OBJECTIVES

After studying this unit, the student will be able to
• list several methods of controlling a motor.
• describe the operation of a magnetic motor starter.
• explain overcurrent protection of a motor and motor circuit.
• determine the size of the components of a motor circuit.
• determine the size of wire for a group of motors.
• wire a start-stop station or a single-contact control device.
• identify common control devices from their schematic symbols.
• wire a simple control circuit from a control ladder diagram.
• discuss protection of motor control circuits.
• name the NEMA enclosure types and give an example of their applications.

Electric motors present some special problems from the standpoint of control. An electric motor will try to provide the power required by a load, even if it results in self-destruction. Therefore, a motor must be protected from overloads. A motor draws up to six times as much current when the rotor is not turning as it does when operating at full speed. Control contacts and wires must be capable of carrying this high current during starting without causing damage or excessive voltage drop. If a motor should stall, the disconnect switch and control device must be capable of handling the high locked-rotor current. For example, a 100-hp, 460-V, 3-phase electric motor powering an irrigation pump draws 124 A when operating at full load. The locked-rotor current of the motor, however, is nearly 750 A, NEC Table 430-151. The motor starter and disconnect switch must be capable of interrupting 750 A in the event the motor stalls. If the disconnect or controller is not rated for this high level of current, it could explode the instant it is opened.

Motor circuits will be safe and motors will be protected provided the wiring procedures of NEC Article 430 are applied. Proper sizing of motor overload protection will ensure many years of dependable service.
TYPES OF MOTOR CONTROLLERS

A controller is simply a means of closing the circuit supplying power to an electrical motor, NEC 430-81(a). Controlling may be accomplished manually or automatically. The simplest motor controller is an attachment plug and receptacle. This method is permitted only for portable motors rated at \( \frac{1}{3} \) hp and less, NEC Section 430-81(c). Motors larger than \( \frac{1}{3} \) hp are permitted to be cord connected, but the starting and stopping of the motor must be accomplished by one of the means discussed next.

The branch-circuit protective device, such as a circuit breaker, may serve as the controller for stationary motors, not larger than \( \frac{1}{3} \) hp, that are normally allowed to operate continuously. An example is a clock motor, NEC Section 430-81(b). These motors are designed with a high impedance, and they cannot be overloaded even if the rotor stalls.

A time-delay circuit breaker is permitted to serve as a motor controller, NEC Section 430-83, Exception No. 2. This is frequently the case with farm machinery. Circuit breakers are subject to failure after repeated on and off cycling and, therefore, they are not the best choice for a controller. It is also difficult to size a circuit breaker small enough to provide overload protection for the motor, and still not trip due to the high inrush starting current of the motor.

A fusible knife switch, Figure 17-1, can serve as a motor controller, provided the switch has a horsepower rating sufficient for the motor supplied, NEC Section 430-90. Time-delay fuses can usually be sized small enough to provide overload protection, and still not blow during starting. The knife switch must be rated in horsepower, NEC Section 430-83. The switch must also have a voltage rating sufficient for the circuit. A 250-V switch is required for motors operating at 120 V, 208 V, and 240 V. A 600-V switch is required for motors operating at 277 V or 480 V.

An ordinary snap switch rated in amperes or horsepower is permitted to be used as a controller for motors rated at not more than 2 hp, and for circuits operating at not more than 300 V, NEC Section 430-83, Exception No. 1.

The general-use snap switch must have an ampere rating twice that of the full-load current of the motor. A \( \frac{1}{3} \)-hp motor, for example, draws 7.2 A full-load current at 115 V. A general-use snap switch with a 15-A rating would be required for this motor.

\[
7.2 \text{ A} \times 2 = 14.4 \text{ A}
\]

Switches rated for use only on alternating-current circuits are permitted to control motors with a full-load current of 80% of the current rating of the switch. Therefore, a 30-A ac switch is permitted to supply a motor which draws 24 A.

\[
30 \text{ A} \times 0.8 = 24 \text{ A}
\]

A 2-hp electric motor operating at 115 V draws 24 A. Snap switches for motors are available which do provide overload protection, Figure 17-2. This type of switch, rather than an ordinary switch, is preferred for controlling motors up to 2 hp.

A manual motor starter rated in horsepower provide reliable control and overload protection for motors up to about 5 hp single phase, and 10 hp 3 phase, Figure 17-3. A thermally activated trip mechanism opens the motor circuit automatically if an overload occurs. The overload heaters are sized based upon the full-load current rating of the motor. Manual motor starters are available for both single- and 3-phase motors.

Magnetic motor starters use an electric solenoid to close the contacts and start the motor, Figure 17-4. These motor starters may be operated by a person actually activating a starting control, or they may be operated automatically. Only the magnetic motor starter can be controlled automatically. Magnetic motor starters can operate motors of up to several hundred horsepower.
Thermally activated overload relays break the circuit to the coil of the starter if a motor overload occurs. The overload heaters are sized for the nameplate full-load current of the motor.

**MAGNETIC MOTOR STARTER CONSTRUCTION AND OPERATION**

Understanding the operation and components of a magnetic motor starter is important when wiring a motor circuit, as well as when performing repairs when there is a malfunction. Only one manufacturer’s motor starter is shown in the text, but all have essentially the same features.

The main contacts, Figure 17-5, are inside the main part of the starter. After many years of service, these contacts may become pitted and burned from the arcing as they open the circuit. Replacement kits for the main contacts are available.

Electrical power supplied to the coil of the solenoid closes the motor-starter contacts. The coil must be rated for the voltage of the control circuit electrical supply, Figure 17-6. Typical voltages are 24, 120, 208, 240, 277, and 480 volts. A coil is replaceable. If the coil becomes damaged, only the coil need be replaced. The steel solenoid core fits all coils made for the particular size and model of motor starter.

An auxiliary holding contact, Figure 17-7, is supplied with the motor starter. It is required when a start-stop station is used as the control device. The holding contact is replaceable should a short circuit occur in the control wiring, causing damage to the holding contact.
An overload relay section is added to the motor starter to sense motor current. This entire unit can be removed from the motor starter, Figure 17-8. A normally closed contact is usually sealed inside the overload section. Some models have one normally closed contact, while others have two or three. If this section becomes damaged, the entire section usually must be replaced.

Heating elements are added to this section sized for the nameplate full-load current of the motor. These overload heaters are replaceable.

**NEMA SIZES**

The National Electrical Manufacturers Association (NEMA) has developed a standard numbering system for motor starter sizes. The same numbering system is used by all manufacturers. The sizes range from 00 to 8. The larger the number, the greater is the horsepower rating of...
the starter. The starters are rated according to the current they will be expected to carry continuously, and interrupt if the motor should stall. The motor current depends upon the supply voltage. Naturally then, a given size of motor starter could handle a higher horsepower motor at 460 V than at 230 V. NEMA sizes and horsepower ratings are given in Table 17-1.

Motor starters are available with two poles or three poles. The 2-pole motor starter is used for single-phase motors. Two-pole motor starters are usually available up to NEMA size 3. A 3-pole motor starter may be used for either a 3-phase motor or a single-phase motor. If a 3-pole starter is used for a single-phase motor, only two of the three poles are used. The third pole is simply ignored. Since 3-pole motor starters are more readily available than 2-pole starters, this is a common practice.

