Circuit Layout and Specifications

UNIT OBJECTIVE

Upon completion of this unit, you will be familiar with device ratings, symbols, abbreviations, and circuit diagrams used to characterize control circuits.

DISCUSSION OF FUNDAMENTALS

Important information is displayed on labels and nameplates located directly on industrial control components and motors. These ratings are particularly useful for replacing parts during maintenance operations.

To illustrate and define elements and functions easily, electrical diagrams are utilized. They are made of graphic symbols and device designations. Schematic diagrams focus on circuit functions, without taking into account the physical arrangement, whereas **wiring diagrams** include all the devices in the system and show their physical relationships.

Specifications Reading

EXERCISE OBJECTIVE

Interpret the information found on motor nameplates and specification labels.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Rating labels of control devices
- NEMA and IEC standards
- Pilot and control-circuit device rating
- Motor nameplate data and wiring information

DISCUSSION

When servicing or installing industrial control equipment, it is vital to comprehend the information characterizing the components of the circuits. This exercise gives an overview of the data that can be extracted from nameplates and labels.

Rating labels of control devices

Control devices are marked with information permitting their use under the right conditions. Figure 2-1 is an example of label for a contactor.

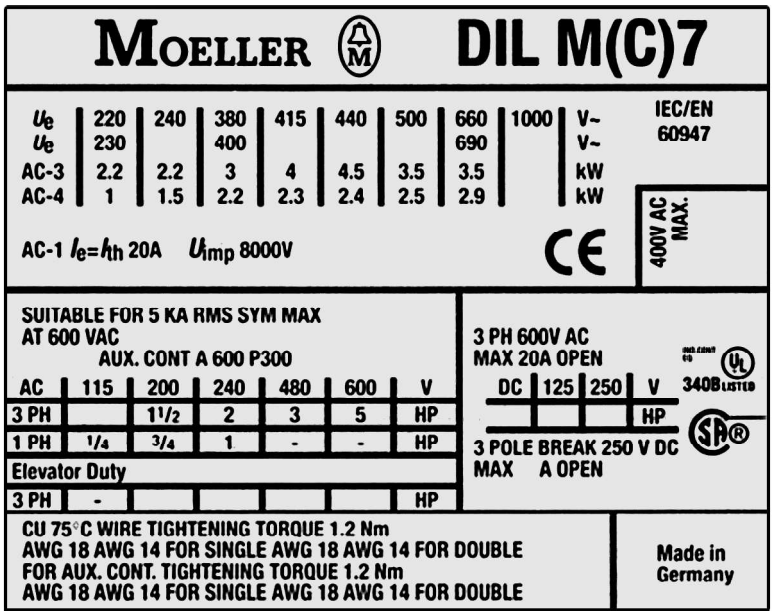


Figure 2-1. Contactor label.

Certification marks indicate that a product has been evaluated for compliance to national and international standards by a formal process, and that it complies with applicable standards for safety and performance. If we refer to the contactor label shown in Figure 2-1, we see that it meets the IEC, UL, CSA, and EN standards.

NEMA and IEC standards

Industrial control device ratings can be provided according to the National Electrical Manufacturers Association (NEMA) and/or the International Electrotechnical Commission (IEC). For example, if we take a motor starter or a contactor, both NEMA and IEC ratings can be specified for that device, but they will be different for a given motor power.

As Table 2-1 shows, NEMA motor starters and contactors are given size ratings, which depend on the continuous current rating, or the motor power and voltage. NEMA components are intended to be interchangeable between same-size devices. Because the exact application is not defined, they are designed to have more reserve capacity than their IEC counterparts. For that reason, NEMA devices are usually bigger and more expensive.

Table 2-1. NEMA sizes for three-phase single-speed full-voltage starters and contactors (non-plugging and non-jogging duty).

NEMA sizes for motor starters and contactors						
NEMA size	Continuous current rating (A)	Horsepower				Service-limit current rating (A)
		60 Hz		50 Hz		
		200 V	230 V	380 V	460 or 575 V	
00	9	1½	1½	1½	2	11
0	18	3	3	5	5	21
1	27	7½	7½	10	10	32
2	45	10	15	25	25	52
3	90	25	30	50	50	104
4	135	40	50	75	100	156
5	270	75	100	150	200	311
6	540	150	200	300	400	621
7	810	-	300	-	600	932
8	1215	-	450	-	900	1400
9	2250	-	800	-	1600	2590

On the other hand, IEC motor starters and contactors do not have standard sizes. Instead, they are described by their utilization category (see Table 2-2), power (hp or kW), thermal current (I_{th}), rated operational current (I_e) and rated operational voltage (U_e). For the same application, IEC devices are usually cheaper and smaller than their NEMA counterparts. However, they are more application sensitive and require greater knowledge from the buyer.

