed with time delays between the shutdowns (except for emergency stops) so that no material is left on the conveyors. This is an example of a simple sequence control. Separate starters could be used, but it is common to build a special controller panel that incorporates starters for each motor, timers, and control relays (see CONTROL RELAYS on page 43). See Figure 1-3 below for a typical control panel.

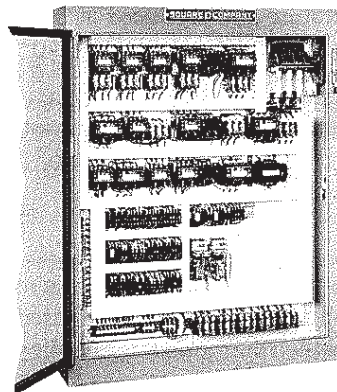


Figure 1-3 Control Panel

Chapter 2 - Enclosures

ENCLOSURES

NEMA and other organizations have established standards of enclosure construction for control equipment. In general, equipment would be enclosed for one or more of the following reasons:

- To prevent accidental contact with live parts
- To protect the control from harmful environmental conditions
- To prevent explosion or fires which might result from the electrical arc caused by the control

This chapter describes the common types of NEMA enclosures.

NEMA Type 1 - General Purpose

The NEMA Type 1 enclosure (Figure 2-1) is primarily intended to prevent accidental contact with the enclosed apparatus. It is suitable for general purpose applications indoors where it is not exposed to unusual service conditions. A NEMA Type 1 enclosure serves as protection against light indirect splashing and to some extent dust, however it is not dusttight.

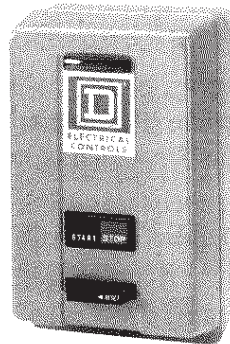


Figure 2-1 NEMA Type 1 - General Purpose Enclosure

NEMA Type 3 - Dusttight, Raintight

The NEMA Type 3 enclosure (Figure 2-2) is intended to provide protection against specified weather hazards. It is suitable for applications outdoors or in subways and tunnels, on ship docks, canal locks and construction sites. It is dusttight, raintight and sleet-resistant.

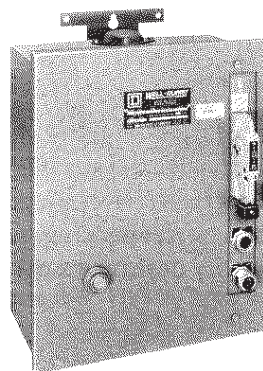


Figure 2-2 NEMA Type 3 - Dusttight, Raintight Enclosure

**NEMA Type 3R - Rainproof,
Sleet Resistant**

The NEMA Type 3R enclosure (Figure 2-3) protects against interference in operation of the contained equipment due to rain and resists damage from exposure to sleet. It is designed with conduit hubs and external mounting, as well as drainage provisions.

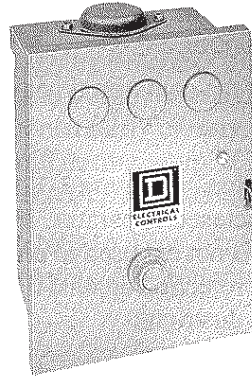


Figure 2-3 NEMA Type 3R - Rainproof, Sleet Resistant Enclosure

NEMA Type 4 - Watertight

The NEMA Type 4 enclosure (Figure 2-4, left) is designed to be watertight and is suitable for applications outdoors such as on ship docks and in dairies and breweries.

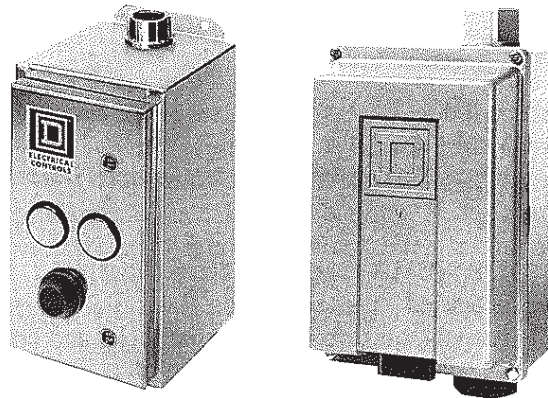


Figure 2-4 NEMA Type 4 - Watertight Enclosure (left) and NEMA Type 4X - Watertight, Corrosion-Resistant (right)

**NEMA Type 4X - Watertight,
Corrosion-Resistant**

The NEMA Type 4X enclosure (Figure 2-4, right) is generally constructed along the lines of NEMA Type 4 enclosures (see NEMA Type 4 above) except it is made of a material that is highly resistant to corrosion. For this reason, it is ideal in applications such as paper mills and in meat packing, fertilizer and chemical plants where contaminants would ordinarily destroy a steel enclosure over a period of time.

**NEMA Type 7 - Hazardous
Locations - Class I**

The NEMA Type 7 enclosure (Figure 2-5, left and center) is designed to meet the application requirements of the National Electrical Code for Class I hazardous locations. In this type of equipment, the circuit interruption occurs in air.

“Class I locations are those in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures.”

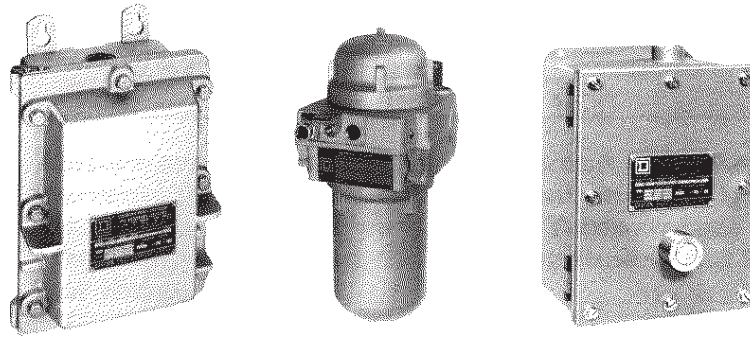


Figure 2-5 Hazardous Location Enclosures. NEMA Type 7 Class I , Bolted (left) and Spin Top® (center). NEMA Type 9 Class II, Groups E, F and G (right)

NEMA Type 9 - Hazardous Locations - Class II

The NEMA Type 9 enclosure (Figure 2-5, right) is designed to meet the application requirements of the National Electrical Code for Class II hazardous locations.

“Class II locations are those which are hazardous because of the presence of combustible dust.”

The letters following the class and type number indicate the particular groups of hazardous locations (as defined in the National Electrical Code) for which the enclosure is designed. The designation is incomplete without suffix letters.

NEMA Type 12 - Industrial Use

The NEMA Type 12 enclosure (Figure 2-6) is designed for use in industries where it is desirable to exclude such materials as dust, lint, fibers and flyings, and oil or coolant seepage.

There are no conduit openings or knockouts in the enclosure, and mounting is by means of flanges or mounting feet.

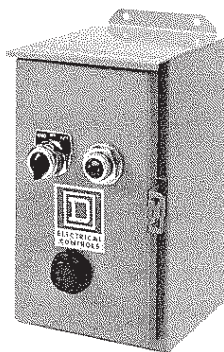


Figure 2-6 NEMA Type 12-Dusttight, Driptight Enclosure

**NEMA Type 13 - Oiltight,
Dusttight**

The NEMA Type 13 enclosure (Figure 2-7) is generally of cast construction, gasketed to permit use in the same environments as NEMA Type 12 devices (see NEMA Type 12 - Industrial Use on page 9). The essential difference is that due to its cast housing, a conduit entry is provided as an integral part of the NEMA Type 13 enclosure and mounting is by means of blind holes rather than mounting brackets.

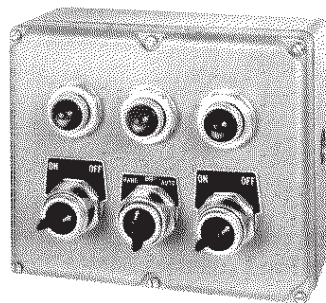


Figure 2-7 NEMA Type 13 - Oiltight, Dusttight

PROTECTION OF THE MOTOR

Motors can be damaged, or their effective life reduced, when subjected to a continuous current only slightly higher than their full load current rating (see Full Load Current on page 4) times the service factor (see Motor Service Factor on page 6).

NOTE

Motors are designed to handle inrush or locked rotor currents (see Locked Rotor Current on page 4) without excessive temperature rise (see Temperature Rise on page 5), provided the accelerating time is not too long nor the duty cycle too frequent.

Damage to insulation and windings of the motor can also be sustained on extremely high currents of short duration, as in ground faults and short circuits.

All currents in excess of full load current can be classified as overcurrents. In general, however, a distinction is made based on the magnitude of the overcurrent and the equipment to be protected.

An overcurrent up to locked rotor current is usually the result of a mechanical overload on the motor. Article 430 (Part C) of the National Electrical Code (see National Codes and Standards on page 2) entitled "Motor Running Overcurrent (Overload) Protection" covers the subject of protection against this type of overcurrent. In this manual, "motor running overcurrent (overload) protection" is referred to as "overload protection" and designates protection against overcurrents not exceeding locked rotor current (see Overload Protection on page 12).

Overcurrents due to short circuits or ground faults are much higher than locked rotor currents. Equipment used to protect against damage due to this type of overcurrent must not only protect the motor, but also the branch circuit conductors and the motor controller. Provisions for the protective equipment are specified in Article 430 (Part D) entitled "Motor-branch-circuit Short Circuit And Ground Fault Protection". In this manual, the above title is referred to as "overcurrent protection" and designates protection against high overcurrents typically encountered in short circuits or ground faults (see OVERCURRENT PROTECTION below).

Motor overload protection differs from overcurrent protection, and each is separately covered in the following paragraphs.

OVERCURRENT PROTECTION

The function of the overcurrent protective device is to protect the motor branch circuit conductors, control apparatus and motor from short circuits or ground faults. The protective devices commonly used to sense and clear overcurrents are thermal magnetic circuit breakers and fuses. NEMA type code letters on motor nameplates indicate the maximum percentage of full load current (see Full Load Current on page 4) that the motor is allowed to endure. The short circuit device must be capable of carrying the starting current of the motor, but the device setting must not exceed 250% of full load current (with no NEMA type code letter on the motor), or from 150 to 250% of full load current (depending upon NEMA type code letter of

ing current, it may be increased, but must in no case exceed 400% of the motor full load current.

The National Electrical Code (see National Codes and Standards on page 2) requires (with a few exceptions) a means to disconnect the motor and controller from the line, in addition to an overcurrent protective device to clear short circuit faults. The circuit breaker illustrated in Figure 3-1 (left) incorporates fault protection and disconnect in one basic device. When the overcurrent protection is provided by fuses, a disconnect switch is required and the switch and fuses are generally combined as illustrated in Figure 3-1 (right).

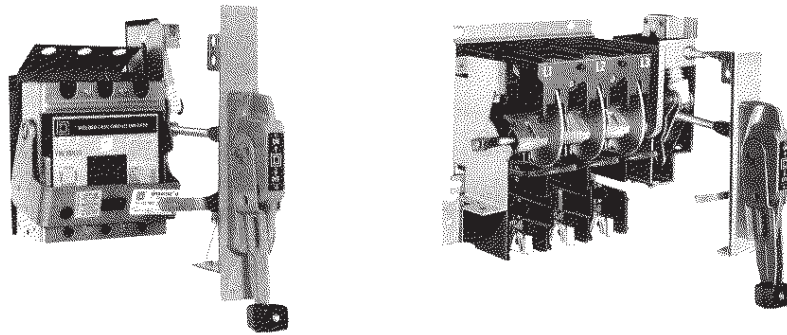


Figure 3-1 Circuit Breaker (left) and Fusible Disconnect (right)

OVERLOADS

A motor has no intelligence and will attempt to drive any load, even if excessive. Exclusive of inrush or locked rotor current (see Locked Rotor Current on page 4) when accelerating, the current drawn by the motor when running is proportional to the load, varying from a no load current (approximately 40% of full load current) to the full load current rating (see Full Load Current on page 4) stamped on the motor nameplate. When the load exceeds the torque rating (see Torque on page 5) of the motor, it draws higher than full load current and the condition is described as an overload. The maximum overload exists under locked rotor conditions, in which the load is so excessive that the motor stalls or fails to start, and as a consequence draws continual inrush (locked rotor) current.

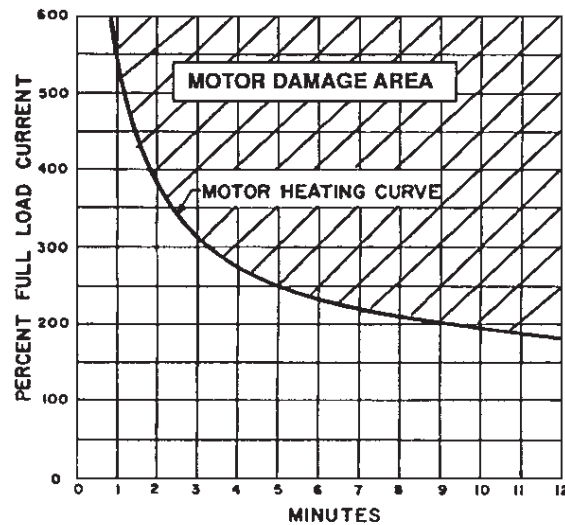
Overloads can be electrical or mechanical in origin. Single phasing of a polyphase motor and low line voltage are examples of electrical overloads.

Overload Protection

The effect of an overload is an excessive rise in temperature in the motor winding due to current higher than full load current (see Full Load Current on page 4). The larger the overload, the more quickly the temperature will increase to a point that is damaging to the insulation and lubrication of the motor. An inverse relationship, therefore, exists between current and time - the higher the current, the shorter the time before motor damage or "burn out" occurs.

All overloads shorten motor life by deteriorating the insulation. Relatively small overloads of short duration cause little damage, but if sustained they are just as harmful as overloads of greater magnitude. The relationship between the magnitude (percent of full load) and duration (time in minutes) of an overload is illustrat-

ed by the motor heating curve shown in Figure 3-2 below. The ideal overload protection for a motor is an element with current sensing properties similar to the heating curve of the motor, which acts to open the motor circuit when full load current is exceeded. The operation of the protective device should allow the motor a harmless overload, but quickly remove the motor from the line when an overload persists too long.



On 300% overload, the particular motor for which this curve is characteristic will reach its permissible temperature limit in three minutes. Overheating or motor damage occurs if the overload persists beyond this limit.

Figure 3-2 Motor Heating Curve

Overload Protection - Fuses

Fuses are not designed to provide overload protection. Their basic function is to protect against short circuits (overcurrents). When starting, motors draw a high inrush current which is generally six times the normal full load current (see Full Load Current on page 4). Single element fuses have no way of distinguishing between this temporary and harmless inrush current and a damaging overload. Thus, a fuse chosen on the basis of motor full load current would blow every time the motor started. On the other hand, if a fuse were chosen large enough to pass the starting or inrush current, it would not protect the motor against small, harmful overloads which might occur later. Dual element or time delay fuses can provide motor overload protection, but they suffer the disadvantage of being non-renewable and must be replaced.