Single-phase and 3-phase horsepower ratings on a motor starter are not equivalent. NEMA sizes are equivalent, however, insofar as the current they will handle. Some 3-pole motor starters list both the single-phase and polyphase horsepower ratings, others do not. There is a simple rule that should be followed: A 3-pole motor starter will handle a single-phase motor with horsepower rating only half as large as a 3-phase motor. For example, a NEMA size 2 3-pole motor starter will handle a 15-hp, 230-V, 3-phase motor. The same size motor starter is capable of handling only a 7½-hp, single-phase, 230-V motor. The reason is clear when the full-load current for each motor is compared from NEC Tables 430-148 and 430-150. This rule does not hold true exactly, however, for the NEMA small sizes 00 and 0, as shown in Table 17-1. For sizes 1 and larger, the horsepower essentially doubles as the size number is increased by 1.

### Table 17-1: Motor horsepower and voltage ratings for NEMA size motor starters

<table>
<thead>
<tr>
<th>NEMA Size</th>
<th>Single phase 115 V</th>
<th>230 V</th>
<th>Three phase 200 V</th>
<th>230 V</th>
<th>460 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>1/2</td>
<td>1</td>
<td>1 1/2</td>
<td>1 1/2</td>
<td>2</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>1P</td>
<td>3</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>7 1/2</td>
<td>10</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>7 1/2</td>
<td>15</td>
<td>25</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>50</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>—</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>6</td>
<td>—</td>
<td>—</td>
<td>150</td>
<td>200</td>
<td>400</td>
</tr>
<tr>
<td>7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>450</td>
<td>900</td>
</tr>
</tbody>
</table>

**NEMA ENCLOSURE TYPES**

The enclosure for housing the motor starter is selected for the type of environment in the area. NEMA has developed a standard numbering system for types of electrical equipment enclosures.

The enclosure type, except NEMA 1, is required to be marked on motor starter enclosures, NEC Section 430-91. This is a recent Code requirement; therefore, most motor starters presently in use are not so marked. NEC Table 430-91 gives NEMA enclosure types for motor starters, listing the outdoor and indoor conditions for which they are suitable.

Common enclosures used for agricultural, commercial, and industrial locations are as follows.

**NEMA 1:** General-purpose enclosure used in any location that is dry and free from dust and flying flammable materials. Figure 17-9.

**NEMA 3:** Weather-resistant enclosure which is suitable for use outdoors. Not suitable for use in dusty locations.

**NEMA 4:** Watertight and dusttight enclosure suitable for outdoor locations as well as inside wet locations. Water can be sprayed directly on the enclosure without it leaking inside. Suitable for most agricultural locations provided corrosion is not a problem.

**NEMA 4X:** Watertight, dusttight, and corrosion-resistant enclosure suitable for outside and inside wet, dusty, and corrosive areas. Suitable for agricultural buildings. Available with stainless steel and nonmetallic enclosures. Figure 17-10.
NEMA 4X: Corrosion-resistant enclosure for wet or dusty areas.

NEMA 7: Explosionproof enclosure suitable for installation in Class I areas containing hazardous vapors. Must also be rated for the type of hazardous vapor, such as gasoline vapor, Group D, Figure 17-11.

NEMA 9: Dust-Ignition-Proof enclosure suitable for installation in Class II hazardous areas, such as grain elevators. Must be rated for the type of dust, such as grain dust, Group G, Figure 17-12. Some manufacturers build one enclosure rated as NEMA 7 and 9.

NEMA 12: Dusttight, driptight, and oil-retardant enclosure suitable for machine tools and areas where there are flammable flying particles, such as in cotton gins and textile processing and handling operations.

SINGLE-MOTOR BRANCH CIRCUIT

A motor branch circuit consists of several different parts that must be sized properly. The motor is unique because it draws a very high starting current in comparison to the full-load running current. The motor also may stall or break down while in operation. Means must be provided to disconnect power, usually automatically, if a failure occurs. The components of most motor circuits are shown in a diagram at the beginning of NEC Article 430. Information supplied on the motor nameplate is necessary for sizing the circuit components.

- Branch-circuit disconnect
- Branch-circuit short-circuit and ground-fault protection
- Branch-circuit wires
- Motor controller
- Motor running overload protection
- Motor control circuit where a magnetic motor starter is used.

Sizing the motor branch circuit begins with the motor nameplate. Consider the motor nameplate of Figure 17-13. The motor is 3 phase, dual voltage. First, determin
the type of electrical supply available. Assume, in this case, that the electrical supply is 240 V, 3 phase. The motor full-load current therefore, will be 19.2 A.

The type of electrical equipment from which the motor circuit will originate must be determined. Common sources of electrical power for electric motors are:

1. Circuit-breaker panelboards
2. Fusible panelboards
3. Fusible disconnects tapped from a feeder, Figure 17-14
4. Fusible disconnects tapped from a bus duct

**MOTOR FULL - LOAD CURRENT**

The motor full-load current that is used to determine the minimum size of motor circuit components is the current listed in NEC Tables 430-148 and 430-150 (Tables 17-2 and 17-3 in this text). NEC Section 430-6(a). However, this value should be checked against the motor nameplate ampere rating. Sometimes a farm motor may have an ampere rating higher than the value listed in the NEC Tables. In this situation, the higher of the values should be taken for sizing components, (See notes to Tables 17-2 and 17-3).

The nameplate current rating must be used for selecting the maximum size motor running overload protection. This is important because the overload heaters must be sized for a specific motor. If motors are changed, then the overload heaters may have to be changed.

The full-load current for a 3-phase, 208-V electric motor is not listed in NEC Table 430-150. The footnote at the bottom of the table tells how to obtain the correct value. Actually, a 208-V motor usually operates at about 200 V. The correct value is determined by multiplying the full-load current for a 230-V motor by 1.15. For example, a 200-V, 10-hp motor would draw 32 A.

### Table 17-2 (NEC Table 430-148) Full-load currents in amperes; single-phase alternating-current motors

The following values of full-load currents are for motors running at usual speeds and motors with normal torque characteristics. Motors built for especially low speeds or high torques may have higher full-load currents, and multispeed motors will have full-load current varying with speed, in which case the name-plate current ratings shall be used.

To obtain full-load currents of 208- and 200-volt motors, increase corresponding 230-volt motor full-load currents by 10 and 15 percent, respectively.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120 and 220 to 240.