Table 2-2. IEC utilization categories.

IEC starters and contactors utilization categories	
Utilization categories	**Typical applications**
AC-1	Non-inductive or slightly inductive loads, e.g. resistive furnaces.
AC-3	**Squirrel cage motors**, starting and switching off while running at rated speed. Make locked **rotor** current and break **full load current**. Occasionally jog.
AC-4	Squirrel cage motors, starting and switching off while running at less than rated speed. Jogging (inching) and plugging (reversing direction of rotation from other than off condition). Make and break locked rotor current.

Pilot and control-circuit device rating

Pilot and control-circuit devices, such as push buttons and control relays, also have ratings. **Contact rating designations**, shown in Tables 2-3 and 2-4, give an indication of the maximum make and break currents. The letter designates the maximum continuous thermal test current of the unit or assembly. Letters A through E are for AC devices, and letters N through R are for DC devices. Numerical suffixes specify voltage design values of 600, 300, and 150 V.

Table 2-3. Mechanical switching rating for AC control-circuit contact.

AC control-circuit contact ratings											
Contact rating designation	Thermal cont. test current (A)	Maximum current (A)								Voltamperes	
		120 V		240 V		480 V		600 V			
		Make	Break	Make	Break	Make	Break	Make	Break	Make	Break
A150	10	60	6	-	-	-	-	-	-	7200	720
A300	10	60	6	30	3	-	-	-	-	7200	720
A600	10	60	6	30	3	15	1.5	12	1.2	7200	720
B150	5	30	3	-	-	-	-	-	-	3600	360
B300	5	30	3	15	1.5	-	-	-	-	3600	360
B600	5	30	3	15	1.5	7.5	0.75	6	0.6	3600	360
C150	2.5	15	1.5	-	-	-	-	-	-	1800	180
C300	2.5	15	1.5	7.5	0.75	-	-	-	-	1800	180
C600	2.5	15	1.5	7.5	0.75	3.75	0.375	3	0.3	1800	180
D150	1	3.6	0.6	-	-	-	-	-	-	432	72
D300	1	3.6	0.6	0.8	0.3	-	-	-	-	432	72
E150	0.5	1.8	0.3	-	-	-	-	-	-	216	36

Table 2-4. Mechanical switching rating for DC control-circuit contact.

DC control-circuit contact ratings					
Contact rating designation	Thermal continuous test current (A)	Maximum make or break current (A)			
		125 V	250 V	301 to 600 V	Voltamperes
N150	10	2.2	-	-	275
N300	10	2.2	1.1	-	275
N600	10	2.2	1.1	0.4	275
P150	5	1.1	-	-	138
P300	5	1.1	0.55	-	138
P600	5	1.1	0.55	0.2	138
Q150	2.5	0.55	-	-	69
Q300	2.5	0.55	0.27	-	69
Q600	2.5	0.55	0.27	0.1	69
R150	1	0.22	-	-	28
R300	1	0.22	0.11	-	28

Pilot and control-circuit elements have utilization categories different from contactors and motor starters, as Tables 2-5 and 2-6 show.

Table 2-5. AC switching elements utilization categories.

AC switching elements utilization categories	
Category	**Typical applications**
AC-12	Control of resistive loads and **solid state** loads with optical isolation.
AC-13	Control of solid state loads with transformer isolation.
AC-14	Control of small electromagnetic loads (max. 72 VA closed).
AC-15	Control of electromagnetic loads (greater than 72 VA closed).

Table 2-6. DC switching devices utilization categories.

AC switching elements utilization categories	
Category	**Typical applications**
DC-12	Control of resistive loads and **solid state** loads with optical isolation.
DC-13	Control of electromagnets.
DC-14	Control of electromagnetic loads having economy resistors in circuit.

Motor nameplate data and wiring information

A nameplate displays useful information about the motor. The nameplate shown in Figure 2-2 is for a standard, three-phase, nine-lead motor.