Overload Protection - Overload Relays

The overload relay is the heart of motor protection. Like the dual element fuse (see Overload Protection - Fuses on page 13), the overload relay has inverse trip time characteristics, permitting it to hold in during the accelerating period when inrush current is drawn, yet providing protection on small overloads above full load current (see Full Load Current on page 4) when the motor is running. Unlike the fuse, the overload relay is renewable and can withstand repeated trip and reset cycles without need of replacement. It should be emphasized that the overload relay does

not provide short circuit protection. This is the function of overcurrent protective equipment like fuses and circuit breakers.

The overload relay consists of a current sensing unit connected in the line to the motor plus a mechanism, actuated by the sensing unit, which serves to directly or indirectly break the circuit. In a manual starter (see **MANUAL STARTER** on page 19) an overload trips a mechanical latch causing the starter contacts to open and disconnect the motor from the line. In magnetic starters (see page 27), an overload opens a set of control circuit contacts within the overload relay itself. These contacts are wired in series with the starter coil in the control circuit of the magnetic starter. Breaking the coil circuit causes the starter power contacts to open, disconnecting the motor from the line.

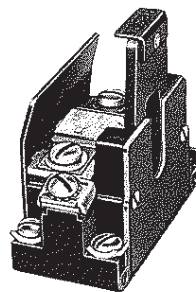
Overload relays can be classified as being either thermal or magnetic. Magnetic overload relays react only to current excesses and are not affected by temperature. As the name implies, thermal overload relays react to the rising temperatures caused by the overload current to trip the overload mechanism. Thermal overload relays can be further subdivided into two types: melting alloy and bimetallic.

Melting Alloy Thermal Overload Relay

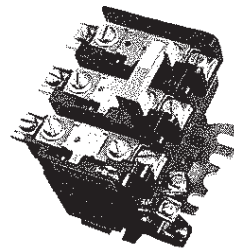
In melting alloy thermal overload relays (Figure 3-3), the motor current passes through a small heater winding. Under overload conditions, the heat causes a special solder to melt allowing a ratchet wheel to spin free thus opening the control circuit contacts (Figure 3-4 on page 15). When this occurs, the relay is said to "trip". To obtain appropriate tripping current for motors of different sizes, or different full load currents (see **Full Load Current** on page 4), a range of thermal units (heaters) is available. The heater coil and solder pot are combined in a one piece, nontamperable unit (Figure 3-5 on page 15). Melting alloy thermal overload relays must be reset by a deliberate hand operation after they trip. A reset button is usually mounted on the cover of enclosed starters. Thermal units are rated in amperes and are selected on the basis of motor full load current, not horsepower.

Bimetallic Thermal Overload Relay

Bimetallic thermal overload relays employ a U-shape bimetal strip associated with a current carrying heater coil. When an overload occurs, the heat will cause the bimetal to deflect and operate a control circuit contact. Different heaters give different trip points. In addition, most relays are adjustable over a range of 85% to 115% of the nominal heater rating (see Figure 3-6 on page 15).

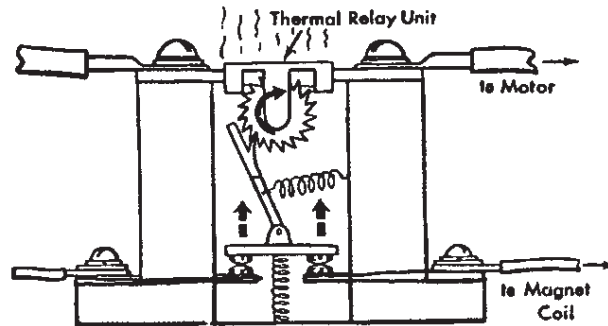


Single Pole



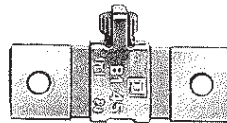
Three Pole

Figure 3-3 Melting Alloy Thermal Overload Relays

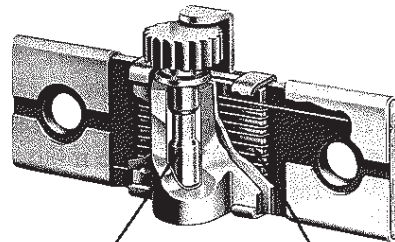


Drawing shows operation of melting alloy overload relay. As heat melts alloy, ratchet wheel is free to turn. The spring then pushes contacts open.

Figure 3-4 Melting Alloy Overload Relay



One Piece Thermal Unit



Solder pot (heat sensitive element) is an integral part of the thermal unit. It provides accurate response to overload current, yet prevents nuisance tripping.

Heating winding (heat producing element) is permanently joined to the solder pot, so proper heat transfer is always insured. No chance of misalignment in the field.

Figure 3-5 Thermal Unit

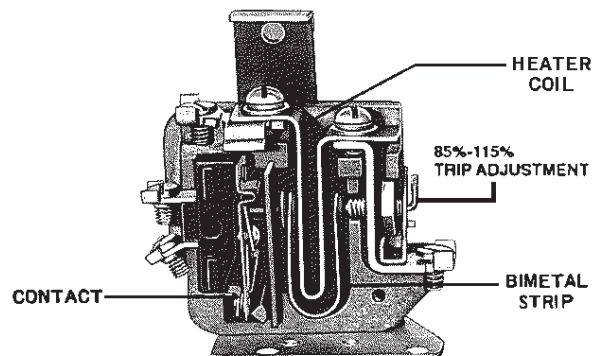


Figure 3-6 Bimetallic Overload Relay with Side Cover Removed

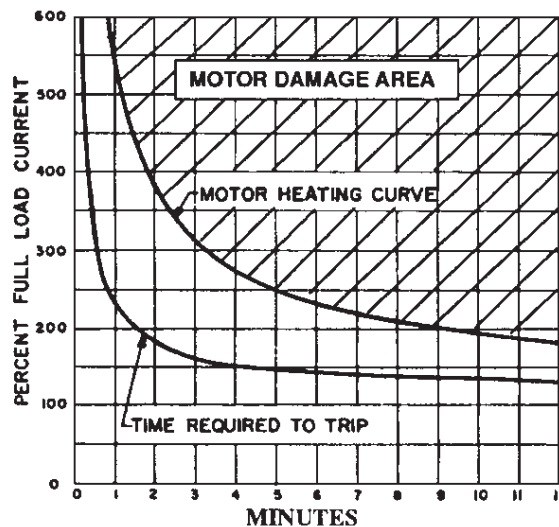
These relays are field convertible from hand reset to automatic reset and vice-versa. On automatic reset after tripping the relay, contacts will automatically reclose when the relay has cooled down. This is an advantage when the relays are inaccessible. However, automatic reset overload relays should not normally be used with 2-wire control (see Two Wire Control on page 34). With this arrangement, the motor will restart when the overload relay contacts reclose after an overload relay trip, and unless the cause of the overload has been removed, the overload relay will trip again. This cycle will repeat and eventually the motor will burn out due to the accumulated heat from the repeated inrush current. More important is the possibility of danger to personnel. The unexpected restarting of a machine may find the operator or maintenance man in a hazardous situation as he attempts to find out why his machine has stopped.

Ambient Compensation

Ambient-compensated bimetallic overload relays are designed for one particular situation; that is, when the motor is at a constant ambient temperature (see Ambient Temperature on page 5) and the controller is located separately in a varying ambient temperature. In this case, if a standard thermal overload relay were used, it would not trip at the same level of motor current if the controller temperature changed. The standard thermal overload relay is always affected by the surrounding temperature. To compensate for temperature variations, an ambient-compensated overload relay is used. Its trip point is not affected by temperature, and it performs consistently at the same value of current.

Thermal Overload Relay Trip Characteristics

Melting alloy and bimetallic overload relays (see Melting Alloy Thermal Overload Relay and Bimetallic Thermal Overload Relay above) are designed to approximate the heat actually generated in the motor. As the motor temperature increases, so does the temperature of the thermal unit. The motor and relay heating curves (Figure 3-7 below) show this relationship. From this graph we can see that no matter how high the current drawn, the overload relay will provide protection yet will not trip unnecessarily.



Graph shows motor heating curve and overload relay trip curve. Overload relay will always trip at a safe value

Figure 3-7 Overload Relay Trip Curve

Thermal Overload Relay Selection

Motor full load current (see Full Load Current on page 4), the type of motor and the possible difference in ambient temperature (see Ambient Temperature on page 5) between the motor and the controller must all be considered when choosing overload relay thermal units or overload heaters. Motors of the same horsepower and speed do not all have the same full load current. Always refer to the motor nameplate for the full load current. Do not use a published table because these tables of motor full load currents show the average or normal full load currents, whereas the full load current of the motor in question may be quite different. Thermal unit selection tables are published on the basis of continuous duty motors with 1.15 service factors (see Motor Service Factor on page 6) operating under normal conditions. The tables are shown in the Square D Digest and also appear on the inside of the door or cover of the controller. These selections will properly protect the motor and allow it to develop its full horsepower, allowing for the service factor, if the ambient temperature is the same at the motor as at the controller. If the temperatures are not the same, or if the motor service factor is less than 1.15, a special procedure is required to select the proper thermal unit. The basic procedure as well as typical variations are covered in the Digest under "Thermal Unit Selection Procedure".

Alarm Contacts

Standard overload relay contacts are closed under normal conditions and open when the relay trips. An alarm signal is sometimes required to indicate when a motor has stopped due to an overload trip. This is done by fitting the overload relay with a set of contacts which close when the relay trips, completing the alarm circuit. These contacts are called alarm contacts and may be used for applications such as indicating lights and audible alarms.

Magnetic Overload Relay

A magnetic overload relay (Figure 3-8) has a movable magnetic core inside a coil which carries the motor current. The magnetic flux set up inside the coil pulls the core upwards. When the core rises far enough (determined by the current and the position of the core) it trips a set of contacts on the top of the relay. The movement of the core is slowed by a piston working in an oil-filled dash pot (similar to a shock absorber) mounted below the coil. This produces an inverse-time characteristic. The effective tripping current is adjusted by moving the core on a threaded rod. The tripping time is varied by uncovering oil bypass holes in the piston. Because of the time and current adjustments, the magnetic overload relay is sometimes used to protect motors having long accelerating times or unusual duty cycles. The instantaneous trip magnetic overload relay is similar, but has no oil-filled dash pot.

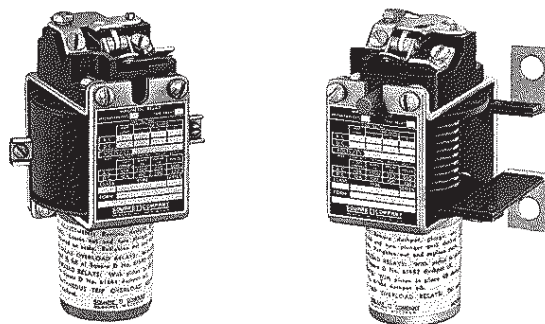


Figure 3-8 Magnetic Overload Relays

NOTES:

MANUAL STARTER

A manual starter is a motor controller whose contact mechanism is operated by a mechanical linkage from a hand-operated toggle or push button. A thermal unit and a direct acting overload mechanism provide motor overload protection (see Overload Protection on page 12). Basically, a manual starter is an On-Off switch with overload relays (see Overload Protection - Overload Relays on page 13).

Manual starters are generally used on small machine tools, fans and blowers, pumps, compressors and conveyors. They have the lowest cost of all motor starters, have a simple mechanism and provide quiet operation with no AC hum (see AC Hum on page 26). Moving a handle to On or pushing the Start button closes the power contacts which remain closed until the handle is moved to Off, or the Stop button is pushed, or the overload relay thermal units trip (see Thermal Overload Relay Trip Characteristics on page 16).

Manual starters are of the fractional horsepower type or the integral horsepower type and usually provide across-the-line starting. Standard manual starters cannot provide low voltage protection (see Low Voltage (Undervoltage Protection) on page 39) or low voltage release (see Low Voltage (Undervoltage Release) on page 38). If power fails, the contacts remain closed and the motor will restart when power returns. This is an advantage for devices such as pumps, fans, compressors and oil burners, but for other applications it can be a disadvantage and can even be dangerous to personnel or equipment.

Manual starters (Figure 4-1, left) or other maintained contact devices (see Maintained Contact on page 38) should not be used in applications where the machine or operator will be endangered if power fails and returns without warning. For dangerous applications such as band saws, drill presses or stamping presses, a magnetic starter (Figure 4-1, right) and momentary contact pilot device giving three wire control (see Three Wire Control on page 35) or a manual starter with low voltage protection should be used for safety purposes.

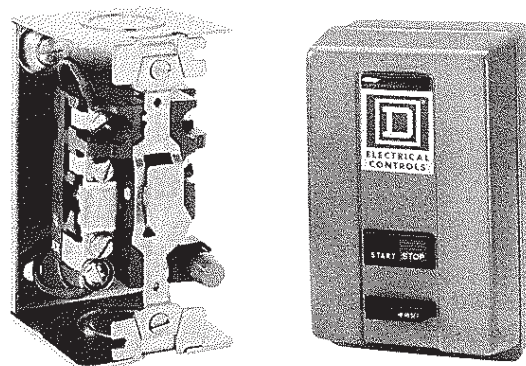


Figure 4-1 Manual Starter (left) and Magnetic Starter (right)

Fractional Horsepower Manual Starter

Fractional horsepower manual starters are designed to control and provide overload protection (see Overload Protection on page 12) for motors of one horsepower or less on 115 or 230 V single phase supplies. They are available in single and two pole versions and are operated by a toggle handle on the front (Figure 4-2 on page 20). When a serious overload occurs, the thermal unit trips to open the starter contacts thus disconnecting the motor from the line. The contacts cannot be reclosed until the overload relay (see Overload Protection - Overload Relays on page 13)

has been reset by moving the handle to the full Off position (after allowing about two minutes for the thermal unit to cool). The open type starter fits into a standard outlet box and can be used with a standard flush plate.

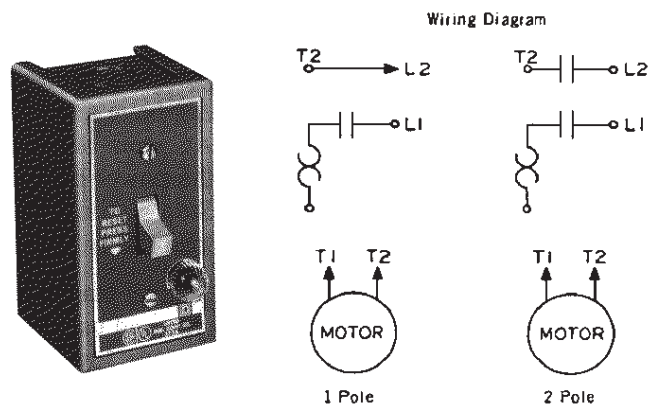


Figure 4-2 Fractional Horsepower Manual Starters

Manual Motor Starting Switches

Manual motor starting switches (Figure 4-3 below) provide On-Off control of single phase or three phase AC motors where overload protection (see Overload Protection on page 12) is not required or is separately provided. Two or three pole switches are available with ratings up to 10 hp, 600 V, three phase. The continuous current rating is 30 A at 250 V maximum and 20 A at 600 V maximum.

The toggle operation of the manual switch is similar to the fractional horsepower starter. Typical applications of the switch include small machine tools, pumps, fans, conveyors and other electrical machinery that has separate motor overload protection. They are particularly suited to switch non-motor loads such as resistance heaters.