<table>
<thead>
<tr>
<th>HP</th>
<th>115 V</th>
<th>230 V</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/6</td>
<td>4.4</td>
<td>2.2</td>
</tr>
<tr>
<td>1/4</td>
<td>5.8</td>
<td>2.9</td>
</tr>
<tr>
<td>1/2</td>
<td>7.2</td>
<td>3.6</td>
</tr>
<tr>
<td>1</td>
<td>9.8</td>
<td>4.9</td>
</tr>
<tr>
<td>1 1/2</td>
<td>13.8</td>
<td>6.9</td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>1 1/2</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
<td>17</td>
</tr>
<tr>
<td>5</td>
<td>56</td>
<td>28</td>
</tr>
<tr>
<td>7 1/2</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>50</td>
</tr>
</tbody>
</table>

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Table 17-3  *(NEC Table 430-150)* Full-load current* 3-phase alternating-current motors

<table>
<thead>
<tr>
<th>HP</th>
<th>Squirrel-Cage and Wound-Rotor Ampères</th>
<th>Synchronous Type +Unity Power Factor Ampères</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>115 V</td>
<td>230 V</td>
</tr>
<tr>
<td>1/2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>5.6</td>
<td>2.8</td>
</tr>
<tr>
<td>1 1/2</td>
<td>10.4</td>
<td>5.2</td>
</tr>
<tr>
<td>2</td>
<td>13.6</td>
<td>6.8</td>
</tr>
<tr>
<td>3</td>
<td>9.6</td>
<td>4.8</td>
</tr>
<tr>
<td>5</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>7 1/2</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>14</td>
</tr>
<tr>
<td>15</td>
<td>42</td>
<td>21</td>
</tr>
<tr>
<td>20</td>
<td>54</td>
<td>27</td>
</tr>
<tr>
<td>25</td>
<td>68</td>
<td>34</td>
</tr>
<tr>
<td>30</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>40</td>
<td>104</td>
<td>52</td>
</tr>
<tr>
<td>50</td>
<td>130</td>
<td>65</td>
</tr>
<tr>
<td>60</td>
<td>154</td>
<td>77</td>
</tr>
<tr>
<td>75</td>
<td>192</td>
<td>96</td>
</tr>
<tr>
<td>100</td>
<td>248</td>
<td>124</td>
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<tr>
<td>125</td>
<td>312</td>
<td>156</td>
</tr>
<tr>
<td>150</td>
<td>360</td>
<td>180</td>
</tr>
<tr>
<td>200</td>
<td>480</td>
<td>240</td>
</tr>
</tbody>
</table>

For full-load currents of 208- and 200-volt motors, increase the corresponding 230-volt motor full-load current by 10 and 15 percent, respectively.

*These values of full-load current are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may require more running current, and multispeed motors will have full-load current varying with speed, in which case the nameplate current rating shall be used.

†For 90 and 80 percent power factor the above figures shall be multiplied by 1.1 and 1.25 respectively.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120, 220 to 240, 440 to 480, and 550 to 600 volts.

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**DISCONNECT FOR A SINGLE MOTOR**

A disconnect for a motor branch circuit must be capable of interrupting the locked-rotor current of the motor. This disconnecting means must disconnect both the motor and the controller from all ungrounded supply conductors, *NEC Section 430-103*. The disconnecting means must be located within sight from the motor controller, *NEC Section 430-102*. The definition of "in sight from" in *NEC Article 100* means that the controller is not more than 50 ft (15.24 m) from the disconnect, and that the controller is actually visible when standing at the disconnect location.

A fusible switch serving as the motor circuit disconnecting means must be rated in horsepower, *NEC Section 430-109*. A circuit breaker serving as a disconnecting means is not required to be rated in horsepower but...
instead will be rated in amperes, NEC Section 430-109. This circuit breaker must have an ampere rating not less than 115% of the motor full-load current, NEC Section 430-110(a).

There are exceptions to these rules for motor disconnects. Motors with a horsepower rating not greater than \( 1/4 \) hp may use the branch-circuit overcurrent device as the disconnect, NEC Section 430-109, Exception No. 1. If the motor is not larger than 2 hp, and operates at not more than 300 V, a general-use switch may serve as the disconnect, NEC Section 430-109, Exception No. 2. The switch must have an ampere rating at least twice that of the full-load current of the motor. An ac switch used on an ac circuit need only be rated at 1.25 times the full-load current of the motor.

Cord- and plug-connected motors may use an attachment plug and receptacle as the motor disconnect. This type of disconnect would be used for motors on portable or movable equipment used on the farm. The plug and receptacle should have a horsepower rating not smaller than the rating of the motor if it is intended to break power while operating, NEC Section 430-109, Exception No. 5. The current rating of the attachment plug and receptacle must be not less than 115% of the full-load current of the motor.

A fusible switch or a circuit breaker is permitted to serve as both the controller and disconnect, NEC Section 430-111. However, the requirements for motor controllers discussed previously must be met.

Assume that the motor of Figure 17-13 will have a fusible switch as the disconnect. The disconnect switch must have a rating marked on the switch of at least \( 7\frac{1}{2} \) hp. However, if a circuit breaker serves as the disconnect, the rating will be in amperes. The minimum ampere rating of the circuit breaker is 1.15 times the full-load current, or 25 A. A 25-A or 30-A circuit breaker would be chosen. A circuit breaker rated at 30 A or more would most likely be chosen, because a 25-A breaker would probably trip due to the high starting current. The value of current from NEC Table 430-150 is used, rather than the nameplate current of 19.2 A.

\[
1.15 \times 22 \text{ A} = 25 \text{ A}
\]

**BRANCH-CIRCUIT WIRES**

The wires supplying a single motor shall have an ampere rating not less than 1.25 times the full-load current of the motor. For a multispeed motor, the highest normal full-load current shall be used, NEC Section 430-22(a).

The minimum ampere rating of the circuit wires for the motor of Figure 17-13 is 28 A.

\[
1.25 \times 22 \text{ A} = 28 \text{ A}
\]

The minimum size copper branch-circuit wire is found in NEC Table 310-16 (included in Unit 9 of this text). If the wire is THWN copper, the minimum size is No. 10 AWG. The footnote at the bottom of NEC Table 310-16 which specifies the maximum rating overcurrent device for wire sizes No. 14, 12, and 10 AWG does not apply in the case of electric motor circuits, NEC Section 210-19(a). Aluminum wire is seldom used for motor circuits. Most terminals in motor starters are rate only for copper wire.

**Problem 17-1**

A single-phase, 5-hp, 230-V electric motor has a nameplate current rating of 26 A. Determine the minimum size copper THWN branch-circuit wire.

**Solution**

Look up the full-load current of a 5-hp single-phase, 230-V motor in NEC Table 430-148. The current value is 28 A. The minimum ampere rating of the wire is 35 A.

\[
1.25 \times 28 \text{ A} = 35 \text{ A}
\]

**SHORT-CIRCUIT PROTECTION**

A branch circuit supplying a single motor is only subjected to excessive current caused by motor overloads or by ground faults and short circuits. Sometimes, a single overcurrent protective device protects against all three conditions while, in many instances, overload protection and protection from ground faults and short circuits are provided separately. First, consider them separately, and size the short-circuit and ground-fault protection for the branch circuit. The overcurrent device is either a fuse or a circuit breaker placed at the beginning of the circuit, Figure 17-15.

The short-circuit and ground-fault protection must be capable of carrying the starting current of the motor, NEC Section 430-52. The maximum rating of a time-delay fuse or an inverse time circuit breaker is determined using NEC Table 430-152 (Table 17-4 in this
An inverse time circuit breaker is an ordinary circuit breaker which provides short-circuit protection, but it will carry an overload for a limited period of time. The code letter given on the nameplate of the motor is needed to determine the maximum size short-circuit and ground-fault protection. The motor of Figure 17-13 has a code letter J. This is an ac 3-phase squirrel-cage motor; therefore from NEC Table 430-152, the maximum size time-delay fuse is 175% of the motor full-load current, or 39 A. The motor full-load current must be taken from NEC Table 430-150. The maximum size inverse time circuit breaker would be 250% of the motor full-load current, or 55 A.