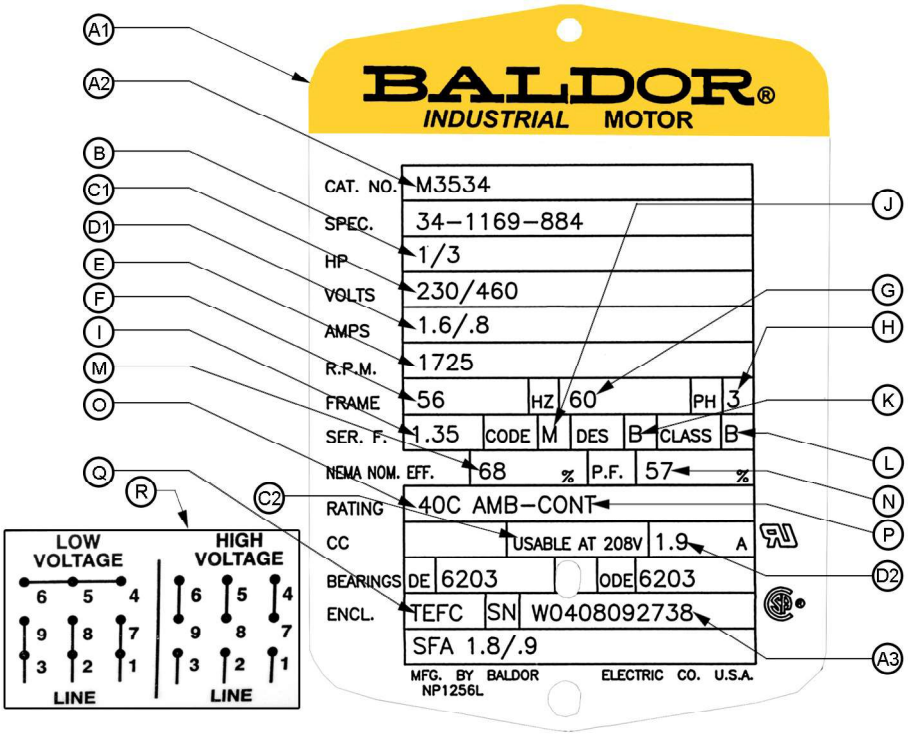


Figure 2-2. Three-phase motor nameplate.

Typically, you will find on a motor nameplate:

A. **Manufacturer's name**, **model**, and **serial number**: This information is invaluable for tracing replacement parts.

B. **Power rating**: The nominal output power at the shaft of the motor is given in kilowatts (kW) or in horsepower (hp).

C. **Rated voltage**: Motors are designed to operate at specific voltage(s). So-called dual voltage motors can be used with two different voltages, depending on how they are connected. Table 2-7 shows that the voltages found on AC motors nameplates are often slightly lower than those of corresponding electrical supply systems.

Table 2-7. NEMA standard nominal and rated 60 Hz polyphase motor voltages.

NEMA nominal system and rated motor voltages	
Nominal system voltage (V)	**Rated motor voltage (V)**
120	115
208	200
240	230
480	460
600	575
2400	2300
4160	4000
6900	6600

D. **Current rating(s)**: The motor rated current at full load and rated voltage, also called full-load ampere (FLA). When a motor draws more current than its FLA, it is said to be overloaded.

E. **Rotation speed**: The rated operating speed of the motor at full load. Motors can have more than one operating speed.

F. **Frame size**: NEMA and IEC have categorized the frames of motors to make them interchangeable, regardless of the manufacturer. Refer to Appendix C for NEMA and IEC Motor Frames Charts. NEMA motors may have a prefix (specific to the manufacturer) and a suffix (indicating the mounting type) in addition to the size number. A "T" or no suffix indicates current NEMA frame standards.

G. **Frequency**: This refers to the frequency of the power source supplying the motor, which is usually 60 or 50 Hz, depending on the country.

H. **Phase**: AC motors will require one or three phases.

I. **Service factor**: A multiplication factor indicating the continuous power overload capacity of a motor. A service factor of 1.0 does not permit overcharging, whereas a service factor of 1.15 enables continuous overload of 15 % without overheating the motor.

J. **Locked rotor code letter**: The code letter is a function of the locked kVA per horsepower, as Table 2-8 shows. Since the inrush current approaches the locked-rotor current, the following equation gives an indication of the starting current that is helpful to size motors' circuit protection:

$$\text{Locked rotor current} = \frac{\text{chart kVA/hp} \times \text{motor hp}}{\text{rated voltage}} \times 577 \ \text{(three phases)}^{*}$$

For a single-phase motor, the multiplication factor is 1000 instead of 577.

For example, a three-phase motor with a locked rotor code letter M and rated 1/3 hp at 230 V will have an approximate locked rotor current of:

$$\frac{(10.6 \times 0.33 \times 577)}{230} = 8.78\ \text{A}$$

Table 2-8. Locked rotor code letters.