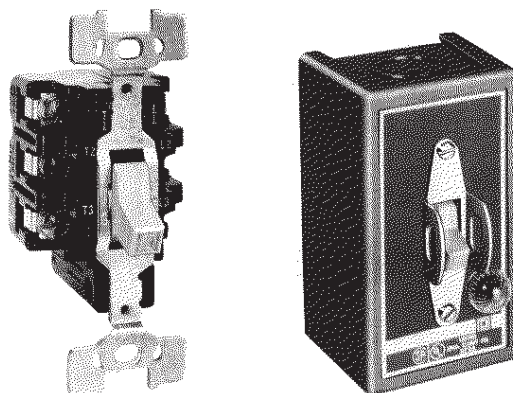


Figure 4-3 Manual Motor Starting Switches

Integral Horsepower Manual Starter

The integral horsepower manual starter (Figure 4-4 page 21) is available in two and three pole versions to control single phase motors up to 5 hp and three phase motors up to 10 hp respectively.

The two pole starters have one overload relay (see Overload Protection - Overload Relays on page 13) whereas three pole starters usually have three overload relays. When an overload relay trips (see Thermal Overload Relay Trip Characteristics on page 16), the starter mechanism unlatches thus opening the contacts to stop the motor. The contacts cannot be reclosed until the starter mechanism has been reset by pressing the Stop button or moving the handle to the Reset position after allowing time for the thermal unit to cool.

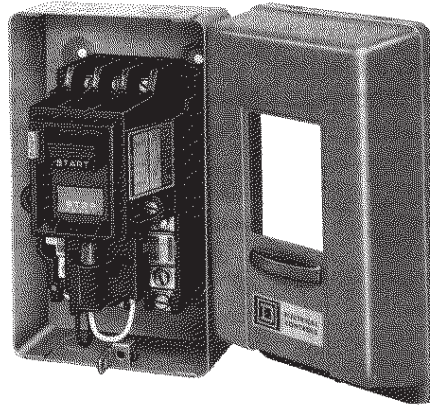


Figure 4-4 Integral Horsepower Manual Starter in a General Purpose Enclosure with Pilot Light

Manual Starter with Low Voltage Protection

Integral horsepower manual starters with low voltage protection prevent automatic restart of motors after a power loss. This is accomplished with a continuous duty solenoid that is energized whenever the line-side voltage is present. If the line voltage is lost or disconnected, the solenoid de-energizes thus opening the starter contacts. The contacts will not automatically close when the line voltage is restored. To close the contacts, the device must be manually reset and the Start button must be pressed. This manual starter will not function unless the line terminals are energized.

Typical applications include conveyors, grinders, mixers, metal and woodworking machinery and applications where local or national electrical codes require low voltage protection.

MAGNETIC CONTROL

A high percentage of applications require the controller to be capable of operation from remote locations or of providing automatic operation in response to signals from pilot devices (see Control Device (Pilot Device) on page 38) such as thermostats, pressure (see PRESSURE SWITCH on page 49) or float switches (see FLOAT SWITCH on page 50) and limit switches (see LIMIT SWITCH on page 48). Low voltage release (see Low Voltage (Undervoltage Release) on page 38) or low voltage protection (see Low Voltage (Undervoltage Protection) on page 39) might also be desired. Manual starters cannot provide this type of control, therefore magnetic starters are used.

The operating principle which distinguishes a magnetic from a manual starter is the use of an electromagnet. The electromagnet consists of a coil of wire placed on an iron core. When current flows through the coil, the iron of the magnet becomes

magnetized attracting the iron bar called the armature (Figure 4-5). The electromagnet can be compared to the permanent magnet in this respect (both will attract the iron bar).

The magnetic field of the permanent magnet will hold the armature against the pole faces of the magnet indefinitely. As a result, the armature cannot be dropped out except by physically pulling it away. In the electromagnet, however, interrupting the current flow through the coil of wire causes the magnet to become de-magnetized and to drop out the armature.

A manual starter must be mounted so that it is easily accessible to the operator. However, a magnetic starter may be remotely mounted with the push button stations, or other pilot devices, mounted anywhere on the machine and connected by control wiring into the coil circuit of the remotely mounted magnetic starter.

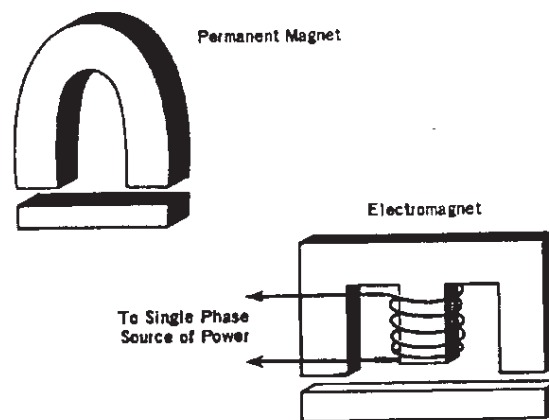


Figure 4-5 Permanent Magnet and Electromagnet

Magnet and Armature Assemblies

In the construction of a magnetic controller, the armature is mechanically connected to a set of contacts, so that when the armature moves to its closed position, the contacts also close. Figure 4-6 on page 23 shows several magnet and armature assemblies in elementary form. When the coil has been energized and the armature has moved to the closed position, the controller is said to be “picked up” and the armature “seated” or “sealed-in”.

Among the common types of magnet and armature assemblies are:

- ❑ Clapper Type - The armature is hinged. As it pivots to close (seal in), the movable contacts close against the stationary contacts.
- ❑ Vertical Action - The action is a straight line motion with the armature and contacts being guided so that they move in a vertical plane.
- ❑ Horizontal Action - Both armature and contacts move in a straight line through a horizontal plane.
- ❑ Bell Crank - A bell crank lever transforms the vertical action of the armature into a horizontal contact motion. The mechanical shock of the armature seating is not transmitted to the contacts, resulting in minimum contact bounce and longer contact life.

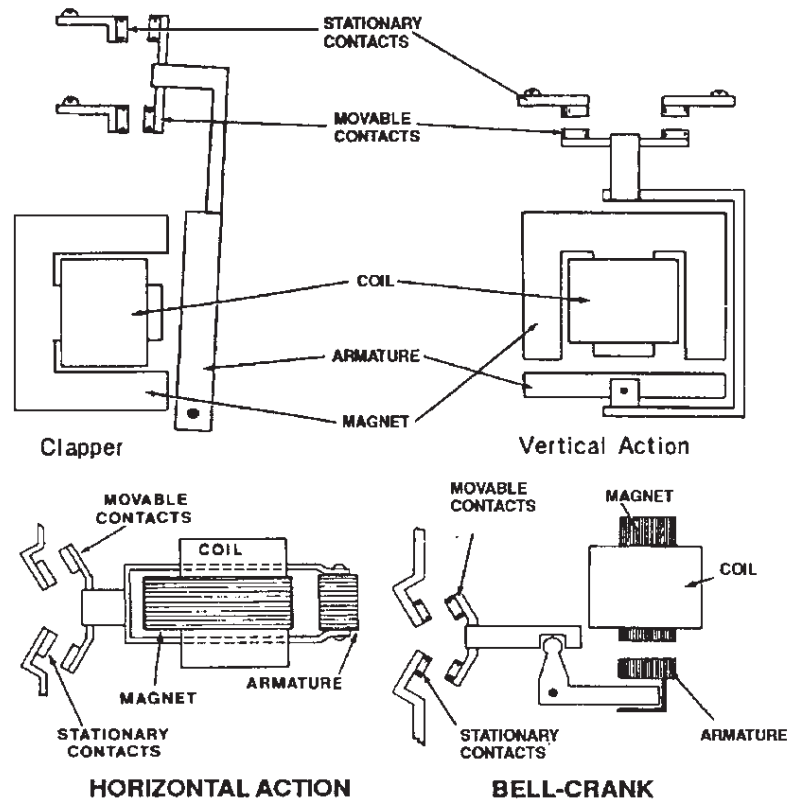


Figure 4-6 Magnet and Armature Assemblies

Magnetic Circuit

The magnetic circuit of a controller consists of the magnet assembly, the coil and the armature. It is called a circuit from a comparison with an electrical circuit. The coil and the current flowing in it cause magnetic flux to flow through the iron in a manner similar to a voltage causing current to flow through a system of conductors. The changing magnetic flux produced by alternating currents results in a temperature rise (see Temperature Rise on page 5) in the iron parts. The heating effect is reduced by laminating the magnet assembly and armature.

Magnet Assembly

The magnet assembly is the stationary part of the magnetic circuit. The coil is supported by, and surrounds part of, the magnet assembly in order to induce magnetic flux into the magnetic circuit.

Armature

The armature is the moving part of the magnetic circuit. When it has been attracted into seated or sealed-in position, it completes the magnetic circuit. To provide maximum pull (to close the contacts) and to help insure quietness, the faces of the armature and the magnet assembly are ground to a very close tolerance.

Air Gap

When a controller's armature has seated, it is held closely against the magnet assembly (see Magnet and Armature Assemblies on page 22). However, a small gap is deliberately left in the iron circuit (Figure 4-7 below). When the coil is de-energized, some magnetic flux (residual magnetism) always remains, and if it were not for the gap in the iron circuit, the residual magnetism might be sufficient to hold the armature in the sealed-in position.

An air gap can be created during the manufacturing process when the magnet faces are ground to close tolerances, and is sometimes described as a "ground air gap". Some magnet assemblies contain a shim of precise thickness made of non-magnetic metal placed in the magnetic flux path. This type of air gap is called a permanent air gap. By design, a magnet assembly could incorporate either or both types of air gaps.

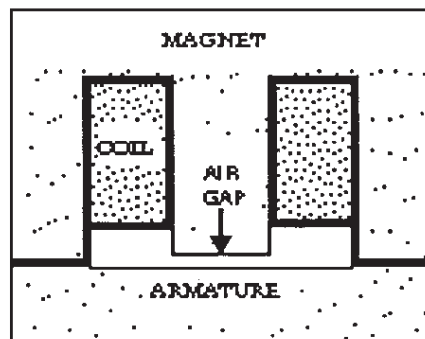


Figure 4-7 Air Gap

Shading Coil

A shading coil is a single turn of conducting material (generally copper or aluminum) mounted in the face of the magnet assembly or armature (see Figure 4-8). The alternating main magnetic flux induces currents in the shading coil and these currents set up auxiliary magnetic flux which is out of phase from the main flux (Figure 4-9 on page 25). The auxiliary flux produces a magnetic pull out of phase from the pull due to the main flux and this keeps the armature sealed-in when the main flux falls to zero (which occurs 120 times per second with 60 cycle AC). Without the shading coil, the armature would tend to open each time the main flux goes through zero. Excessive noise, wear on the magnet faces and heat would result.

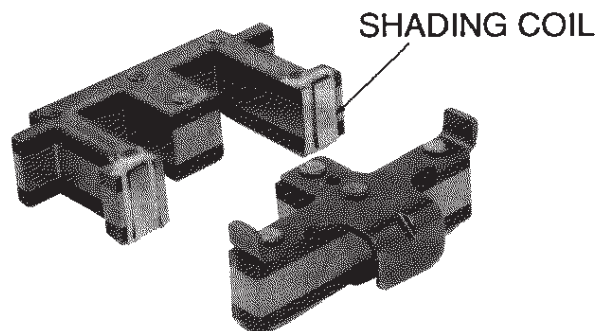


Figure 4-8 Magnet Assembly and Armature with Shading Coil Shown

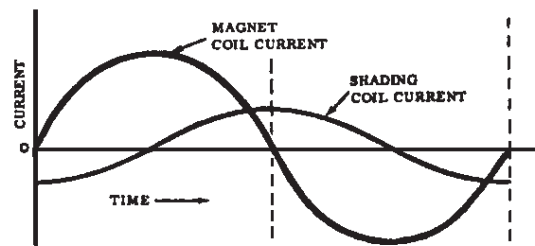


Figure 4-9 Time/Current Curve

Magnet Coil - Inrush and Sealed Currents

The magnet coil has many turns of insulated copper wire wound on a spool. Most coils are protected by an epoxy molding which makes them very resistant to mechanical damage.

When the controller is in the open position, there is a large air gap (not to be confused with the air gap shown in Figure 4-7 on page 24) in the magnetic circuit since the armature is at its furthest distance from the magnet. The impedance of the coil, which in AC magnetic circuits is the property to limit or resist current flow, is relatively low due to the air gap, so that when the coil is energized it draws a fairly high current. As the armature moves closer to the magnet assembly, the air gap is progressively reduced, and with it the coil current, until the armature has sealed in. The final current is referred to as the sealed current. The inrush current is approximately six to ten times the sealed current, however the ratio varies with individual designs. After the controller has been energized for some time, the coil becomes hot. This causes the coil current to fall to approximately 80% of its value when cold.

AC magnet coils should never be electrically connected in series. If one device were to seal-in ahead of the other (which is quite likely if the devices are not identical, and a possibility even if they are) the increased circuit impedance will reduce the coil current so that the slow device will not pick up or, if it does pick up, will not seal. For this reason, AC coils should always be connected in parallel.

Magnet Coil - Inrush and Sealed Current Ratings

Magnet coil data is usually given in volt-amperes (volts times amperes or VA). For example, given a magnetic starter (see page 27) with a coil rated at 600 VA sealed, the inrush current of a 120 V coil equals $600 \text{ VA} / 120 \text{ V}$ or 5 A, and the sealed current is $60/120$ or 0.5 A. The same starter with a coil rated at 480 V or 1.25 A inrush has $60/480$ or 0.125 A sealed.

Pick-up Voltage

The pick-up voltage is the minimum voltage applied to the coil that causes the armature (see Armature on page 23) to move.

Seal-in Voltage

The seal-in voltage is the minimum control voltage required to cause the armature (see Armature on page 23) to seat against the faces of the magnet. On devices using a vertical action magnet and armature, the seal-in voltage is higher than the pick-up voltage to provide additional magnetic pull to insure good contact pressure.

Control devices using the bell crank armature and magnet arrangement are unique in that they have different force characteristics. Devices using this operating principle are designed to have a lower seal-in voltage than pick-up voltage. Contact life is extended, and contact damage under abnormal voltage conditions is reduced.

Drop-out Voltage

If the control voltage is reduced sufficiently, the controller will open. The voltage at which this happens is called the "drop-out" voltage and it is lower than the seal-in voltage.

Magnet Coil - Voltage Variations

NEMA standards require that the magnetic device operate properly at varying control voltages from a high of 110% to a low of 85% of rated coil voltage. This range, established by coil design, ensures that the coil will withstand given temperature rises at voltages up to 10% over rated voltage, and that the armature (see Armature on page 23) will pick up and seal in even though the voltage may drop to 15% under the nominal rating.

Effects of Voltage Variation - Voltage Too High

If the voltage applied to the coil is too high, the coil will draw more than its designed current. As a result, excessive heat is produced and will cause early failure of the coil insulation. The magnetic pull will be too high and will cause the armature (see Armature on page 23) to seat with excessive force. The magnet faces will wear rapidly, leading to a shortened life for the controller. In addition, contact bounce may be excessive, resulting in reduced contact life.

Effects of Voltage Variation - Voltage Too Low

Low control voltage produces low coil currents and reduced magnetic pull. On devices with vertical action assemblies, if the voltage is greater than pick-up voltage but less than seal-in voltage, the controller may pick up but will not seal. With this condition, the coil current will not fall to the sealed value. As the coil is not designed to carry continuously a current greater than its sealed current, it will quickly get very hot and burn out. The armature (see Armature on page 23) will also chatter. In addition to the noise, wear on the magnet faces results.