The motor short-circuit and ground-fault protective device should be sized as small as possible without causing nuisance tripping. Remember that the minimum size in the case of a circuit breaker is 1.15 times the full-load current of the motor, NEC Section 430-58. The motor of Figure 17-13 is shown in Figure 17-16 with all components sized within the limits of the National Electrical Code. A suggested procedure is to determine the overcurrent protection size, using the value determined in NEC Table 430-152. If the motor is not driving a hard-starting load, then choose the next smaller protective device than the value determined. If this is too small, then choose the next size larger. In no case is the fuse permitted to be sized larger than 225% of the full-load current, NEC Section 430-52, Exception No. 2(b). For a circuit breaker, the maximum size is not permitted to exceed 400% for a motor drawing 100 A or less, and 300% for motors drawing more than 100 A, NEC Section 430-52, Exception No. 2(c).

Fuse:

\[ 1.75 \times 22 \text{ A} = 38 \text{ A} \]

(Use a 35-A or 40-A fuse.)

Problem 17-2

A single-phase, 5-hp 230-V electric motor with nameplate full-load current of 26 A drives a normal starting load and has a code letter G. Determine the proper size motor short-circuit protective time-delay fuse.

Solution

Determine the full-load current from NEC Table 430-148 and the fuse multiplier from NEC Table 430-152

<table>
<thead>
<tr>
<th>Full-load current: 28 A</th>
<th>Fuse multiplier: 175%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75 \times 28 \text{ A} = 49 \text{ A}</td>
<td></td>
</tr>
</tbody>
</table>

Use a 50-A fuse. The minimum wire size is No. 1 AWG copper THWN with a rating of 35 A.
Table 17-4  *(NEC Table 430-152) Maximum rating or setting of motor branch-circuit short-circuit and ground-fault protective devices*

<table>
<thead>
<tr>
<th>Type of Motor</th>
<th>Percent of Full-Load Current</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nontime Delay Fuse</td>
<td>Dual Element (Time-Delay) Fuse</td>
</tr>
<tr>
<td>Single-phase, all types</td>
<td>300</td>
<td>175</td>
</tr>
<tr>
<td>All ac single-phase and polyphase squirrel-cage and synchronous motors with full-voltage, resistor or reactor starting:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No code letter</td>
<td>300</td>
<td>175</td>
</tr>
<tr>
<td>Code letter F to V</td>
<td>300</td>
<td>175</td>
</tr>
<tr>
<td>Code letter B to E</td>
<td>250</td>
<td>175</td>
</tr>
<tr>
<td>Code letter A</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>All ac squirrel-cage and synchronous motors† with autotransformer starting:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not more than 30 amps</td>
<td>250</td>
<td>175</td>
</tr>
<tr>
<td>More than 30 amps</td>
<td>200</td>
<td>175</td>
</tr>
<tr>
<td>Code letter F to V</td>
<td>250</td>
<td>175</td>
</tr>
<tr>
<td>Code letter B to E</td>
<td>200</td>
<td>175</td>
</tr>
<tr>
<td>Code letter A</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>High-reactance squirrel-cage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not more than 30 amps</td>
<td>250</td>
<td>175</td>
</tr>
<tr>
<td>More than 30 amps</td>
<td>200</td>
<td>175</td>
</tr>
<tr>
<td>Wound-rotor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No code letter</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Direct-current (constant voltage)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No more than 50 hp</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>More than 50 hp</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

For explanation of Code Letter Marking, see Table 430-7(b). For certain exceptions to the values specified, see Sections 430-52 through 430-54.

*The values given in the last column also cover the ratings of nonadjustable inverse time types of circuit breakers that may be modified as in Section 430-52.

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

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Problem 17-3

Determine the proper size inverse time circuit breaker to provide ground-fault and short-circuit protec­
tion.

Solution

<table>
<thead>
<tr>
<th>Circuit breaker multiplier: 250%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 x 28 A = 70 A</td>
</tr>
</tbody>
</table>

Use a 60-A breaker, if possible. If it is too small, then choose a 70-A breaker.

It is permissible to have an overcurrent device sized larger than the allowable ampere rating of the wire. For example, a 70-A circuit breaker can protect a No. 10 AWG copper THWN wire with a maximum rating of 35 A. It must be remembered that the purpose of this circuit breaker is to protect against ground faults and short circuits only. Overload protection not exceeding the ampere rating of the wire is provided usually in the form of thermal overload heaters in the motor starter. As long as properly sized overload protection is provided somewhere in the circuit, the short-circuit fuse or circuit-breaker protection is permitted to exceed the ampere rating of the motor branch-circuit wire.

RUNNING OVERCURRENT PROTECTION

Electric motors are required to be protected against overload, NEC Section 430-32. Overload protection is usually provided as a device responsive to motor current or as a thermal protector integral with the motor. A device responsive to motor current could be a fuse, a circuit breaker, an overload heater, or a thermal reset switch in the motor housing. An automatically resetting thermal switch placed in the windings will sense winding temperature directly.

The service factor or temperature rise must be known from the motor nameplate when selecting the proper size motor overload protection. These are indicators of the amount of overload a motor can withstand. If a motor has a service factor of 1.15 or greater, the manufacturer has designed extra overload capacity into the motor. In this case, the overload protection may be sized as large as 125% of the nameplate full-load current. Internal heat is damaging to motor-winding insulation. A motor with a temperature rise of 40°C (104°F) or less has been designed to run relatively cool; therefore, it has greater overload capacity. The overload protection may be sized as large as 125% of the nameplate full-load current. A service factor of less than 1.15 or a temperature rise of more than 40°C (104°F) indicates little overload capacity. The overload protection under these circumstances is sized not larger than 115% of the nameplate full-load current.

Size the motor overload protective device at not more than these percents of nameplate full-load current:
- Service factor 1.15 or greater, 125%
- Temperature rise not greater than 40°C (104°F), 125%
- Service factor smaller than 1.15, 115%
- Temperature rise greater than 40°C (104°F), 115%

A time-delay fuse may serve as motor overload protection. Plug fuses or cartridge fuses are used for small motors. The fuse size is determined by selecting the proper multiplying factor, 1.15 or 1.25, based upon the service factor and temperature rise. Standard fuse sizes smaller than 30 A are listed in Unit 6.

Problem 17-4

A 3/4-hp, single-phase water pump motor is operated at 230 V and full-load current of 6.9 A. The motor has a service factor of 1.15 and a code letter K. Determine the maximum size time-delay fuses permitted to serve as running overload protection.

Solution

The full-load current from NEC Table 430-148 is 6.9 A. With a service factor of 1.15, the overload protective device may be 1.25 times the full-load current

\[
1.25 \times 6.9 \text{ A} = 8.6 \text{ A}
\]

Choose an 8-A fuse (refer to fuse sizes listed in Unit 6). If an 8-A fuse will not work, then the next larger size 9 A, may be used provided it does not exceed 140% of the motor nameplate current, \(1.4 \times 6.9 \text{ A} = 9.7 \text{ A}\ NEC Section 430-34\).

Circuit breakers could be used as running overload protection, but they are not available in small-ampere sizes. If they are used for large motors, they will usually trip on starting if they are sized small enough to provide overload protection.

Magnetic and manual motor starters have an overload relay or trip mechanism which is activated by a heater sensitive to the motor current. Typical motor overload heaters are shown in Figure 17-17. The manufacturer of the motor starter provides a chart inside the motor starter listing the part number for thermal overload...
Overload thermal sensing units or heaters trip an overload relay if the motor current becomes excessive.