Locked rotor code letters			
Code letter	**kVA/hp**	**Code letter**	**kVA/hp**
A	0.00-3.15	L	9.0-10.0
B	3.15-3.55	M	10.0-11.2
C	3.55-4.0	N	11.2-12.5
D	4.00-4.5	P	12.5-14.0
E	4.5-5.0	R	14.0-16.0
F	5.0-5.6	S	16.0-18.0
G	5.6-6.3	T	18.0-20.0
H	6.3-7.1	U	20.0-22.4
J	7.1-8.0	V	22.4 and up
K	8.0-9.0		

K. **NEMA design code letter**: This letter gives an indication of the torque's behavior depending on the speed. The most common design letters are A, B, C, and D. Design A motors are specialized motors used for their high pullout torque. Design B motors are standard industrial duty motors. Design C motors have higher starting torque than Design B motors. Design D motors have the highest starting torque, but this drops significantly with speed.

L. **Insulation class**: The type of insulation used in a motor is chosen depending on the expected operating temperature. Figure 2-3 shows the estimated life of different insulation classes, rated with letters. The higher the class letter, the more rugged the insulation.

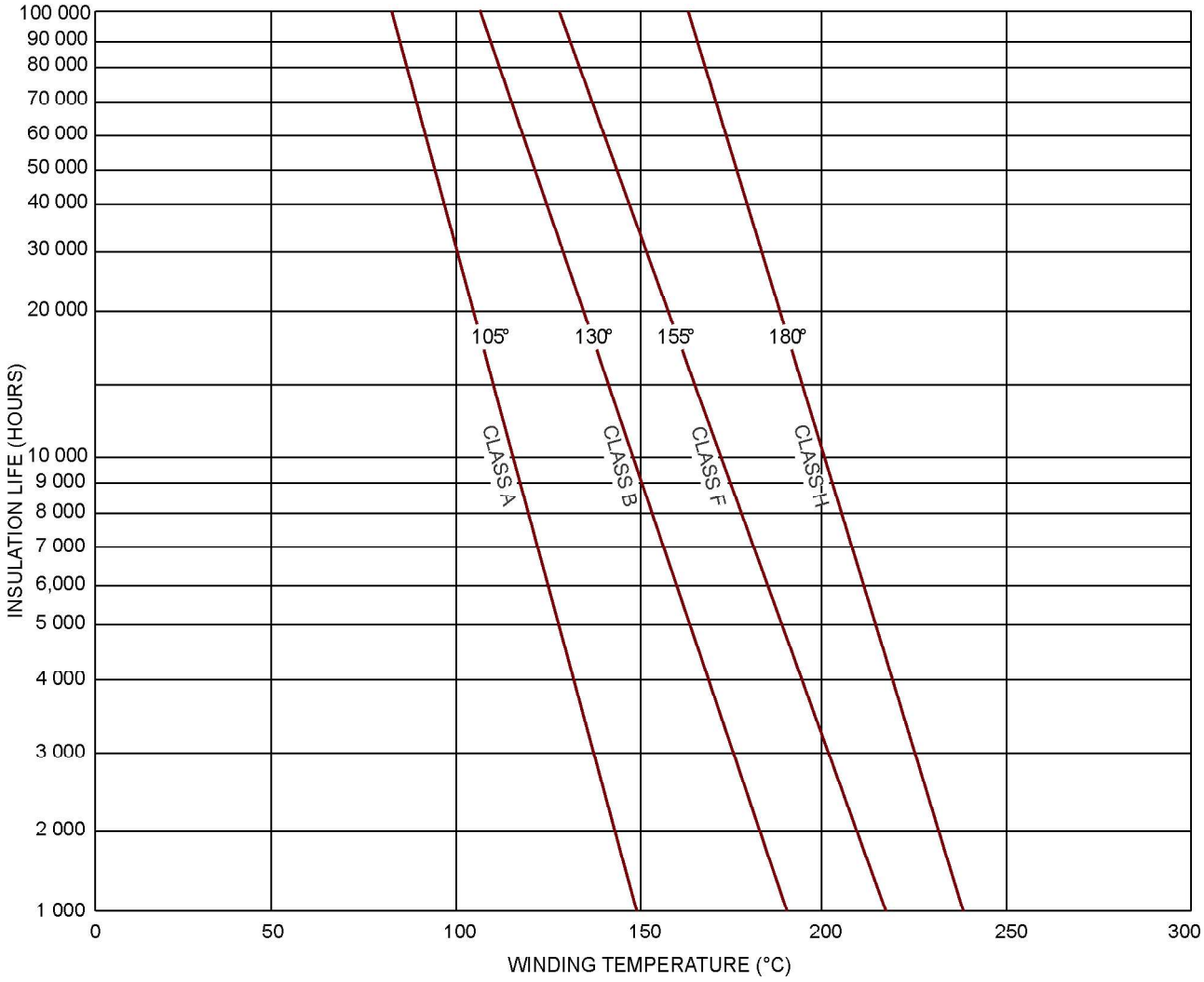


Figure 2-3. Insulation life and winding operating temperature.