In both vertical action and bell crank construction, if the armature does not seal, the contacts will not close with adequate pressure. Excessive heat, with arcing and possible welding of the contacts, will occur as the controller attempts to carry current with insufficient contact pressure.

AC Hum

All AC devices which incorporate a magnetic effect produce a characteristic hum. This hum or noise is due mainly to the changing magnetic pull (as the flux changes) inducing mechanical vibrations. Excessive noise in the contactors (see CONTACTORS on page 41), starters and relays could result from the following operating conditions:

- Broken shading coil (see Shading Coil on page 24)
- Operating voltage too low
- Wrong coil
- Misalignment between the armature and magnet assembly (see Magnet and Armature Assemblies on page 22) - the armature is then unable to seat properly

- ❑ Dirt, rust, filings etc. on the magnet faces - the armature is unable to seal-in completely
- ❑ Jamming or binding of moving parts (contacts, springs, bearings) so that full travel of the armature is prevented
- ❑ Incorrect mounting of the controller. For example, a thin piece of plywood fastened to a wall so that a sounding board effect is produced

Magnetic Starter - Power Circuit

The power circuit of a starter includes the stationary and movable contacts and the thermal unit or heater portion of the overload relay assembly (see Overload Protection - Overload Relays on page 13). The number of contacts (or power poles) is determined by the electrical service. In a three phase, three wire system, for example, a three pole starter is required (Figure 4-10).

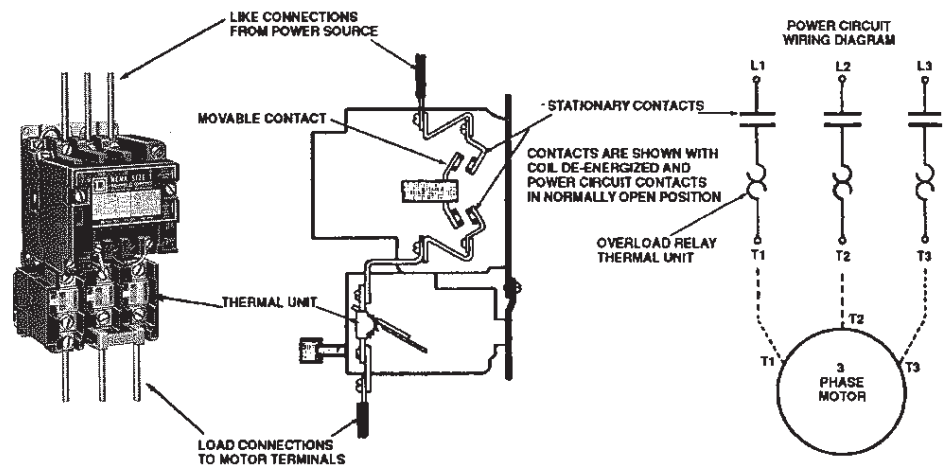


Figure 4-10 Magnetic Starter Power Circuit

Magnetic Starters - NEMA Sizes and Ratings

Power circuit contacts handle the motor load. The ability of the contacts to carry the full load current (see Full Load Current on page 4) without exceeding a rated temperature rise (see Temperature Rise on page 5) and their isolation from adjacent contacts corresponds to NEMA standards established to categorize the NEMA size of the starter. The starter must also be capable of interrupting the motor circuit under locked rotor current (see Locked Rotor Current on page 4) conditions.

To be suitable for a given motor application, the magnetic starter selected should be equal to or exceed the motor horsepower and full load current ratings. For example, a 50 hp motor with 230 V service, polyphase, and a full load current of 125 A will need (according to Table 4-1 on page 28) a NEMA Size 4 starter for normal motor duty. This same NEMA Size 4 starter is derated to motors of 30 hp maximum if jogging (see Jogging (Inching) on page 6) or plugging duty (see Plugging on page 6) were required. If the same 50 hp motor were used for jogging or plugging duty, Table 4-1 indicates that the only controller rated for plugging/jogging duty for a 50 hp motor with a 230 V load is a NEMA size 5 with a 75 hp rating.

NEMA Size	Load Volts	Maximum Horsepower Rating — Nonplugging and Nonjogging Duty		Maximum Horsepower Rating — Plugging and Jogging Duty †		Continuous Current Rating, Amperes — 600 Volt Max.	Service-Limit Current Rating, Amperes *	Tungsten and Infrared Lamp Load, Amperes — 250 Volts Max. ★	Resistance Heating Loads, KW — other than Infrared Lamp Loads ‡		KVA Rating for Switching Transformer Primaries At 50 or 60 Cycles				3 Phase Rating for Switching Capacitors ●	
		Single Phase	Poly-Phase	Single Phase	Poly-Phase				Single Phase	Poly-Phase	Transformers Having Inrush Currents (Worst Case Peak) of Not More Than 20 Times Peak of Continuous Current Rating		Transformers Having Inrush Currents (Worst Case Peak) of Over 20 Through 40 Times Peak of Continuous Current Rating			KVAR
											Single Phase	Poly-Phase	Single Phase	Poly-Phase		
00	115	1/2	...	...	...	9	11	5	...	...	...	...	...	...	...
	200	...	1 1/2	...	...	9	11	5	...	...	...	...	...	...	...
	230	1	1 1/2	...	...	9	11	5	...	...	...	...	...	...	...
	380	...	1 1/2	...	...	9	11	...	...	...	...	...	...	...	...
	460	...	2	...	...	9	11	...	...	...	...	...	...	...	...
575	...	2	...	...	9	11	...	...	...	...	...	...	...	...	...
0	115	1	...	1/2	...	18	21	10	...	...	0.6	...	0.3	...	...
	200	...	3	...	1 1/2	18	21	10	...	...	1.8	...	0.9	...	...
	230	2	3	1	1 1/2	18	21	10	...	...	1.2	2.1	0.6	1.0	...
	380	...	5	...	1 1/2	18	21	...	...	...	...	...	...	...	...
	460	...	5	...	2	18	21	...	...	...	2.4	4.2	1.2	2.1	...
575	...	5	...	2	18	21	...	...	...	3.0	5.2	1.5	2.6	...	
1	115	2	...	1	...	27	32	15	3	5	1.2	...	0.6	...	...
	200	...	7 1/2	...	3	27	32	15	...	9.1	...	3.6	...	1.8	...	
	230	3	7 1/2	2	3	27	32	15	...	10	2.4	4.3	1.2	2.1	...	
	380	...	10	...	5	27	32	...	...	16.5	...	...	...	...	...
	460	...	10	...	5	27	32	...	12	20	4.9	8.5	2.5	4.3	...	
575	...	10	...	5	27	32	...	15	25	6.2	11.0	3.1	5.3	...		
1P	115	3	...	1 1/2	...	36	42	24	...	...	...	...	...	...	...
	230	5	...	3	...	36	42	24	...	...	...	...	...	...	...
2	115	3	...	2	...	45	52	30	5	8.5	2.1	...	1.0	...	...
	200	...	10	...	7 1/2	45	52	30	...	15.4	...	6.3	...	3.1	...	
	230	7 1/2	15	5	10	45	52	30	10	17	4.1	7.2	2.1	3.6	8	
	380	...	25	...	15	45	52	...	...	28	...	...	...	...	...
	460	...	25	...	15	45	52	...	20	34	8.3	14	4.2	7.2	16	
575	...	25	...	15	45	52	...	25	43	10.0	18	5.2	8.9	20		
3	115	...	25	...	15	90	104	60	10	17	4.1	...	2.0	...	...
	200	...	30	...	20	90	104	60	...	31	...	12	...	6.1	...	
	230	...	30	...	20	90	104	60	20	34	8.1	14	4.1	7.0	27	
	380	...	50	...	30	90	104	...	...	56	...	...	...	...	...
	460	...	50	...	30	90	104	...	40	68	16	28	8.1	14	53	
575	...	50	...	30	90	104	...	50	86	20	35	10	18	67		
4	200	...	40	...	25	135	156	120	...	45	...	20	...	10	...	
	230	...	50	...	30	135	156	120	30	52	14	23	6.8	12	40	
	380	...	75	...	50	135	156	...	...	86.7	...	...	...	...	...
	460	...	100	...	60	135	156	...	60	105	27	47	14	23	80	
	575	...	100	...	60	135	156	...	75	130	34	59	17	29	100	
5	200	...	75	...	60	270	311	240	...	91	...	41	...	20	...	
	230	...	100	...	75	270	311	240	60	105	27	47	14	24	80	
	380	...	150	...	125	270	311	...	...	173	...	...	...	...	...
	460	...	200	...	150	270	311	...	120	210	54	94	27	47	160	
	575	...	200	...	150	270	311	...	150	260	68	117	34	59	200	
6Δ	200	...	150	...	125	540	621	480	...	182	...	81	...	41	...	
	230	...	200	...	150	540	621	480	120	210	54	94	27	47	160	
	380	...	300	...	250	540	621	...	...	342	...	...	...	...	...
	460	...	400	...	300	540	621	...	240	415	108	188	54	94	320	
	575	...	400	...	300	540	621	...	300	515	135	234	68	117	400	
7Δ	230	...	300	...	...	810	932	...	180	315	...	...	...	...	240
	460	...	600	...	...	810	932	...	360	625	...	...	...	...	480
	575	...	600	...	...	810	932	...	450	775	...	...	...	...	600

Tables and footnotes are taken from NEMA Standards.

† Ratings shown are for applications requiring repeated interruptions of stalled motor current or repeated closing of high transient currents encountered in rapid motor reversal, involving more than five openings or closings per minute and more than ten in a ten-minute period, such as plug-stop, plug-reverse or jogging duty. Ratings apply to single speed and multi-speed controllers.

* Per NEMA Standards paragraph ICS 2-321.20, the service-limit current represents the maximum ms current, in amperes, which the controller may be expected to carry for protracted periods in normal service. At service-limit current ratings, temperature rises may exceed those obtained by testing the controller at its continuous current rating. The ultimate trip current of over-current (overload) relays or other motor protective devices shall not exceed the service-limit current ratings of the controller.

★ FLUORESCENT LAMP LOADS — 300 VOLTS AND LESS — The characteristics of fluorescent lamps are such that it is not necessary to derate Class 8502 contactors below their normal continuous current rating. Class 8903 contactors may also be used with fluorescent lamp loads. For controlling tungsten and infrared lamp loads, and resistance heating loads, Class 8903 ac lighting contactors are recommended. These contactors are specifically designed for such loads and are applied at their full rating as listed in the Class 8903 Section.

‡ Ratings apply to contactors which are employed to switch the load at the utilization voltage of the heat producing element with a duty which requires continuous operation of not more than five openings per minute. Class 8903 Types L and S lighting contactors are rated for resistance heating loads.

● When discharged, a capacitor has essentially zero impedance. For repetitive switching by contactor, sufficient impedance should be connected in series to limit inrush current to not more than 6 times the contactor rated continuous current. In many installations,

the impedance of connecting conductors may be sufficient for this purpose. When switching to connect additional banks, the banks already on the line may be charged and can supply additional available short-circuit current which should be considered when selecting the impedance to limit the current.

The ratings for capacitor switching above assume the following maximum available fault currents:

NEMA Size 2-3: 5,000 A RMS Sym.
NEMA Size 4-5: 10,000 A RMS Sym.
NEMA Size 6-7: 18,000 A RMS Sym.

If available fault current is greater than these values, connect sufficient impedance in series as noted in the previous paragraph.

The motor ratings in the above table are NEMA standard ratings and apply only when the code letter of the motor is the same as or occurs earlier in the alphabet than is shown in the table below.

Motors having code letters occurring later in the alphabet may require a larger controller.

Motor HP Rating	Maximum Allowable Motor Code Letter
1 1/2-2	L
3-5	K
7 1/2 & above	H

Table 4-1 Electrical Ratings for AC Magnetic Contactors and Starters

Magnetic Starter - Coil Circuit

The circuit to the magnet coil, which causes a magnetic starter to pickup and drop-out, is distinct from the power circuit. Although the power circuit can be single-phase or polyphase, the coil circuit is always a single phase circuit. Elements of a coil circuit (Figure 4-11) include the following:

- ❑ The magnet coil
- ❑ The control contact(s) of the overload relay assembly
- ❑ A momentary or maintained contact pilot device, such as a push-button station or a pressure, temperature, liquid level or limit switch
- ❑ In lieu of a pilot device, the contact(s) of a relay or timer
- ❑ An auxiliary contact on the starter, designated as a holding circuit interlock, which is required in certain control schemes

The coil circuit is generally identified as the control circuit, and contacts in the control circuit handle the coil load.

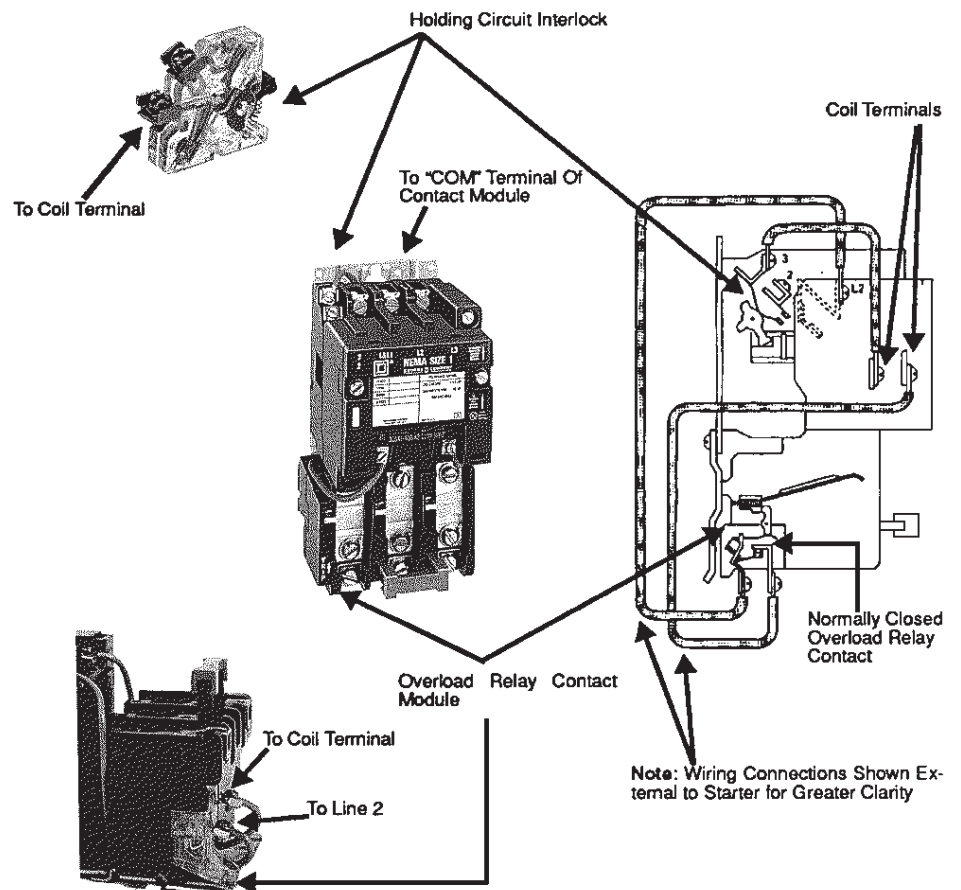


Figure 4-11 Coil Circuit

Magnetic Starter - Control Circuit

The inter-wiring shown in Diagram A of Figure 4-12 covers only the control circuit wiring provided by the factory. Per NEMA Standards, the single phase control circuit is conventionally wired between Line 1 (L1) and Line 2 (L2). As review of Wiring Diagram A will show, the control circuit is connected to the single phase circuit at Line 2, but like a lamp plug with only one prong, there is no control circuit connection to Line 1(L1).