Heaters. The heaters are sized according to the actual full-load current listed on the motor nameplate. Find the heater number from the manufacturer’s list corresponding to the motor nameplate full-load current. A typical manufacturer’s overload heat selection chart is shown in Figure 17-18.

An example will help to learn how the overload heater chart is used. A 3-phase motor nameplate full-load current for 230-V operation is 1.5 A. The proper overload heater to use is thermal unit No. B 2.40. The NEC allows this heater to be sized at 125% of the motor nameplate full-load current provided the service factor is 1.15 or larger, or the temperature rise is not greater than 40°C (104°F). The manufacturer has taken this into consideration when setting up the chart. If the service factor is less than 1.15 or if the temperature rise is greater than 40°C (104°F), then the heater will be 10% oversized.

The motor is then vulnerable to burnout. If the motor service factor is less than 1.15, multiply the motor full-load current on the nameplate by 0.9 and use this new value to size the overload heater. For the example, multiplying 1.5 A by 0.9 gives 1.35 A. The overload heater corresponding to 1.35 A is a thermal unit No. B 2.10.

A thermal protector integral with the motor and installed by the manufacturer is permitted to serve as the overload protection, NEC Section 430-32(a)(2). The manufacturer is required to size the thermal protector according to the multiplying factors in the NEC.

The number of overload protective devices required for a motor is specified in the NEC. If fuses are used, one fuse shall be placed in each ungrounded conductor supplying the motor, NEC Section 430-36. The number of thermal overload heaters is specified in NEC Table 430-37. The minimum is one for a single-phase motor, and three for a 3-phase motor.

The rules for sizing components for a single-motor branch circuit are summarized in Figure 17-19.

**Problem 17-5**

A single-phase, 3-hp electric motor operates at 230 V, and draws 17 A full-load current. The service factor is 1.2 and the code letter is M. The motor disconnect is a fusible switch and the controller is a magnetic motor starter. Determine the following:

1. Minimum rating disconnect switch
2. Minimum NEMA size motor starter
3. Minimum size copper THW wire
4. Time-delay fuse size for short-circuit and ground-fault protection
5. Proper overload heater from the chart in Figure 17-18

**Solution**

1. The disconnect switch must be rated in horsepower; therefore, the minimum is 3 hp.
2. Using Table 17-1, the minimum size motor starter for a single-phase, 3-hp motor is NEMA Size 1.
3. Look up the motor full-load current in NEC Table 430-148. Multiply the current by 1.25.

\[
1.25 \times 17 \, \text{A} = 21 \, \text{A}
\]

From NEC Table 310-16 (refer to Unit 9), the minimum copper THW wire size is No. 12 AWG.

4. The short-circuit time-delay fuse multiplier is found in NEC Table 430-152 for a single-phase motor with the code letter M. Multiply the full-load current by 1.75.

\[
1.75 \times 17 \, \text{A} = 30 \, \text{A}
\]

Use a 30-A time-delay fuse.

5. The overload heater is based upon 125% of full-load current because the service factor is greater than 1.15. Therefore, look up the heater part number corresponding to a motor full-load current of 17 A. The proper thermal overload heater is thermal unit No. B 32.

---

**FEEDER SUPPLYING SEVERAL MOTORS**

Groups of motors may be supplied by a single feeder. An example would be a feeder from the main service in a barn to the motor control center in a feed room. The feeder wires are required to have a minimum rating equal to the sum of the full-load current of all motors supplied, plus 25% of the full-load current of the largest motor, NEC Section 430-24. Consider the following example with single-phase, 230-V motors:

- Silo unloader—5 hp, 28 A
- Silo unloader—3 hp, 17 A
- Conveyor—1 hp, 8 A
- Bunk Feeder—2 hp, 12 A

The minimum size wire must have an ampere rating of 72 A.

\[
28 + 17 + 8 + 12 + (0.25 \times 28) = 72 \, \text{A}
\]

Using copper THWN, the minimum size is No. 4 AWG.
Next, the disconnect must be selected for the motor feeder. The disconnect for a feeder serving a group of motors shall have a horsepower rating not less than the sum of the horsepower ratings of the motors served, NEC Section 430-112. For the example, a fusible disconnect switch must have a horsepower rating not less than \(5 + 3 + 1 + 2 = 11\) hp. The disconnect to be chosen would probably be rated at 15 hp.

If a circuit breaker serves as the disconnect, it must have a current rating not less than 115% of the sum of the full-load currents of all the motors served, NEC Section 430-110(c)(2). For the example, this would be 75 A.

\[
1.15 \times (28 + 17 + 8 + 12) = 1.15 \times 65 = 75\text{ A}
\]

The minimum size standard circuit breaker would be 80 A.

Typically, feeders serving groups of motors will be sized large enough to provide for future expansion. Therefore, the previous calculations serve only as a guide. To make sure that the feeder is adequate for present and future needs, the feeder in the example would not be sized for the minimum, but rather for at least 100 A. The wire size could possibly be either No. 3 AWG copper THW or No. 1 AWG THW aluminum. The overcurrent protection would then be sized according to the ampere rating of the feeder, NEC Section 430-62(b).

The short-circuit protection for a feeder supplying a specific fixed motor load can be sized according to the rules of NEC Section 430-62(a). This only applies to a fixed motor load that will not be changed in the future. Consider the previous example, assuming that circuit breakers serve as the disconnect and short-circuit protection for each motor. A fusible disconnect switch will serve as the short-circuit protection for the feeder. Figure 17-20 shows the sizes of wire and overcurrent protection for each circuit.

The maximum rating of short-circuit protection for the feeder is determined by taking the maximum size motor branch-circuit short-circuit device and adding to it the full-load current of all other motors served. The larg-
est branch-circuit protection for the example is a 60-A
circuit breaker for the 5-hp motor. Add to this 60 A the
full-load currents for the 3-hp, 2-hp and 1-hp motors.
The fuse size is 100 A maximum.

<table>
<thead>
<tr>
<th>60</th>
<th>+</th>
<th>17</th>
<th>+</th>
<th>12</th>
<th>+</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>+</td>
<td>25</td>
<td>=</td>
<td>102 A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It must be remembered that the feeder overcurrent
device is permitted to exceed the ampere rating of the
feeder only when the feeder is supplying a specific motor
load. The panelboard is often used to serve other loads;
therefore, the feeder then must be protected at its am­
pacity. For the example, a No. 3 AWG copper wire in­
stead of a No. 4 should be chosen.

For group motor installations, dual-element, time­
delay fuses for each motor may be sized at 125% of the
motor full-load current rating. This provides motor
branch-circuit protection, as well as running overload
protection.

The main feeder dual-element, time-delay fuse may
generally be sized at 1½ times the ampere rating of the
largest motor of the group, plus the full-load current rat­
ing of the other motors of the group.

\[(1.5 \times 28) + 17 + 8 + 12 = 79 A\]

(Use 80-A fuses.)
This fuse size would be a minimum.