Locked rotor codes, NEMA design codes, and insulation classes are all made up of letters, which may lead to some confusion.

M. **Efficiency**: The ratio of mechanical power produced to the electrical power input required by the motor. Unused energy is converted into heat.

N. **Power factor**: Motors are inductive loads and require reactive power. A higher power factor means that the motor consumes proportionally more real power, thus drawing less apparent power. In general, motors developing more power have a superior power factor.

O. **Ambient temperature**: Indicates the maximum recommended temperature of the air surrounding the motor. Usually 40°C or 104°F.

P. **Duty rating**: Motors are classified as either continuous or intermittent duty. The latter can be run continuously only for a given period of time, after which it must be allowed to cool down before restarting. An example of an intermittent duty motor is an air compressor.

Q. **Enclosure type**: Motors have enclosures of two different types: open and enclosed. Table 2-9 lists some of the more common designs for specific operating conditions.

Table 2-9. Typical motor enclosures.

Typical motor enclosures	
Types	**Characteristics**
Open drip-proof (ODP)	Protection effective against liquids of entry angles up to 15 degrees from vertical.
Splash-proof (Open)	Protection effective against liquids of entry angles up to 100 degrees from vertical.
Guarded (Open)	Guarded by limited size openings.
Weather protected type 1 (WPI) (Open)	Openings minimize entrance of rain, snow, and airborne particles.
Weather protected type 2 (WPII) (Open)	Like WPI with additional passages to eject high-velocity particles blown into motors.
Waterproof (Enclosed)	Exclude leakage except around shaft.
Totally enclosed fan-cooled (TEFC)	Constructed with a small fan on the rear shaft to cool motors.
Totally enclosed air over (TEAO)	Rely upon the strong air flow of the fan or blower which they are driving to cool them.
Totally enclosed non-ventilated (TENV)	Have no fan. Dissipate their heat by radiation through enclosure.
Totally enclosed water-cooled (TEWC)	Cooled by circulating water.
Totally enclosed blower-cooled (TEBC)	Used for variable speed motors. Constant speed blowers pull air to keep motors cool at all operating speeds.
Totally enclosed explosion-proof (TEXP)	Withstand internal gas explosion and prevent ignition of external gas.

R. **Motor connection diagram**: The indications for proper wiring may be located on the nameplate, in the conduit box, or on a separate plate.

S. **Motor type** (not shown in Figure 2-2): Manufacturers classify motors by their electrical and mechanical characteristics (squirrel-cage, induction, split-phase, permanent magnet, etc.).

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Brake motor
- Contactor
- Control relay

PROCEDURE

In this exercise, you will examine data on a motor nameplate, a contactor, and a control relay to extract some useful information.

Brake motor

1. Examine the nameplate of the Brake Motor, Model 3176-A, and fill out Table 2-10:

Table 2-10. Brake Motor nameplate.

Ratings	208 V	380 V	415 V *	380 V *
Power source frequency (Hz)	60	50	50	60
Power rating (hp)				
Full-load current (A)				
Number of phases				
Service factor				
Enclosure type				
Duty rating				
Maximum ambient temperature (°C)				
Rotation speed (r/min)				
Design code letter NEMA				
Locked rotor code letter				
Insulation class				
* If the nameplate of the Brake Motor does not indicate the characteristics of your version, refer to Appendix F.				

2. Referring to the locked rotor code letter, determine the maximum starting current at a 230-V rated motor voltage. Show your calculations.

_____

_____

_____

3. What is the estimated insulation life, in hours, of this motor if it is used continuously with windings at a temperature of 150° C?

Insulation life:_____

Contactor

4. Examine carefully the enclosure and rating label of the Contactor, Model 3127. What voltages can be used to control the coil?

50 Hz: _____

60 Hz: _____

5. On the rating label, what is the recommended power rating for 220/230/240 V, AC-3 utilization?

Recommended power rating: _____

6. What certification marks appear on the rating label?

_____

Control relay

7. Examine carefully the enclosure and rating label of the Control Relay, Model 3130. What voltages can be used to control the coil?