Wiring Diagram B of Figure 4-12 illustrates that the control circuit is completed by the additional wiring of a two wire pilot device (see Control Device (Pilot Device) on page 38) between terminal three on the auxiliary contact and terminal 1 (L1) on the starter.

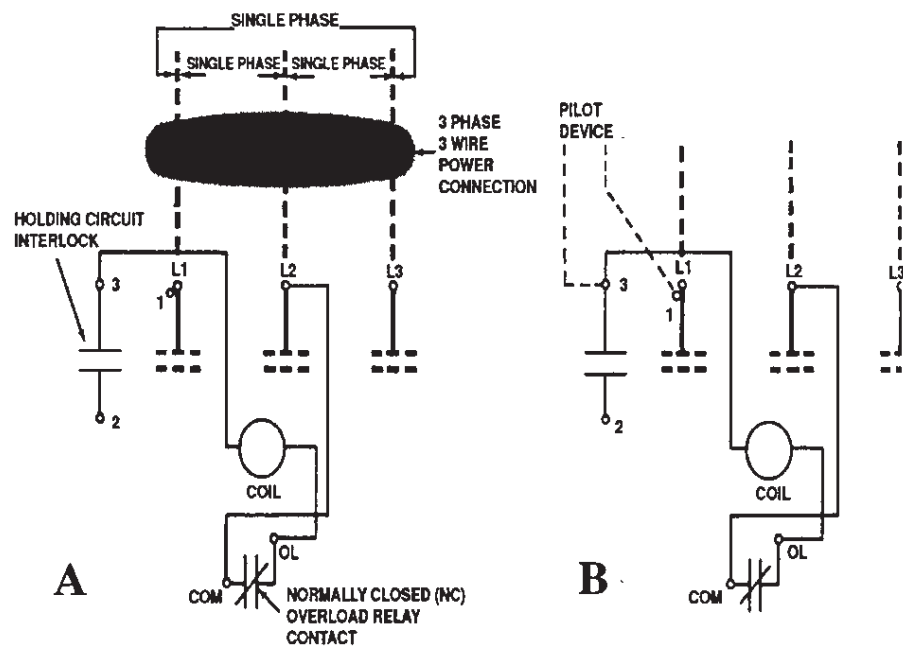


Figure 4-12 Wiring Diagrams A and B

Magnetic Starter - Control Circuit Currents

Although the power circuit and control circuit voltage may be the same, the current drawn by the motor in the power circuit is much higher than that drawn by the coil in the control circuit

Pilot devices (see Control Device (Pilot Device) on page 38) and contacts of timers and relays used in control circuits are not generally horsepower rated, and the current rating is low compared to the power contacts of starters or contactors (see CONTACTORS on page 41).

Inrush and sealed currents of a control circuit can be determined by reference to a magnet coil table (see Table 4-2 on page 31).

A standard duty push button with a rating of 15 A inrush, 1.5 A normal (sealed) current at 240 V 60 Hz can satisfactorily be used to control the coil circuit of a three

pole NEMA Size 3 starter or contactor, which has an inrush current of 2.9 A (700 VA / 240 V) and a sealed current of 0.2 A (46 VA / 240 V).

As a comparison of the differences in current, the power circuit contacts of the above starter may be controlling a 30 hp polyphase motor, drawing a full load current (see Full Load Current on page 4) of 78 A.

Listed in Table 4-2 are the identification numbers, ratings and operating characteristics of magnet coils for standard relays, contactors, starters and timers. Coils are also available for other voltages and frequencies, in addition to those listed here.

AC magnet coils are designed to operate on line voltages fluctuating as much as 15% below and 10% above nominal rating. DC coils have corresponding limits of 20% below and 10% above nominal rating.

REPLACEMENT AC MAGNET COILS FOR MAGNETIC CONTACTORS AND STARTERS

Equipment To Be Serviced				Coil Prefix or Class and Type	SUFFIX NUMBER (Complete Coil Number Consists of Prefix or Class and Type Followed by Suffix Number.)													Coil Volt-Amperes					
Device	Size	Type	Poles		Hz	24 Volts	110-115 Volts	120 Volts	208 Volts	220 Volts	240 Volts	277 Volts	380 Volts	440 Volts	480 Volts	550 Volts	600 Volts	In-rush	Sealed				
Coils for Present Design Magnetic Contactors and Starters Classes 8502, 8536, 8538, 8539, 8606, 8630, 8640, 8647, 8650, 8651, 8702, 8736, 8739, 8810, 8811, 8812, and 8903	20 Amp.	L	2-6	9998L	60	23	44	44	50	Δ	53	55	60	62	63	65	65	150	30				
			50	24	44	45	52	53	54	56	60	62	63	65	66	140	30						
		8-12	9998LH	60	23	44	44	50	Δ	53	55	60	62	63	65	65	180	35					
		50	24	44	45	52	53	54	56	60	62	63	65	66	170	35							
	LX	2-4	9998L	60	23	44	44	50	Δ	53	55	60	62	63	65	65	150	...					
		50	24	44	45	52	53	54	56	60	62	63	65	66	140	...							
	6-12	9998LH	60	23	44	44	50	Δ	53	55	60	62	63	65	65	180	...						
		50	24	44	45	52	53	54	56	60	62	63	65	66	170	...							
	00	SAΔ (Series B)	All	9998SAC	60	23	Δ	45	52	Δ	54	55	59	Δ	62	Δ	65	65	165	33			
				50	24	45	52	54	59	62	65	65	165	33									
	0, 1, 1P & 30 Amp.	SB, SC & SM	All	31041-400	60	20	Δ	42	43	48	Δ	51	51	52	56	Δ	60	61	Δ	62	64	245	27
				50	22	42	43	48	51	53	57	60	61	62	64	232	26						
				31041-402	60	20	Δ	42	43	48	Δ	51	51	52	56	Δ	60	61	Δ	62	64	245	27
				50	22	42	43	48	51	53	57	60	61	62	64	232	26						
	2 & 60 Amp.	SD & SP	2 & 3	31063-400	60	16	Δ	38	39	44	Δ	47	49	53	Δ	57	Δ	60	61	311	37		
			50	17	38	39	44	47	48	49	53	54	57	58	Δ	60	61	296	36				
			2 & 3	31063-411	60	16	Δ	38	39	44	Δ	47	48	49	53	Δ	57	Δ	60	61	311	37	
			50	17	38	39	44	47	48	49	53	54	57	58	Δ	60	61	438	38				
3 & 100 Amp.	SE & SQ	2 & 3	31074-400	60	16	Δ	38	39	44	Δ	47	48	49	53	Δ	57	Δ	60	61	700	46		
		50	17	38	39	44	47	48	49	53	54	57	58	Δ	60	61	678	47					
		4 & 5	31091-400	60	16	Δ	38	39	44	Δ	47	48	49	53	Δ	57	Δ	60	61	1185	85		
		50	17	38	39	44	47	48	49	53	54	57	58	Δ	60	61	1260	89					
4 & 200 Amp.	SF & SV	All	31091-400	60	16	Δ	38	39	44	Δ	47	48	49	53	Δ	57	Δ	60	61	1185	85		
			50	17	38	39	44	47	48	49	53	54	57	58	Δ	60	61	1260	89				
5 & 300 Amp.	SG & SX	All	31096-400	60	09	Δ	09	10	15	Δ	18	19	21	Δ	24	Δ	29	29	2970	212			
			50	09	09	10	15	18	19	22	24	29	30	2970	250								
6 & 7	SH & SJ	2-3	Coil Part Number 31104-400-50 (All System Voltages)													1530	...						
			50	09	09	15	Δ	18	19	22	24	29	30	2970	1250	...							
400, 600 & 800 Amp.	SY, SZ, SJ (Elect. Held)	2-3	31104-418	60	09	Δ	09	15	Δ	18	19	21	Δ	24	Δ	29	29	1530	...				
			50	09	09	15	Δ	18	19	22	24	29	30	2970	1250	...							

Δ Use next higher voltage, 60 hertz coil.
 ○ VA values for these coils are 120% of the values shown.

▲ Use on Type S series B devices only.
 ■ Coil numbers include latch assemblies. Do not remove unlatch coil. Complete latch assembly must be replaced.

Table 4-2 Magnet Coil Data (continued on next page)

REPLACEMENT AC MAGNET COILS FOR RELAYS, TIMERS AND CONTACTORS

Equipment To Be Serviced			Coil Prefix or Class and Type	Hz	SUFFIX NUMBER (Complete Coil Number Consists of Prefix or Class and Type Followed by Suffix Number)														Coil Volt-Amperes	
Device	Type	Poles			24	110-115	120	208	220	240	277	380	440	480	550	600	In-rush	Sealed		
					Volts	Volts	Volts	Volts	Volts	Volts	Volts	Volts	Volts	Volts	Volts	Volts				

TABLE 1

CLASSES 8501, 8508 AND 9050

8501 & 8508 (Relays)	BH & BR	All	1861-S1	60 50	R22B R23B	R29B R30A	R30A R31A	R32B	R32B R33A	R33A R34A	R39B	R35B	R35B† R36A	R36A R37A	R36B R37A	R37A R38A	R37A R38B	160 120	30 26
	DDO DEO	All	2959-S49	60 50	W24B W25B	W31A W31B	W31B W32B	W34A	W34A W34B	W34B W35B	W35A	W36B	W36B W37A	W37A W37B	W37B W38B	W38A W38B	W38B	62 52	12 11
	DO-20 to DO-42	2-4	2959-S1	60 50	W26A W26B	W32B W33A	W33A W33B	W35B	W35B W36A	W36A W36B	W36B	W38B	W38B† W39A	W39A W39B	W39B W40A	W39B W40A	W40A W40B	58 52	12 11
	DO-44 to DO-62	6 & 8	2959-S49	60 50	W24A W26A	W30B W31A	W31A W32A	W33B	W33B W34A	W34A W35A	W34B	W38B	W38B† W37A	W37A W38A	W37B W38A	W37B W38A	W38A W39A	100 75	25 22
	G	All	31021-400	60 50	39 41	59 60	60 62	67	△ 69	69 71	70 72	.....	.....	.....	.....	.....	.....	100 90	13 13
	H	2-8	31071-423	60 50	23 24	44 44	44 45	50 52	△ 53	53 54	55	60	62	62 63	65	65	65	150 140	30 30
	H8-—	All	9998-DN8C	50 60	24	110	120	208	220	240	277	380	.....	480	.....	.....	.....	.....	.....
	H9-—	All	9998-DN9C	50 60	24	110	.....	.....	220	240	.....	380	.....	.....	.....	.....	.....	.....	.....
	HX	8-12	31071-424	60 50	23 24	..... 44	44 45	50 52	△ 53	53 54	55	.....	62	62	65	65	180 170	35 35	
	L	All	9998-CRL†	60 50	618 518	801	801 556	665 565	..... 802	802 569	721	.....	803	803 581	804	804 586	120 115	17.5 17.5	
	PH	All	9998-PD2C	60 50	24C	110A	110A	208C	.....	220A	220A	277C	380B	440A	440A	.....	600C	50 50	7.3 7.3
	X	All	9998-X*	60 50	23 24	..... 44	44	51	..... 53	53	55	.....	62	62	65	65	148 143	23 25	
9050 (Timer)	A 1E, 1D, 5DE	All	2959-S1	60 50	W26A W26B	W32B W33A	W33A W33B	W35B	W35B W36A	W36A W36B	W36B	.....	W38B	W39A	W39B	W40A W40B	62 52	12 11	
	A All Others	All	2959-S49	60 50	W25A W25B	W31B W32A	W32A W32B	W34A W34B	W34B W35A	W35A W35B	W36A	.....	W37B	W38A	W38B	W39A W39B	74 68	17 17	
	B††	All	1861-S1	60 50	R22B R22C	R29B R30A	R30A R31A	R32B	R32B R33A	R33A R33C	.....	.....	R35† R36A	R36A R36C	R36B R37A	R37A R37C	160 120	30 22	
B▲	All	31017-400	60 50	33 34	.....	54 55	61	61	63 64	65	.....	70 72	72 73	73 75	75 76	165 155	27 27		

TABLE 2

MECHANICALLY HELD UNLATCH COILS — CLASSES 8501, 8508 and 8903

NOTE: A latch coil is also used with mechanically held devices.

8501 (Relay)	HL■	2-8	31071-963-■	60 50	50	52	53	..... 54	54	55	.....	56	56	57	57	18 17	18 17		
	HXL■	8-12	31071-964-■	60 50	50	52	53	..... 54	54	55	.....	56	56	57	57	18 17	18 17		
8508 (Relay)	A & P	All	2959-S13	60 50	W24B W25B	W31B W32A	W32A W33A	W34B	W34B W35A	W35A W36A	W35B	.....	W37B†	W38A	W39A	W38B W39A	W39A W40A	39 28	15 11
	D & M1	All	2959-S13	60 50	W23B W24B	W30A W30B	W30B W31B	W33A W33B	W33A W33B	W33B W34B	.....	.....	W36A	W36A W36B	W36B	W37A W37B	W37B	39 12	10
8508 (Contactor)	C, D & E	All	1861-S1	60 50	R22B R23B	R29B R30A	R30A R31A	R32B	R32B R33A	R33A R34A	R33B	.....	R35B	R35B R36A	R36A R37A	R36B R37A	R37A R38A	.....	.....
8903 (Lighting Contactors)	LX	All	9998LX	60 50	23	..... 44	44	51	..... 53	53	55	.....	62	62	65	65	25	.....
	SM, SP	All	2959-S13	60 50	W23B W24B	△ W30B	W30B W31B	W33A	△ W33B	W33B W34B	W34A	.....	W36A	△ W36B	W36B	△ W37B	W37B	80	.....
	SQ, SV, SX, SY, SZ	All	31096-416	60 50	03	△ 09	09	15	△ 18	18	20	.....	22	24	24	28	28	550	.....
SJ	All	31123-403	60 50	03	△ 09	09	15	△ 18	18	20	.....	22	24	24	28	28	2100	.....

◎ VA values for these coils are 120% of the values shown.
 †† Series B (Double Pole) and Series D (Single Pole).
 † Replaces Series 31111-400-coil.
 * To order an unlatch coil add the letter "L" to the type number and the letter "B" to the suffix number. Example: For a 120V 60Hz unlatch coil order a Class 9998 Type XL-44B. Price for the

‡ Coils also rated 380 volts, 50 hertz.
 ▲ Series C (Double Pole) and Series E (Single Pole).
 △ Use next higher voltage, 60 hertz coil.
 ■ Coil numbers include latch assemblies. Do not remove unlatch coil. Complete latch assembly must be replaced.