**FEEDER TAPS**

A common practice is to tap motor branch circuits
directly from a motor feeder. This is permitted as long as
the branch-circuit wire is terminated at an overcurrent
device sized properly for the circuit, NEC Section 430­
28. The branch-circuit wire size may be smaller than the
feeder wire size. If the tap wire from the feeder to the
overcurrent device is not more than 10 ft (3.05 m), and
is enclosed in raceway, the branch-circuit wire may be as
small as necessary to serve the motor load. However, if
the tap is more than 10 ft (3.05 m) but not more than
25 ft (7.62 m) in length, the branch-circuit wire must
have an ampere rating at least one-third the rating of the
feeder conductors.

Consider the example of a No. 4 AWG copper THW
feeder wire supplying the three motors of Figure 17-21.
The tap wire from the feeder to the fusible disconnect for
the ½-hp and 10-hp, 230-V, single-phase motors is not
required to be a minimum size because the tap is not
more than 10 ft (3.05 m) long. However, the 1½-hp
motor tap is more than 10 ft (3.05 m) long; therefore, it
must have an ampere rating not less than one-third that of
the feeder wire, or a minimum rating of 28 A. If the
wires are copper THW, then the minimum size is No.
10 AWG. If the tap had not been more than 10 ft
(3.05 m) long, then the 1½-hp motor circuit could have
been wired with No. 14 AWG THW copper wire.

\[\frac{85 A}{3} = 28-A minimum for 1\frac{1}{2}-hp motor tap\]

**MOTOR CONTROL CIRCUIT**

A magnetic motor starter is operated with an electric
solenoid coil. A diagram of the power flow to the motor
and the control circuit is included with each magnetic
motor starter.

A typical diagram is shown in Figure 17-22. The
heavy lines show the power flow to the motor. The nar­
row lines belong to the control circuit which is prewired

---

Figure 17-21 Motor branch-circuit taps from a feeder
The motors are single phase.
by the manufacturer. The holding contact or interlock is the set of contacts between terminals 2 and 3. These contacts close at the same time the main contacts close. The control wire goes from terminal 3 to the coil which closes the contacts, then from the coil through a normally closed overload relay contact. Some motor starters have as many as three of these contacts in series. If the motor overloads, the thermal units will heat up and trip open this overload relay contact, breaking the control circuit and deenergizing the coil. This opens the motor circuit. From the normally closed overload relay contact, the control circuit wire goes to terminal L2. The terminals of the overload relay are shown in Figure 17-23.

Figure 17-22  Schematic diagram of a magnetic motor starter

Figure 17-24  Simple switch device, such as a thermostat, controlling a magnetic motor starter

Consider the situation where a simple switching device, such as a thermostat, is used to control the motor, Figure 17-24. When the thermostat closes, it must complete the circuit to energize the motor starter coil. Power is obtained from terminal 1, which is located next to terminal L1. The other side of the thermostat is connected to terminal 3. When the thermostat closes, electrical current flows from terminal 1 through the thermostat to the coil. From the coil, current flows through the overload relay contact to terminal L2. When the thermostat opens, the circuit is broken and the main contacts open. Only two wires are required when a simple switch device is used to control the motor starter; terminal 2 is not used.

A start-stop station (also called a push-button station) is another common device used to control a motor. The start and stop push buttons are momentary contacts. They immediately return to their original position after they have been pressed. Figure 17-25 shows a momentary contact push-button station.

A start-stop motor control circuit is shown in Figure 17-26. This requires a 3-wire control circuit. Current can flow from terminal 1 through the normally closed stop button. As soon as the start button is depressed, current flows to terminal 3 and then through the coil to complete the circuit. The main contacts and the holding contact between terminals 2 and 3 are now closed. When the start button is released the start contact opens, but current now flows from terminal 2 to terminal 3 through the
Figure 17-25  Start-stop station for a magnetic motor starter (Courtesy of Square D Company)

holding contact, keeping the coil energized and the contacts closed. Now the only way to stop the motor is to press the stop button or open the overload relay. Diagrams for wiring common motor control circuits are contained inside the motor starter. It is a good idea to put numbers on the control circuit wires to help keep them identified. Figure 17-27 shows the start-stop station wires connected to the motor starter. Compare Figure 17-27 with the diagram of Figure 17-26.

The diagram of Figure 17-26 is a schematic control wiring diagram for a motor control circuit. It is a little difficult to visualize the operation of the complete control circuit. Examine Figure 17-28 where two separate start-stop stations are wired independently to operate the motor. The schematic diagram can be confusing. A type of diagram which helps to visualize easily the components and operation of a control circuit is called a ladder diagram. The entire control circuit is drawn horizontally across the diagram between the two power wires L1 and L2.

Figure 17-29 is a ladder diagram for the start-stop control circuit of Figure 17-26. The flow of current can be traced easily from L1 to L2 through each component. Figure 17-30 is a ladder-type control diagram of the two start-stop stations of Figure 17-28. Stop buttons are wired in series so that any one of them can break the circuit. The start buttons must be wired in parallel so that any one of them can energize the coil. The holding contact is always wired in parallel with the start buttons.

**INTERLOCKING MOTORS**

Two electric motors can be interlocked so that the second one cannot run unless the first one is running. This may be necessary to prevent plugging of a materials handling system. For example, if a conveyer stops, it may be desirable to shut down the silo unloader feeding

Figure 17-26  Start-stop station controlling a magnetic motor starter

Figure 17-27  Three wires are required to control a magnetic motor starter with a start-stop station.
the conveyer. Another common interlock technique is used to prevent two large motors from operating at the same time. This may be desirable to keep the electrical demand as low as possible in order to reduce the monthly electric bill. Extra interlock contacts can be added to a magnetic motor starter, Figure 17-31. Normally open and normally closed interlocking contacts are available. In Figure 17-32, motor B will operate only if motor A is operating. In Figure 17-33, motor D cannot operate if motor C is operating. In ladder diagrams, only the control circuits are shown. All parts labeled A are inside motor starter A, and similarly with parts B, C, and D. A confusing aspect of a ladder control diagram is that parts normally located physically together in the actual wiring may be located at any appropriate location on the ladder diagram.

**THERMAL PROTECTION IN MOTOR WINDINGS**

A motor may have a thermal protector in the windings to sense motor overheating. This thermal protector may be required to be wired-in as a part of the control circuit wiring. In this case, the thermal protector is simply wired in series with the control circuit. If the thermal protector opens, the control circuit is broken and the motor stops. A ladder diagram of a thermal protector in a control circuit is shown in Figure 17-34.
CONTROL DEVICES

Common control ladder diagrams and schematic wiring diagrams use some basic symbols and terminology. Switches and contacts are the basic control components, and they take several different forms. Switches and contacts may be operated mechanically by a timer or by some change in condition, such as temperature, pressure, flow, liquid level, or humidity.

Switches and contacts are described by the number of poles and the number of throws. The number of poles is the number of paths into a switch or contact. The number of throws is the number of paths leaving each pole.

It must also be known if the switch or contact is in the open or closed position when it is in the unactivated state. If the switch or contact is open when in the unactivated state, it is considered to be normally open (NO); when it is in the opposite position, it is said to be normally closed (NC). Common single-pole, single-throw
Another very common and versatile switch or contact arrangement is the double-pole, single-throw (DPST) contact. Some of the most common types are shown in Figure 17-37. The double-pole, double-throw (DPDT) contacts are common with control switches and timing relays, Figure 17-38.