50 Hz: _____

60 Hz: _____

8. On the rating label, what is the rated operational current for 400 V, AC-15 utilization?

Rated operational current: _____

9. What certification marks appear on the rating label?

_____

CONCLUSION

Nameplates are installed on motors to help the purchaser for maintenance purposes and the manufacturer with customer service. These plates display useful information concerning the motor ratings, model, and connection.

Industrial control devices, including motor starters, contactors, pilot devices, and control relays, are rated by the NEMA and/or the IEC. Those specifications are usually located on rating labels. NEMA devices tend to be interchangeable, whereas IEC devices are more specific to the application, and thus require more knowledge.

REVIEW QUESTIONS

1. What is a NEMA frame 56 motor shaft diameter? (Refer to Appendix C.)

   a. 5/8 inch (1.59 cm)

   b. ½ inch (1.27 cm)

   c. 3/4 inch (1.91 cm)

   d. 1 inch (2.54 cm)

2. What is the name of the ratio of mechanical power produced to the electrical power input required by the motor?

   a. Power factor

   b. Power rating

   c. Service factor

   d. Efficiency

3. A motor nameplate reads 230/460 V, 1.5/0.7 A. When connected in series to a 460 V supply, how much current will a fully-loaded motor draw?

   a. 0.7 A

   b. 1.5 A

   c. 1.6 A

   d. 0.8 A

4. According to NEMA standards, what size of starter would be used with a 6 hp, three-phase motor at 230 V?

   a. 00

   b. 0

   c. 1

   d. 2

5. What utilization category is used for a contactor frequently making and breaking locked rotor current of a three-phase squirrel-cage motor?

   a. AC-1

   b. AC-2

   c. AC-3

   d. AC-4

Symbols, Designations, and Diagrams

EXERCISE OBJECTIVE

- Identify symbols and designations used on electrical diagrams.
- Become familiar with schematic and wiring diagrams.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Wiring diagrams
- Schematic diagrams
- Graphic symbols
- Designations
- Target tables

DISCUSSION

Electricians, technicians, and engineers use diagrams when working on electrical circuits. Schematic and wiring diagrams show the electrical relationships of the components. They are a form of shorthand in which the components are shown by symbols rather than actual scale drawings.

The width of lines does not affect the meaning of symbols. However, wider lines may be used for power wiring in contrast to control wiring. The angle at which a connecting line is brought to a symbol usually has no particular significance.

Wiring diagrams

Wiring diagrams are useful in building circuits, since the connections can be made exactly as they appear on the diagram. A wiring diagram provides a means of tracing the wires for troubleshooting or during normal preventive maintenance. Wiring diagrams are also called **connection diagrams**.

Figure 2-4 shows the wiring diagram of a motor control system. This diagram represents the station physically, the relative position of each device, and the different connections. The main parts of the motor starter are labeled on the diagram, so that a comparison can be made with the actual starter.