Table 4-2 Magnet Coil Data (continued from previous page)

WIRING DIAGRAM

By superimposing the power circuit diagram (left) over the control circuit diagram (right) in Figure 5-1, a composite picture of all points of connection on the magnetic starter can be obtained. The combined illustration (Figure 5-2) is identified as a wiring diagram and it shows, as closely as possible, the actual location of all of the component parts of the starter. The dotted lines represent power circuit connections made to the starter by the user.

Since wiring connections and terminal markings are shown, this type of diagram is helpful when wiring the starter or tracing wires when troubleshooting. Note that bold lines denote the power circuit and thin lines are used to show the control circuit. Conventionally, in AC magnetic equipment black wires are used in power circuits and red wires are used for control circuits.

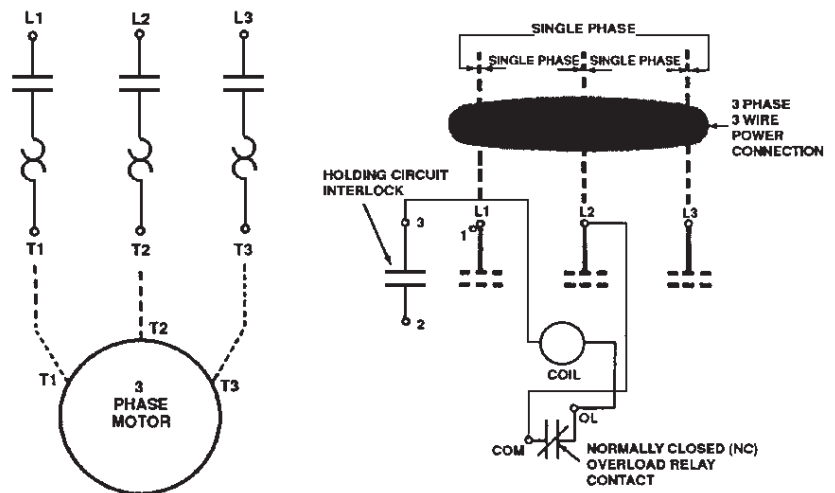


Figure 5-1 Power Circuit (left) and Control Circuit (right) Diagrams

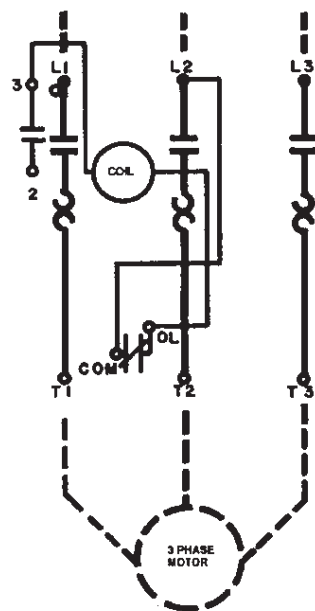


Figure 5-2 Wiring Diagram

A wiring diagram, however, is limited in its ability to convey a clear picture of the sequence of operation of a controller. Where an illustration of the circuit in its simplest form is desired, the elementary diagram (Figure 5-3) is used.

ELEMENTARY DIAGRAM

The elementary diagram (Figure 5-3) gives a simple picture of the circuit. The devices and components are not shown in their actual positions. All the control circuit components are shown as directly as possible between a pair of vertical lines representing the control power supply. The arrangement of the components is designed to show the sequence of operation of the devices, and helps in understanding how the circuit operates. The effect of operating various interlocks and control devices can be readily seen which helps in troubleshooting, particularly with the more complex controllers. This form of electrical diagram is sometimes referred to as a "schematic" or "line" diagram.

Two Wire Control

In Figure 5-3, two wires connect the control device (which could be a thermostat, float switch, limit switch or other maintained contact device (see Maintained Contact on page 38) to the magnetic starter (see page 29). When the contacts of the control device close, they complete the coil circuit of the starter, causing it to pick up and connect the motor to the power source. When the control device contacts open, the starter is de-energized, stopping the motor.

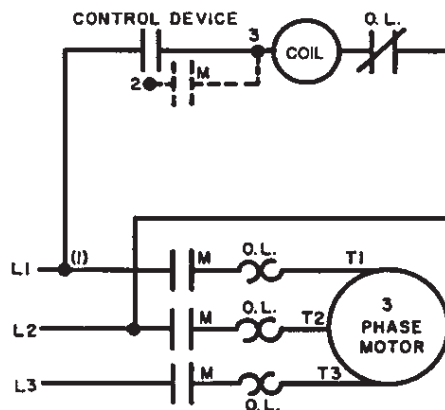


Figure 5-3 Elementary Diagram of Starter with Two Wire Control

Two wire control provides low voltage release, but not low voltage protection. Wired as illustrated, the starter will function automatically in response to the control device without the attention of an operator.

The dotted portion shown in the Elementary Diagram in Figure 5-4 represents the holding circuit interlock (see HOLDING CIRCUIT INTERLOCK on page 37) furnished on the starter, but not used in two wire control. For greater simplicity, this portion is omitted from the conventional two wire elementary diagram.

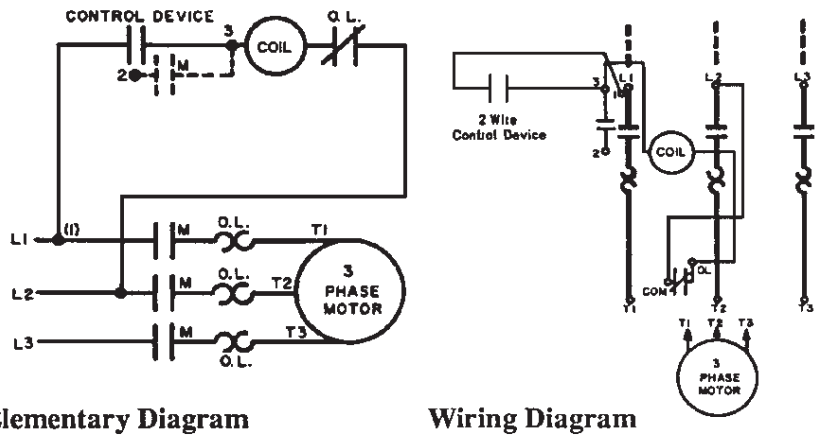


Figure 5-4 Diagram of a Starter with Two Wire Control

Three Wire Control

A three wire control circuit uses momentary contact Start-Stop buttons (see Momentary Contact on page 38) and a holding circuit interlock (see HOLDING CIRCUIT INTERLOCK on page 37), wired in parallel with the Start button, to maintain the circuit (Figure 5-5).

Pressing the normally open Start button completes the circuit to the coil. The power circuit contacts in L1, L2 and L3 close, completing the circuit to the motor, and the holding circuit contact (mechanically linked with the power contacts) also closes. Once the starter has picked up, the Start button can be released, as the now closed contact provides an alternate current path around the reopened start contact.

Pressing the normally closed Stop button will open the circuit to the coil, causing the starter to drop out. An overload condition, which causes the overload contact to open, a power failure, or a drop in voltage to less than the seal-in value would also de-energize the starter. When the starter drops out, the interlock contact re-opens, and both current paths to the coil, through the Start button and the interlock, are now open. Since three wires from the push button station are connected into the starter (at points 1, 2 and 3) this wiring scheme is commonly referred to as three wire control (Figure 5-5).

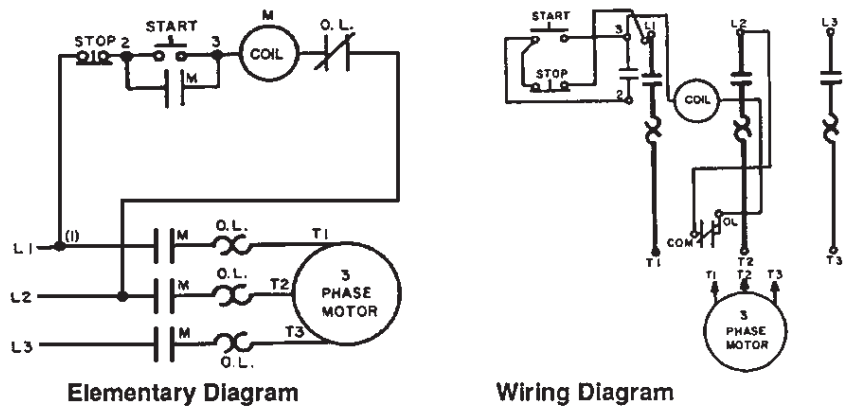


Figure 5-5 Diagram of a Starter with Three Wire Control

NOTES:

Chapter 6 - Power Devices

HOLDING CIRCUIT INTERLOCK

The holding circuit interlock (Figure 6-1, left) is a normally open (N.O.) auxiliary contact provided on standard magnetic starters (page 27) and contactors (see CONTACTORS on page 41). It closes when the coil is energized to form a holding circuit for the starter after the Start button has been released. For reasons of economy or design, an additional normally open power pole is sometimes used to perform the holding circuit interlock function.

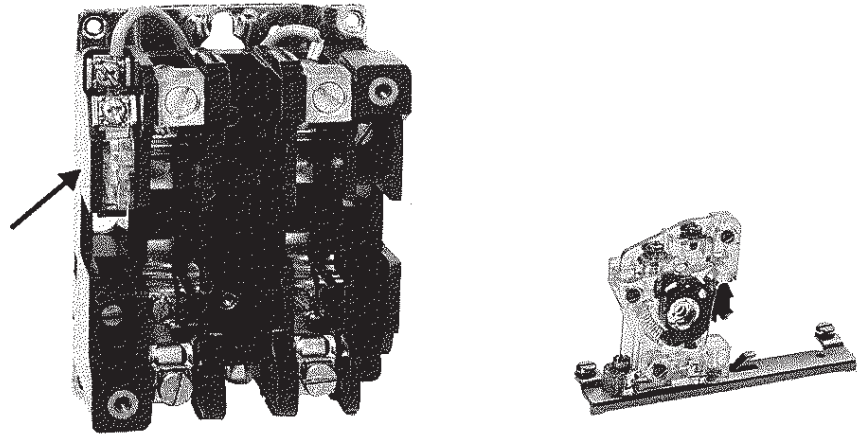


Figure 6-1 A Contactor Showing Holding Circuit Interlock (left) and an Electrical Interlock with Normally Closed Contact (right)

Auxiliary Contacts

In addition to the main or power contacts which carry the motor current and the holding circuit interlock, a starter can be provided with externally attached auxiliary contacts, commonly called "electrical interlocks" (Figure 6-1, right, and Figure 6-2). Auxiliary contacts are rated to carry only control circuit currents, not motor currents. Normally open (N.O.) and normally closed (N.C.) versions are available.

Among a wide variety of other applications, auxiliary contacts can be used to control magnetic devices where sequence operation is desired, to electrically prevent another controller from being energized at the same time and to make circuits indicate alarms, pilot lights, bells, or other signals. Auxiliary contacts are available in kit form and can easily be added in the field.

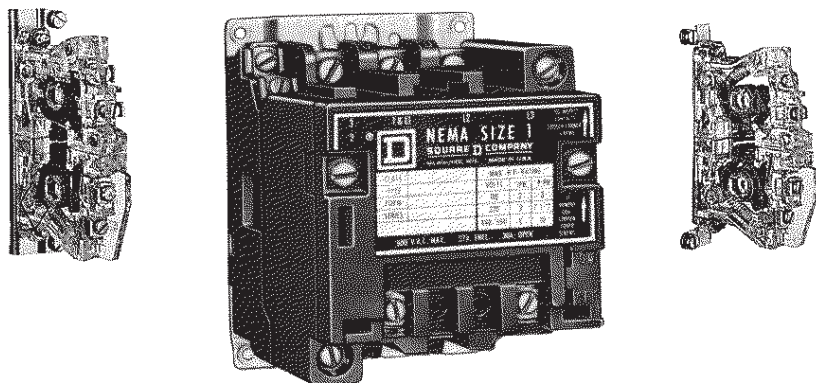


Figure 6-2 Magnetic Contactor with Detached External Auxiliary Contacts

Control Device (Pilot Device)

A device which is operated by some non-electrical means (such as the movement of a lever) and has contacts in the control circuit of a starter is called a "control device". Operation of the control device controls the starter and hence the motor. Typical control devices are control stations (see CONTROL STATION (PUSH BUTTON STATION) on page 47), limit switches (see LIMIT SWITCH on page 48), foot switches (FOOT SWITCH on page 49), pressure switches (see PRESSURE SWITCH on page 49) and float switches (see FLOAT SWITCH on page 50). The control device may be of the maintained contact or momentary contact type. Some control devices have a horsepower rating and are used to control directly small motors through the operation of their contacts. When used in this way, separate overload protection (see Overload Protection on page 12) such as a manual starter would be appropriate since the control device does not usually incorporate overload protection.

Maintained Contact

A maintained contact control device is one which, when operated, will cause a set of contacts to open (or close) and stay open (or closed) until a deliberate reverse operation occurs. A conventional thermostat is a typical maintained contact device. Maintained contact control devices are used with two wire control.

Momentary Contact

A standard push button is a typical momentary contact control device. Pushing the button will cause normally open contacts to close and normally closed contacts to open. When the button is released, the contacts revert to their original states. Momentary contact devices are used with three wire control or jogging (see Jogging (Inching) on page 6) service.

Low Voltage (Undervoltage Release)

By the nature of its control circuit connections, a two wire control scheme provides "low voltage release". The term describes a condition in which a reduction or loss of voltage will stop the motor, but in which motor operation will automatically resume as soon as power is restored.

If the two wire control device (see Two Wire Control on page 34) is closed, a power failure or drop in voltage below the seal-in value will cause the starter to drop out. However, as soon as power is restored or the voltage returns to a level high enough to cause the armature (see Armature on page 23) to pick up and seal, the starter contacts will re-close and the motor will again run. This is an advantage in applications involving unattended pumps, refrigeration processes and ventilating fans.

In many applications, however, the unexpected restarting of a motor after power failure is undesirable, as in a process where a number of motors must be restarted, or operations performed, in a prescribed sequence. In some applications, the automatic restart presents the possibility of danger to personnel or damage to machinery and work in process.

If protection from the effects of a low voltage condition is required, the two wire control scheme is not suitable. Three wire control, which provides the desired protection, should be used.

**Low Voltage
(Undervoltage
Protection)**

The three wire control scheme (see Three Wire Control on page 35) provides “low voltage protection”. In both two and three wire control, the starter drops out and the motor stops in response to a low voltage condition or power failure.

When power is restored, however, the starter connected for three wire control will not pick up because the reopened holding circuit contact and the normally open Start button contact prevent current flow to the coil. To restart the motor after a power failure, the low voltage protection offered by three wire control requires that the Start button be depressed. A deliberate action must be performed, insuring greater safety than that provided by two wire control. Manual starters with low voltage protection offer this same type of protection.

**FULL VOLTAGE
(ACROSS-THE-
LINE) STARTER**

As the name implies, a full voltage or across-the-line starter directly connects the motor to the power source. The starter can be either manual or magnetic.

A motor connected in this fashion draws full inrush current and develops maximum starting torque (see Torque on page 5) so that it accelerates the load to full speed in the shortest possible time.

With some loads the high starting torque will damage belts, gears and couplings, and material being processed. High inrush current can produce line voltage dips which cause lamp flicker and disturbances to other loads. Lower starting currents and torques are therefore often required, and are achieved by reduced voltage starting.