The common types of switches and contacts are incorporated into various types of control devices. Only single-pole, single-throw contacts are shown in the following diagrams; however, the other types of contacts discussed previously are available. Control device schematic symbols that are frequently used are shown in Figure 17-39. A limit switch is a device which is activated when something presses against the lever arm or actuator. It may be of the two-position type or the momentary-contact type, Figure 17-40. Limit switches are frequently used to sense material flow in an automatic materials handling or processing system, such as a grain-drying system or an animal feeding system.

A current-sensing relay is a magnetic coil which closes a set of contacts when the current reaches a preset level, Figure 17-41. An application of a current-sensing relay is a feed grinder with an automatic conveyer sup-
Limb switch

Thermostat

Heating type

Cooling type

Flow switch

Closes with reduced flow

Closes with increased flow

Pressure or vacuum switch

Closes with pressure drop

Closes with pressure rise

Liquid-level switch

Closes with rise in level

Closes with fall in level

**Figure 17-39 Control device schematic symbols**

Applying grain to the grinder. As long as the grinder is fully loaded, the conveyor is off. As soon as the grinder load-current drops, indicating the grinder is not full, the current-sensing relay closes the contacts and turns on the conveyor. A ladder diagram of the control system is shown in Figure 17-42.

Time-delay relays are used on many types of processes or machines where a time delay of a few seconds or minutes is desired. A typical example is a grain-dryer control. The time-delay relay consists of one or more contacts and a timing device. Once power is supplied to the timing relay, it begins timing. After the preset time period, the contact or switch is activated to the alternate position. The schematic diagram for a time-delay relay is shown in Figure 17-43. After the timing is complete, the switch moves in the direction of the arrow at the bottom of the schematic symbol. Some types of time-delay relays are shown in Figure 17-44.

A typical timing relay may have an eight-pin socket, Figure 17-45. The timer voltage can be specified, but 120 V is common. This timing relay is a double-pole, double-throw type. Only the required contacts are used. Figure 17-46 shows a ladder diagram for two electric motors, one of which is operated with a timing relay.

**Figure 17-40 A limit switch is activated by making contact with solid material.**

**Figure 17-41 A current-sensing relay will open or close a contact upon rise or fall of current flow to a motor or other equipment.**
The start-stop station activates motor A and the timer of the timing relay. After a 30-second delay, motor B operates.

**LOW-VOLTAGE CONTROL**

A magnetic motor starter may be operated from a control transformer-supplied 24-V or 120-V system. This is of importance particularly for a large 460-V motor. A control transformer may step down the 460-V line voltage to 120 V. If the transformer is an integral part of the motor controller, it is permitted to be protected by fuses installed on the primary of the transformer, *NEC Section 430-72(c)*. Fuseholders are usually supplied as an integral part of the transformer. The wiring of a transformer-supplied control circuit is shown in Figure 17-47. The factory-installed jumper wire between terminals X2 and L2 must be removed. (The X2 marking on the motor controller can be seen in Figure 17-23.)

The control electrical supply may be completely external to the motor branch circuit. A typical example would be a programmable controller operating a group of motors. The programmable controller output would most likely be a 24-V signal, which can be used to operate the low-voltage control system.
likely be 120 V to energize the motor starter coil. Figure 17-48 shows a motor starter operated from an external electrical supply.

**PROTECTING THE CONTROL CIRCUIT**

The motor control circuit is considered a Class 1 remote-control circuit, and it falls within the scope of *NEC Article 725*, as well as *Part F of Article 430*. The motor control circuit wire may be tapped directly from the motor circuit wires, usually L1 and L2. Further, the control circuit wire carries only the current required by the coil in the motor starter; therefore, it is permitted to be a smaller wire size than is required for the motor circuit. The sizes of the motor control circuit wires are usually Nos. 14 or 12 AWG copper.

A start-stop station is often mounted in the cover of the motor controller. In this installation, the control circuit wires are completely within the motor controller. This wire need not be protected by a fuse, provided the motor circuit short-circuit and ground-fault protective device has a rating not more than the value in Column B of Table 17-5. Table 17-5 is derived from *NEC Section 430-72* and *NEC Table 430-72(b)*.

Consider the example of a 3-phase, 230-V, 15-hp motor which has a full-load current of 42 A, Figure 17-
Table 17-5  Maximum rating permitted for motor short-circuit and ground-fault protective device if supplemental protection is not provided for the control circuit wires (This table is derived from NEC Section 430-72 and NEC Table 430-72(b)).

<table>
<thead>
<tr>
<th>Copper Control Wire Size, AWG</th>
<th>Maximum Ampere Rating of Motor Circuit Short-Circuit and Ground-Fault Protective Device</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wires Completely Within Motor Starter Enclosure Column B</td>
</tr>
<tr>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>12</td>
<td>120</td>
</tr>
<tr>
<td>10</td>
<td>160</td>
</tr>
</tbody>
</table>

For other situations, see NEC Section 430-73, 725-12, or 725-35.

49. The motor circuit wire is No. 6 AWG THWN copper, and the motor circuit short-circuit protection is a 70-A time-delay fuse. The control circuit wire inside the controller enclosure is permitted to be No. 14 AWG, according to Column B of Table 17-5.

The motor circuit in the example has a second control station remote from the controller. The control wires are considered protected by the motor circuit short-circuit and ground-fault protective device provided it does not exceed the value of Column C of Table 17-5 for the size of control circuit wire in use. The minimum size wire to the remote station for the motor of Figure 17-49 is No. 10 AWG, unless separate overcurrent protection is provided for the control circuit. Fuse holders are available to add to the motor starter to protect the control circuit wires, Figure 17-50. Control circuit wire No. 18 AWG

![Diagram](Image)

Figure 17-49  The control circuit wires may be smaller than the motor circuit wires and still be tapped directly from the main wires.

Unit 17  Motor Control  365
The control circuit wires for large motors may require protection by a set of fuses in the motor starter.

Consider an example where a remote start-stop station controls a 7.5-hp, single-phase, 230-V electric motor with a full-load current of 40 A. The motor circuit wire is No. 8 AWG copper THW, and the short-circuit protection is an 80-A circuit breaker. If the control circuit wire is No. 14 AWG copper, then control circuit fuses are required, according to Column C of Table 17-5. Figure 17-51 shows the wiring of the control circuit with fuse protection added.

Motor control circuit conductors are required to be provided with suitable mechanical protection where they are subject to physical abuse, NEC Section 430-73. If an external source of power is used to control the motor such as is shown in Figure 17-48, the disconnect for the motor circuit and control circuit must be adjacent, NEC Section 430-74. If they are not adjacent, a warning label must be placed at the motor controller indicating that two separate disconnects are required to shut off power in the controller. The location of the control circuit disconnect must be specified at the motor controllers so that maintenance personnel will know where to find it.

**REVERSING MOTOR STARTERS**

Electric motors may be called upon to drive a machine which must be reversible. An example is a fee conveyer that operates in either direction to deliver feed to two batches of animals. A reversible motor starter is required to select the desired direction. For a 3-phase motor, only two lead wires to the motor must be reversed. However, for a single-phase motor, the starting winding leads must be reversed with respect to the running windings.

The least expensive means of reversing electric motors of small horsepower sizes is with a manually operated drum switch, Figure 17-52. The drum switch has

![Diagram of a drum switch for reversing motor starters](image-url)
A manually operated drum controller can be used to reverse an electric motor.