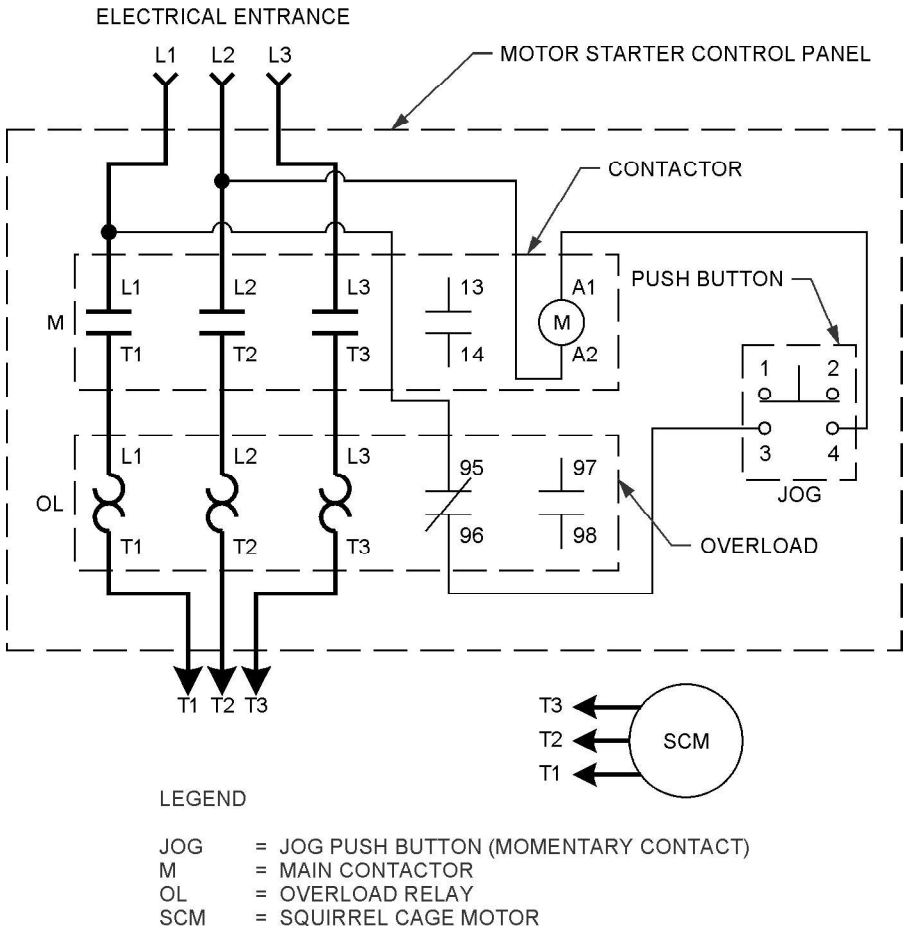


Figure 2-4. Wiring diagram of a motor control system.

Schematic diagrams

Schematic diagrams show the electrical connections and functions of a specific circuit arrangement. These drawings facilitate tracing the circuit, as they do not take account of the device's physical position, size, or shape. Schematic diagrams are sometimes referred to as **elementary diagrams**.

Figure 2-5 represents the schematic diagram of the same motor control system as in Figure 2-4. Symbols and functions of each device are indicated on this diagram.

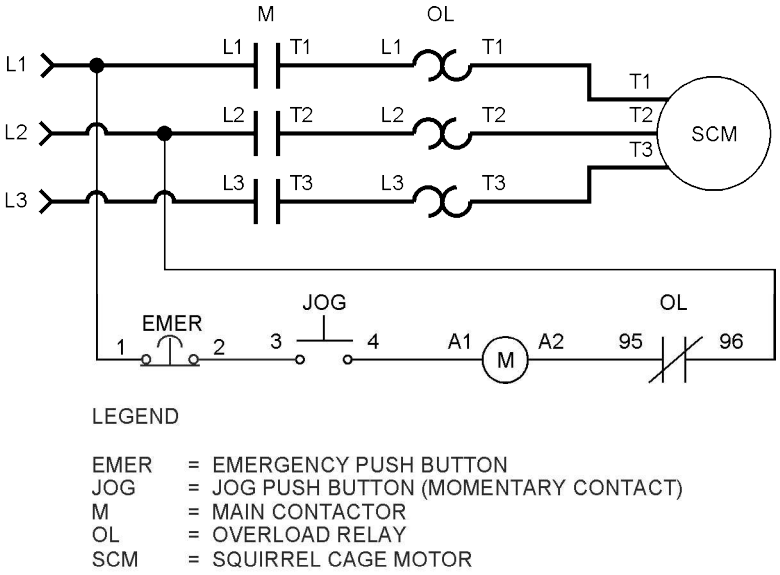


Figure 2-5. Schematic diagram of a basic motor control system.

Graphic symbols

Symbols are graphic representations employed in diagrams to represent the different circuit components. Appendix B shows NEMA standard symbols generally used for industrial control circuit diagrams. A table comparing NEMA and IEC symbols is also presented in Appendix B.

Terminal symbols can be added to each attachment point of the represented devices. Typically, control system terminals are marked with numbers and/or letters for identification. Figure 2-6 shows the differences between NEMA and IEC terminal markings.