**CONTROL
VOLTAGE SOURCES**

The coil circuit of a magnetic starter (see page 27) or contactor (see CONTACTORS on page 41) is distinct from the power circuit. The coil circuit could be connected to any single phase source of power and the controller would be operable, provided the coil voltage and frequency match the service to which it is connected.

Common Control

When the control circuit is connected to L1 and L2 of the starter, the voltage of the control circuit is always the same as the power circuit voltage and the term “common control” is used to describe the relationship. Other variations include separate control and control through a control circuit transformer.

**Control Circuit
Transformer**

It is sometimes desirable to operate push buttons or other control circuit devices at a voltage lower than the motor voltage. In Figure 6-3 (page 40), a single phase control transformer (with dual voltage 240-480 V primary, 120 V secondary) has its 480 V primary connected to the 480 V three phase, three wire service brought into the starter.

Note, however, that the control circuit is now connected to the 120 V secondary of the transformer, rather than being connected to L1 and L2, as in common control.

The coil voltage is therefore 120 V, and the push-button or other control devices operate at the same voltage level. Fuses (see Overload Protection - Fuses on page 13) are used to protect the control circuit, and it is common practice to ground one side of the transformer secondary.

Separate Control

Control of a power circuit by a lower control circuit voltage can also be obtained by connecting the coil circuit to a separate control voltage source, rather than to a transformer secondary.

The term used to describe this wiring arrangement is "separate control". As is evident from Figure 6-4, the coil rating must match the control source voltage, but the power circuit can be any voltage (up to a 600 V maximum.)

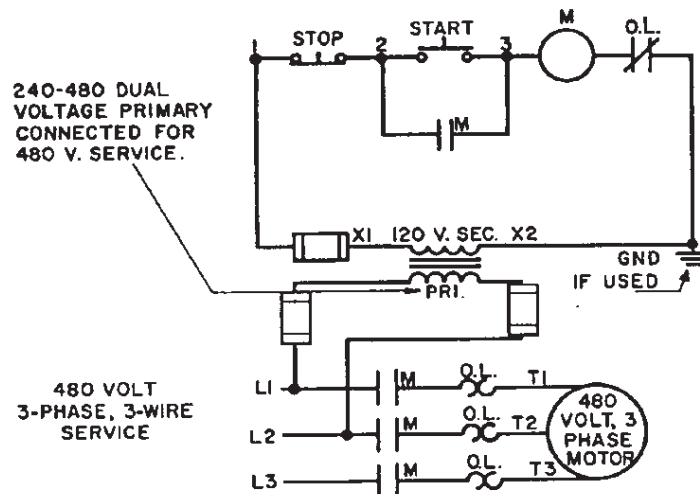


DIAGRAM A - CONTROL CIRCUIT TRANSFORMER

Figure 6-3 Control Circuit Transformer

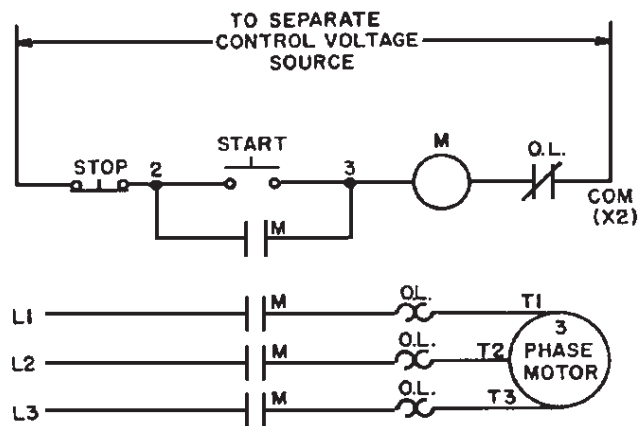


DIAGRAM B - SEPARATE CONTROL

Figure 6-4 Separate Control

Chapter 7 - Relays, Timers, Starters and Switches

CONTACTORS

The general classification of "contactor" covers a type of electromagnetic device designed to handle relatively high currents. A special form of contactor exists for lighting load applications and will be discussed separately.

The conventional contactor is identical in construction and current carrying ability to the equivalent NEMA size magnetic starter (see Table 4-1 on page 28). The magnet assembly (see Magnet Assembly on page 23), coil, contacts, holding circuit interlock (see HOLDING CIRCUIT INTERLOCK on page 37) and other structural features are the same.

The significant difference is that the contactor does not provide overload protection (see Overload Protection on page 12). Contactors, therefore, are used to switch high current, non-motor loads, or are used in motor circuits if overload protection is separately provided. A typical application of the latter is in a reversing starter.

Lighting Contactor

Filament type lamps (tungsten, infrared, quartz) have inrush currents of approximately 15-17 times the normal operating currents. Standard motor control contactors must be derated if used to control this type of load to prevent welding of the contacts on the high initial current.

Per Table 4-1 on page 28, a NEMA Size 1 contactor has a continuous current rating of 27 A, but if used to switch certain lighting loads, it must be derated to 15 A. The standard contactor, however, need not be derated for resistance heating or fluorescent lamp loads since these do not impose as high an inrush current.

Lighting contactors differ from standard contactors in that a holding circuit interlock (see HOLDING CIRCUIT INTERLOCK on page 37) is not normally provided, since this type of contactor is frequently controlled by a 2-wire pilot device (see Control Device (Pilot Device) on page 38) such as a time clock or photoelectric relay.

Unlike standard contactors, lighting contactors are not horsepower rated or categorized by NEMA size, but are designated by ampere ratings (20, 30, 60, 100, 200, 300 A). It should be noted that lighting contactors are specialized in their application, and should not be used on motor loads.

Mechanically Held Contacts

In a conventional contactor, current flow through the coil creates a magnetic pull to seal in the armature (see Armature on page 23) and maintain the contacts in a switched position. Normally open contacts will be held closed, normally closed contacts will be held open. Because the contactor action is dependent on the current flow through the coil, the contactor is described as "electrically held." As soon as the coil is de-energized, the contacts will revert to their initial position.

"Mechanically held" versions of contactors and relays are also available. The action is accomplished through use of two coils and a latching mechanism. Energizing one coil (latch coil) through a momentary signal causes the contacts to switch. A mechanical latch holds the contacts in this position, even though the initiating signal is removed, and the coil is de-energized. To restore the contacts to their initial position, a second coil (unlatch coil) is momentarily energized.

Mechanically held contactors and relays are used where the slight hum of an electrically held device would be objectionable, as in auditoriums, hospitals and churches.

REVERSING STARTER

Reversing the direction of motor shaft rotation is often required. Three phase squirrel cage motors (see AC SQUIRREL CAGE MOTOR on page 4) can be reversed by reconnecting any two of the three line connections to the motor. By interwiring two contactors, an electromagnetic method of making the reconnection can be obtained.

As seen in the power circuit (Figure 7-1), the contacts (F) of the forward contactor, when closed, connect L1, L2 and L3 to motor terminals T1, T2 and T3 respectively. As long as the forward contacts are closed, mechanical and electrical interlocks prevent the reverse contactor from being energized.

When the forward contactor is de-energized, the second contactor can be picked up, closing its contacts (R) which reconnect the lines to the motor. Note that by running through the Reverse contacts, L1 is connected to motor terminal T3, and L3 is connected to motor terminal T1. The motor will now run in the opposite direction.

Whether operating through either the forward or reverse contactor, the power connections are run through an overload relay assembly which provides motor overload protection (see Overload Protection on page 12). A magnetic reversing starter, therefore, consists of a starter and contactor which are suitably interwired with electrical and mechanical interlocking to prevent the coil of both units from being energized at the same time.

Manual reversing starters employing two manual starters (see MANUAL STARTER on page 19) are also available. As in the magnetic version, the forward and reverse switching mechanisms are mechanically interlocked, but since coils are not used in the manually operated equipment, electrical interlocks are not required.

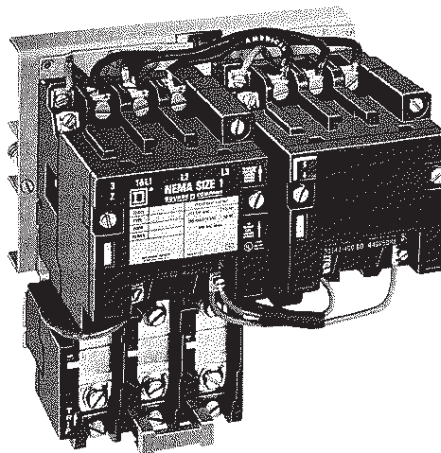
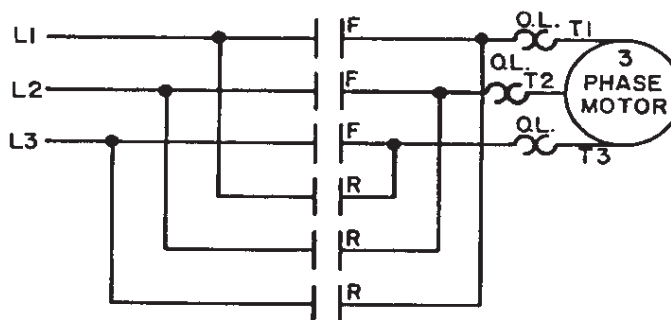


Figure 7-1 Size 1 Three Pole Reversing Starter

COMBINATION STARTER

A combination starter is so named since it combines a magnetic starter (see page 27) and a disconnect means, which might incorporate a short circuit protective device, in one enclosure.

Compared with a separately mounted disconnect and starter, the Combination Starter takes up less space, requires less time to install and wire, and provides greater safety.

Safety to personnel is assured because the door is mechanically interlocked, so that it cannot be opened without first opening the disconnect.

Combination starters can be furnished with circuit breakers or fuses to provide overcurrent protection (see **OVERCURRENT PROTECTION** on page 11), and are available in non-reversing and reversing versions.

CONTACTOR- RELAY COMPARISON

A control relay is an electromagnetic device similar in operating characteristics to a contactor. The contactor, however, is generally employed to switch power circuits or relatively high current loads.

Relays, with few exceptions, are used in control circuits, and consequently their lower ratings (6 A maximum at 600 V) reflect the reduced current levels at which they operate.

Contactors generally have from one to five poles. Although normally open and normally closed contacts can be provided, the great majority of applications use the normally open contact configuration, and there is no conversion of contact operation in the field.

As compared to contactors, it is not uncommon to find relays used in applications requiring 10 or 12 poles per device, with various combinations of normally open and normally closed contacts. In addition, some relays have convertible contacts, permitting changes to be made in the field from normally open to normally closed operation, or vice versa, without requiring kits or additional components.

CONTROL RELAYS

A relay is an electromagnetic device whose contacts are used in control circuits of magnetic starters (see page 27), contactors, solenoids, timers and other relays. Relays are generally used to amplify the contact capability or multiply the switching functions of a pilot device (see **Control Device (Pilot Device)** on page 38).

Current Amplification

Figure 7-2 and Figure 7-3 (page 44) demonstrate how a relay amplifies contact capacity. Figure 7-2 represents a "current amplification". Relay (CR) and starter coil (M) voltages are the same, but the ampere rating of the temperature switch is too low to handle the current drawn by the starter coil (M). A relay is interposed between the temperature switch and starter coil. The current drawn by the relay coil (CR) is within the rating of the temperature switch, and the relay contact (CR) has a rating adequate for the current drawn by the starter coil.

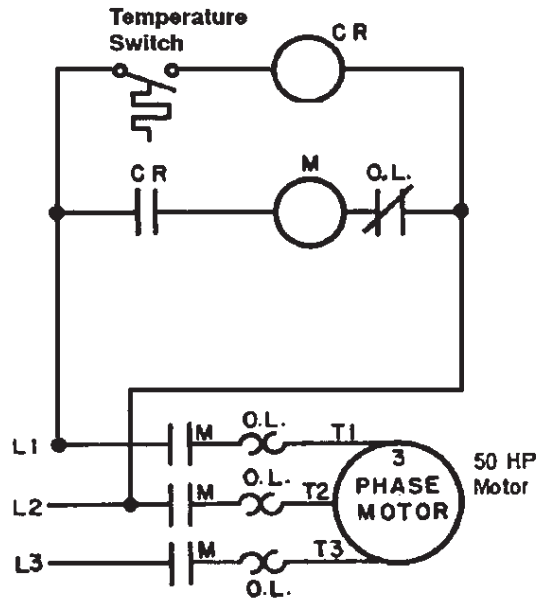


Figure 7-2 Current Amplification

Voltage Amplification

Figure 7-3 represents a “voltage amplification”. A condition may exist in which the voltage rating of the temperature switch is too low to permit its direct use in a starter control circuit operating at some higher voltage. In this application, the coil of the interposing relay (CR) and the pilot device are wired to a low voltage source of power compatible with the rating of the pilot device. The relay contact (CR), with its higher voltage rating, is then used to control the operation of the starter.

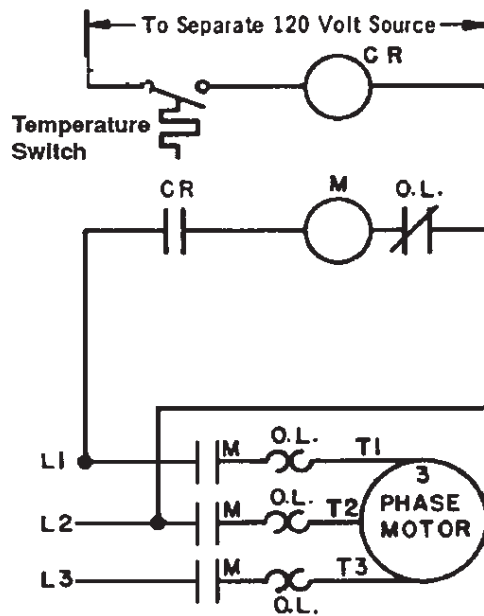


Figure 7-3 Voltage Amplification

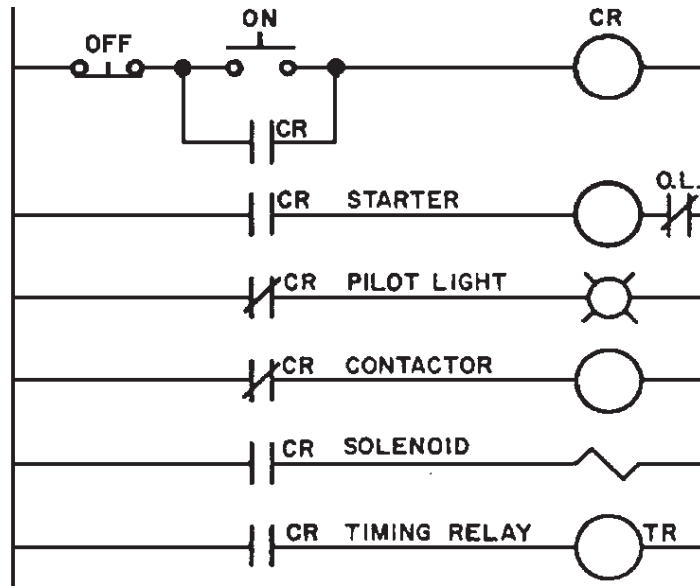


Figure 7-4 Control Circuit

Figure 7-4 represents another use of relays, which is to multiply the switching functions of a pilot device with a single or limited number of contacts. Depressing the On button in the control circuit energizes the relay coil (CR). Its normally open contacts close to complete the control circuits to the starter, solenoid and timing relay, and one contact forms a holding circuit around the On button. The normally closed contacts open to de-energize the contactor and turn off the pilot light.