Figure 17-53 A drum controller connected to reverse a 3-phase electric motor

forward, a reverse, and an off position. Figure 17-53 shows the wiring of one type of drum switch to reverse a 3-phase motor. Note the phase rotation at the motor for the forward and the reverse positions. A single-phase motor is more difficult to reverse.

Electric motors of large-horsepower sizes can only be reversed with a reversing magnetic motor starter. This type has two magnetic contactors, Figure 17-54. A three-function, forward-stop-reverse, push-button station is required. Figure 17-55 shows the wiring of a reversing magnetic starter for a 3-phase electric motor. The two magnetic contactors must be electrically or mechanically

Figure 17-54 A reversing magnetic motor starter
Stop

Figure 17-55 Ladder diagram of the control circuit for a reversing magnetic motor starter. The normally closed interlocking contacts prevent both contactors from being closed at the same time, causing a short circuit.

interlocked to prevent both from being closed at one time. Closing both at one time will cause a short circuit.

**COMBINATION MOTOR STARTER**

The motor circuit disconnect short-circuit and ground-fault protection and the magnetic starter can be combined in one cabinet. These units are convenient when a fusible disconnect switch and magnetic motor starter will be installed at the same location. These units are called combination motor starters. A typical combination motor starter is shown in Figure 17-56.

**REVIEW**

Refer to the *National Electrical Code* when necessary to complete the following review material. Write your answers on a separate sheet of paper.

1. A plug and receptacle is permitted to serve as a motor controller for portable motors rated at what horsepower and less?

2. The locked-rotor current of a 5-hp, 230-V, single-phase motor is how many amperes?

3. According to the motor starter nameplate in the illustration at the top of the next page, this motor starter may be used to control a 25-hp, 460-V motor. Explain which change must be made to make the motor starter suitable for controlling a 460-V motor.

4. The largest size single-phase, 230-V electric motor which is permitted to be controlled with the motor starter in the illustration at the top of the next page is how many horsepower?
5. In the upper left-hand corner of the motor starter nameplate in the illustration above are the numbers 3 and 2. These are the terminal numbers for which of the following?
   a. Main contacts
   b. Coil
   c. Holding contacts
   d. Overload relay

6. The minimum size motor starter required for a 100-hp, 460-V, 3-phase electric motor is what NEMA size?

7. A motor starter is to be installed within an area of an agricultural building subject to dusty, damp, and corrosive conditions. The type of enclosure suitable for these conditions is what NEMA enclosure?

8. The full-load current of a 3-hp, single-phase, 230-V electric motor is how many amperes?

9. The minimum size copper THW branch-circuit wire for a 10-hp, 230-V, 3-phase motor with a nameplate current of 24 A is No. ___?___ AWG.
   a. 12
   b. 10
   c. 8
   d. 6

10. The motor of Problem No. 9 has a service factor of 1.20, and code letter M. The maximum size time-delay fuse that can serve as running overcurrent protection is:
    a. 25 A
    b. 30 A
    c. 40 A
    d. 50 A

11. The motor circuit disconnect is required to be within sight from the controller, which means actually visible from the controller, and not more than how many feet (meters) from the controller?
12. A circuit breaker will serve as the disconnect, as well as the short-circuit and ground-fault protection for a motor circuit. The motor is rated 2 hp, single-phase, 230 V, 11 A with code letter H. The maximum size circuit breaker under normal starting conditions is:
   a. 15 A
   b. 20 A
   c. 30 A
   d. 40 A

13. The electric motor in Problem No. 12 has a service factor of 1.10. Using the overload thermal unit selection chart of Figure 17-18, the correct overload heater is thermal unit No.:
   a. B 17.5
   b. B 19.5
   c. B 22
   d. B 25

14. The maximum size time-delay fuse used for short-circuit and ground-fault protection for a 75-hp, 460-V, 3-phase motor, code letter M, under normal starting conditions is:
   a. 100 A
   b. 125 A
   c. 150 A
   d. 175 A

15. A 225-A, single-phase, feeder conductor No. 3/0 AWG THHN copper supplies several motors in a feed room of a beef farm. A 5-hp, 230-V motor is tapped directly from the feeder with a fusible disconnect switch 15 ft (4.57 m) from the point of the tap. The minimum size copper THHN tap conductor permitted is No. 2 AWG:
   a. 10
   b. 8
   c. 6
   d. 4
16. On a separate sheet of paper, redraw and complete the control wiring diagram to operate the magnetic motor starter with a start-stop station.

![Control Wiring Diagram](image1)

17. On a separate sheet of paper, redraw and complete the control wiring diagram to operate the magnetic motor starter with a pressure switch.

![Control Wiring Diagram](image2)

18. The schematic control diagram has a start-stop push-button station operating a magnetic motor starter with an emergency stop push button mounted on the machine. On a separate sheet of paper, draw a ladder control diagram for the circuit.

![Ladder Control Diagram](image3)

19. A magnetic motor starter coil is energized from a separate 115-V source. Show how to wire the control circuit. On a separate sheet of paper, redraw the motor controller and control circuit wires. A control circuit wire in the motor starter must be removed.

![Control Circuit Wire Removal](image4)
20. The start-stop push-button station turns on motor A and, after a time delay of 30 seconds, motor B is turned on by the time-delay relay. The time-delay is the type that instantly resets when power to the timer is interrupted. On a separate sheet of paper, draw a ladder diagram of the control system.
OBJECTIVES

After studying this unit, the student will be able to

• select an adequate type and size of flexible cord for supplying portable equipment.
• choose a cord plug and connector adequate for the current and voltage of the supplied equipment.
• select and install controllers for electric motors on portable equipment.
• install a flexible cord, plug, and connector in a manner so as to prevent strain on the cord and moisture from entering the wiring or connections.

Flexible cords are frequently used on farms to supply portable electrical equipment and permanently connected equipment which must be moved during normal operation. A top-unloading silo unloader is a typical example of permanently attached equipment which is moved during normal use, Figure 18-1. Cords supplying equipment in agricultural locations are required to be approved for hard usage, NEC Section 547-3(c).

CORD TYPES

Types of flexible electrical cords are listed in NEC Table 400-4. Basically, several types of cords are suitable for agricultural use. These types include junior hard-service cord Types SJ and SJT. These cords are permitted to be used for portable equipment in damp locations, and are classified by the NEC as hard-usage cords. They are available in sizes No. 18 to No. 10 AWG. They are available as 2-, 3-, or 4-conductor cord. If the cords are suitable for use in areas where they will be exposed to oil and grease, they will have the letter O in the type, such as SJO or SJTO. The conductors inside these cords are protected by a tough outer covering.

Judgment must be applied regarding the severity of the conditions of use for flexible cords. Most cords used for agricultural applications should be rated for the extra-hard usage designation. Hard-service cord fits this classification and carries the Types S or ST. These types are also suitable for use in damp locations. The oil-resistant types are SO and STO. Hard-service cord is available in sizes No. 18 to No. 2 AWG. Cords are also available with two or more conductors.

Portable electric heating equipment, such as infrared heat-lamp fixtures, may be called upon to operate continuously for days or weeks. Flexible cords also may be subjected to excessive heat from the heating unit as well as continuous current flow. These cords must be capable of withstanding elevated operating temperatures without deterioration of the conductor insulation or the outer jacket. These are classified as jacketed heater cords.