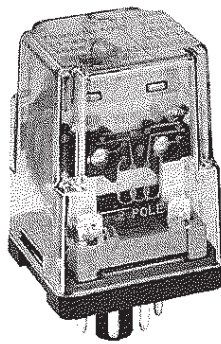
In the circuit shown in Figure 7-4, a single pole push-button contact can, through the use of an interposing 6-pole relay, control the operation of a number of different loads such as a pilot light, starter, contactor, solenoid and timing relay.

Relays are commonly used in complex controllers to provide the logic to set up and initiate the proper sequencing and control of a number of interrelated operations.

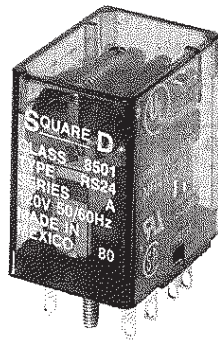
Relay Variations

Relays differ in voltage ratings (120, 300, 600 V), number of contacts, contact convertibility, physical size, and in attachments to provide accessory functions such as mechanical latching (see Mechanically Held Contacts on page 41) and timing.

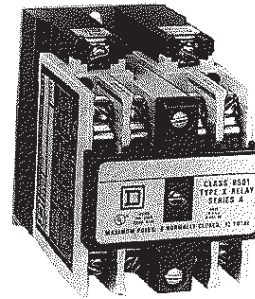
In selecting a relay for a particular application, one of the first steps should be to determine the control voltage at which the relay will operate. Once the voltage is known, the relays which have the necessary contact rating can be further reviewed, and a selection made, on the basis of the number of contacts and other characteristics needed.



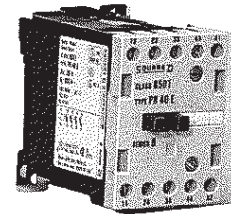
120 V Relay



120 V Relay



NEMA Rated
600 V Relay



IEC Rated 600 V
Relay

Figure 7-5 Relay Variations

TIMERS AND TIMING RELAYS

A pneumatic timer or timing relay (Figure 7-6) is similar to a control relay (see CONTROL RELAYS on page 43), except that certain of its contacts are designed to operate at a pre-set time interval after the coil is energized or de-energized. A delay on energization is also referred to as “on delay”. A time delay on de-energization is also called “off delay”.

A timed function is useful in applications such as the lubricating system of a large machine, in which a small oil pump must deliver lubricant to the bearings of the main motor for a set period of time before the main motor starts.

In pneumatic timers, the timing is accomplished by the transfer of air through a restricted orifice. The amount of restriction is controlled by an adjustable needle valve, permitting changes to be made in the timing period.

Solid state timers are also available. These devices time electronically and can provide longer timing ranges and greater precision.

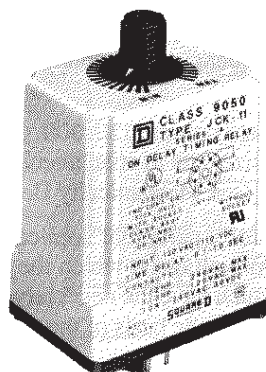


Figure 7-6 Timing Relay

DRUM SWITCHES

A drum switch (Figure 7-7 below) is a manually operated multi-position, multi-pole switch which carries a horsepower rating and is used for applications such as manual reversing of single or three phase motors. Drum switches are available in several sizes and can be momentary contact (see Momentary Contact on page 38) or maintained contact (see Maintained Contact on page 38). Separate overload protection (see Overload Protection on page 12), via manual or magnetic starters (see page 27), must usually be provided since drum switches do not include this function.

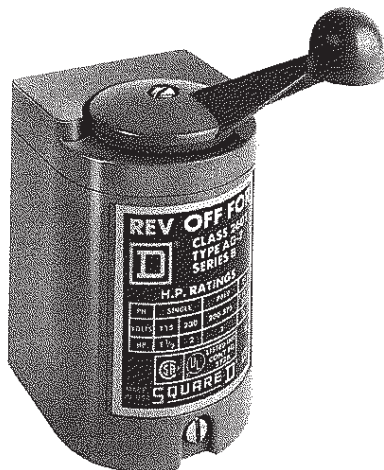


Figure 7-7 Drum Switch

CONTROL STATION (PUSH BUTTON STATION)

A control station (Figure 7-8 below) may contain push buttons, selector switches and pilot lights. Push buttons may be momentary (see Momentary Contact on page 38) or maintained contact (see Maintained Contact on page 38). Selector switches are usually maintained contact, or can be spring return to give momentary contact operation. Standard duty stations will handle the coil currents of contactors up to Size 4. Heavy duty stations have higher contact ratings and provide greater flexibility through a wide variety of operations and interchangeability of components.

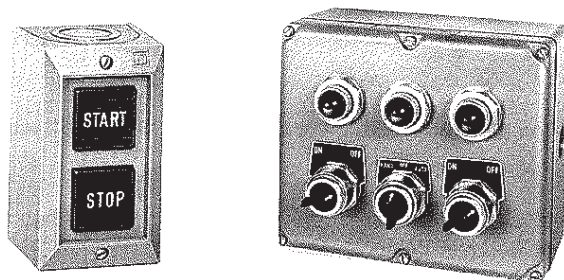


Figure 7-8 Push Button Stations

LIMIT SWITCH

A limit switch (Figure 7-9 below) is a control device which converts mechanical motion into an electrical control signal. Its main function is to limit movement, usually by opening a control circuit when the limit of travel is reached. Limit switches may be momentary contact (see Momentary Contact on page 38) or maintained contact (see Maintained Contact on page 38) types. Among other applications, limit switches can be used to start, stop, reverse, slow down, speed up or recycle machine operations.

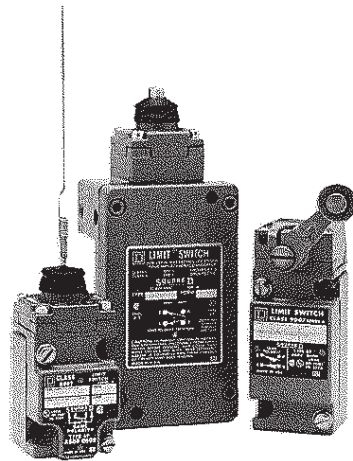


Figure 7-9 Limit Stations

SNAP SWITCH

Snap switches (Figure 7-10 below) for motor control purposes are enclosed, precision switches which require low operating forces and have a high repeat accuracy. They are used as interlocks, as the switch mechanism for control devices such as precision limit switches, and as pressure switches. They are also available with integral operators for use as compact limit switches and door operated interlocks. Single pole double throw (SPDT) and double pole double throw (DPDT) versions are available.

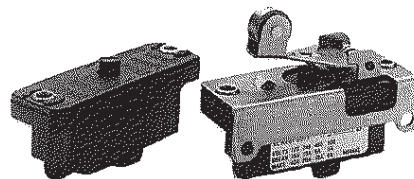


Figure 7-10 Snap Switches

FOOT SWITCH

A foot switch (Figure 7-11 below) is a control device operated by a foot pedal used where the process or machine requires that the operator have both hands free. Foot switches have momentary contacts (see Momentary Contact on page 38) but are available with latches that enable them to be used as maintained contact devices (see Maintained Contact on page 38). The foot switch generally comes enclosed in a guard to protect against unintentional operation.

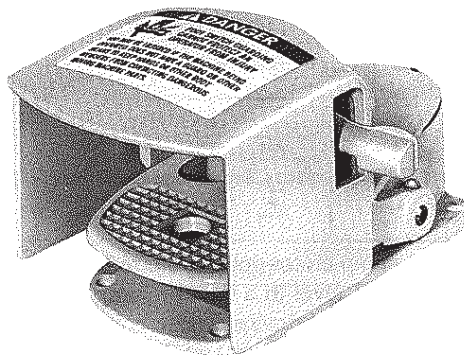


Figure 7-11 Foot Switch

SOLID STATE SENSORS

Certain applications require the use of “no touch” sensing. Many varieties of sensors are available, most falling into one of two categories: proximity (Figure 7-12 right) and photoelectric (Figure 7-12, left). Proximity sensors detect the disturbance of an electric field generated by the device. Photoelectric sensors detect the breaking of a beam of light.

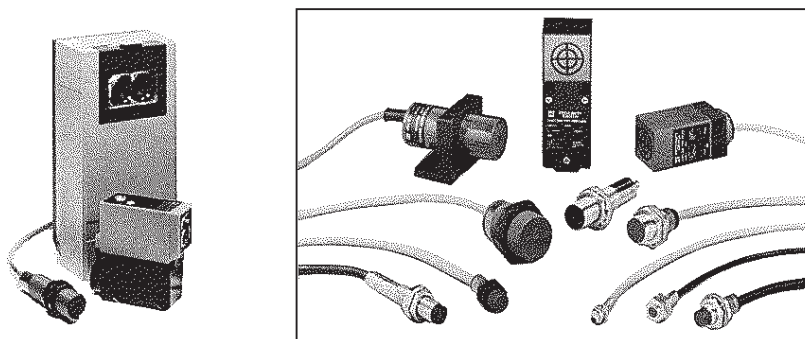


Figure 7-12 Solid State Sensors: Photoelectric (left) and Proximity (right)

PRESSURE SWITCH

The control of pumps, air compressors, welding machines, lube systems, and machine tools requires control devices which respond to the pressure of a medium such as water, air or oil. The control device which does this is a pressure switch.

The pressure switch (Figure 7-13 on page 50) has a set of contacts which are operated by the movement of a piston, bellows or diaphragm against a set of springs. The spring pressure determines the pressures at which the switch closes and opens its contacts.

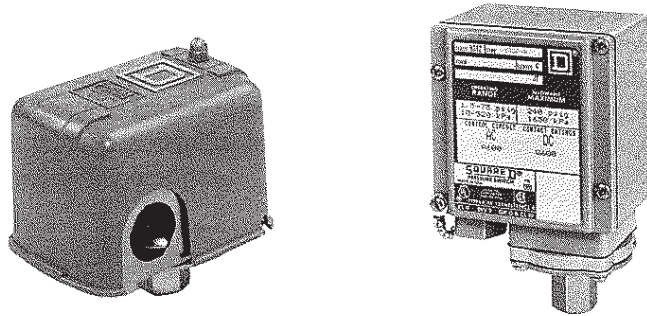


Figure 7-13 Pressure Switches: Commercial (left) and Machine Tool (right)

FLOAT SWITCH

When a pump motor must be started and stopped according to changes in water (or other liquid) level in a tank or sump, a float switch (Figure 7-14 below) is used. This is a control device whose contacts are controlled by movement of a rod or chain and counterweight, fitted with a float. For closed tank application, the movement of a float arm is transmitted through a bellows seal to the contact mechanism.

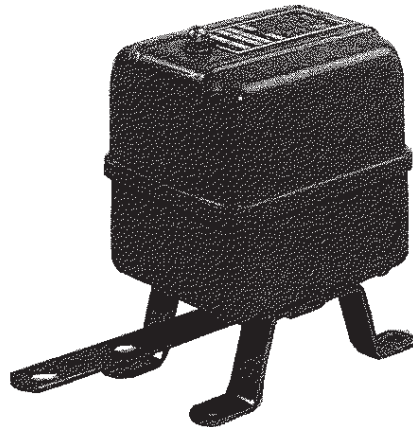


Figure 7-14 Float Switch

STANDARD ELEMENTARY DIAGRAM SYMBOLS

The diagram symbols shown below have been adopted by the Square D Company and conform where applicable to standards established by the National Electrical Manufacturers Association (NEMA).

SWITCHES												
DISCONNECT		CIRCUIT INTERRUPTER	CIRCUIT BREAKER WITH THERMAL O.L.	CIRCUIT BREAKER WITH MAGNETIC O.L.	CIRCUIT BREAKER WITH THERMAL AND MAGNETIC O.L.	LIMIT SWITCHES		FOOT SWITCHES				
						NORMALLY OPEN	NORMALLY CLOSED	N.O.	N.C.			
						HELD CLOSED	HELD OPEN					
PRESSURE & VACUUM SWITCHES		LIQUID LEVEL SWITCH		TEMPERATURE ACTUATED SWITCH		FLOW SWITCH (AIR, WATER ETC.)						
N.O.	N.C.	N.O.	N.C.	N.O.	N.C.	N.O.	N.C.					
SPEED (PLUGGING)		ANTI-PLUG	SELECTOR									
			2 POSITION		3 POSITION		2 POS. SEL. PUSH BUTTON					
			1-CONTACT CLOSED		1-CONTACT CLOSED		1-CONTACT CLOSED					
PUSH BUTTONS						PILOT LIGHTS						
MOMENTARY CONTACT			MAINTAINED CONTACT			ILLUMINATED						
SINGLE CIRCUIT		DOUBLE CIRCUIT		TWO SINGLE CRT.		ONE DOUBLE CRT.		INDICATE COLOR BY LETTER				
N.O.	N.C.	N.O. & N.C.		MUSHROOM HEAD	WOBBLE STICK			NON PUSH-TO-TEST	PUSH-TO-TEST			
CONTACTS				COILS		OVERLOAD RELAYS		INDUCTORS				
INSTANT OPERATING		TIMED CONTACTS - CONTACT ACTION RETARDED AFTER COIL IS:				SHUNT	SERIES	THERMAL	MAGNETIC	IRON CORE		
		ENERGIZED		DE-ENERGIZED								
WITH BLOWOUT	WITHOUT BLOWOUT	N.O.T.C.	N.C.T.O.	N.O.T.O.	N.C.T.C.							
										AIR CORE		
TRANSFORMERS				AC MOTORS				DC MOTORS				
AUTO	IRON CORE	AIR CORE	CURRENT	DUAL VOLTAGE	SINGLE PHASE	3 PHASE SQUIBBEL CAGE	2 PHASE 4 WIRE	WOUND ROTOR	ARMATURE	SHUNT FIELD	SERIES FIELD	COMM. OR COMPENS. FIELD

SUPPLEMENTARY CONTACT SYMBOLS

SPST, N.O.		SPST, N.C.		SPDT		TERMS
SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK		SPST - SINGLE POLE SINGLE THROW
						SPDT - SINGLE POLE DOUBLE THROW
DPST, 2 N.O.		DPST, 2 N.C.		DPDT		DPST - DOUBLE POLE SINGLE THROW
SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	SINGLE BREAK	DOUBLE BREAK	DPDT - DOUBLE POLE DOUBLE THROW
						N.O. - NORMALLY OPEN
						N.C. - NORMALLY CLOSED

Table 7-1 Standard Elementary Diagram Symbols

Full Line Control from Square D

Square D is a worldwide supplier of products, systems and services for the distribution, application and control of electrical energy. The company primarily serves industrial and construction markets, as well as public utilities, individual consumers and government agencies. Square D's full line of control products includes:

- * AC Drives
- * SY/MAX Automation Products
- * Control Transformers
- * Crane Control
- * Definite Purpose Contactors and Starters
- * IEC Contactors and Overload Relays
- * Lighting Controllers
- * Medium Voltage Control
- * NEMA rated Controllers
- * Push Buttons
- * Relays, Timers and Terminal Blocks
- * Electromechanical and Solid State Sensors

Square D
Automation and Control Business
P.O. Box 27446, Raleigh, NC 27611, USA

Square D Canada
6675 Rexwood Road
Mississauga, Ontario L4V 1V1

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