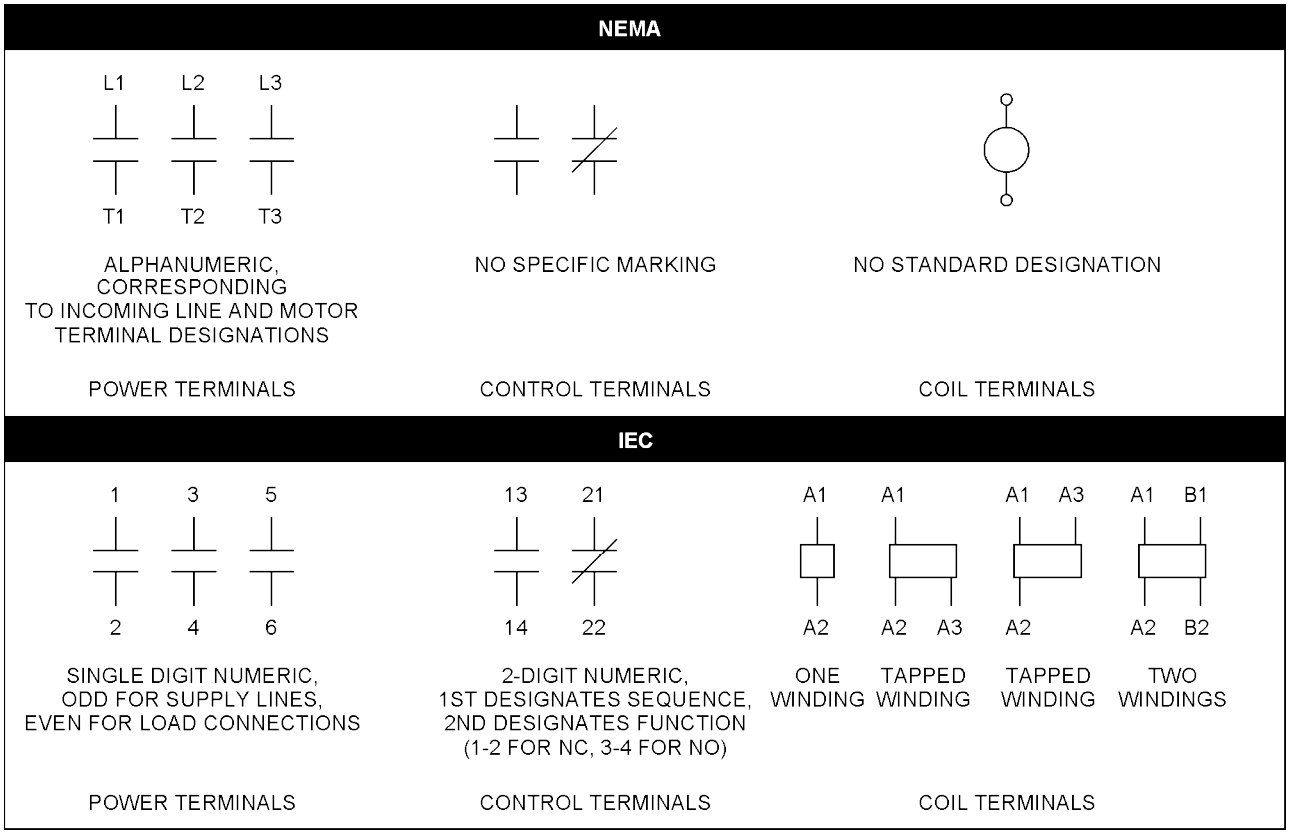


Figure 2-6. NEMA and IEC terminal markings.

Although NEMA diagrams do not show terminals which are not accessible, all terminals in this manual are detailed for better comprehension.

Designations

Device designations (abbreviations), listed in Appendix B, are used jointly with graphic symbols to indicate the functions of particular devices on diagrams. If we take a look at Figure 2-5, "OL" stands for "Overload" and "M" for "Main contactor."

Two or more designations can be combined to describe a single device. Numbers or letters may be added to the basic device designations to distinguish devices performing similar functions. For example, the first control relay initiating a jog function can be designated "1JCR. "

Target tables

A **target table** is used to indicate the contacts condition of a device, depending on its state.

The diagram in Figure 2-7 indicates how the lines and the load are connected to the Cam Switch. Table 2-11 is a target table showing which contacts close to reverse a three-phase motor, and which contacts close to run the motor forward. Each "X" represents a closed contact.

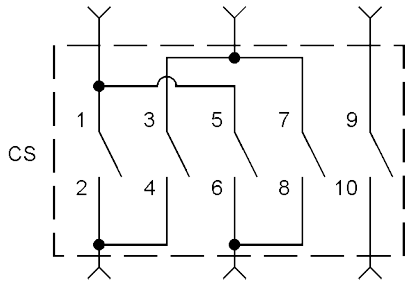


Figure 2-7. Cam Switch motor connections.

Table 2-11. Target table of the Cam Switch.

Contact	Position		
	F	O	R
1–2	X		
3–4			X
5–6			X
7–8	X		
9–10	X		X
X = Contact closed			

PROCEDURE

In this exercise, you will draw and identify different symbols and designations used on electrical diagrams. You will also draw a complete schematic diagram from a corresponding wiring diagram

Refer to Appendix B for symbols and designations.

1. Draw the symbols corresponding to the items listed below, by referring to Appendix B. Assume that the NEMA standard is used, if no standard is specified.

Items	Symbols
Normally open contact	
Single throw toggle switch	
Diode	
Normally closed contact (IEC)	
Fixed resistor	
Relay operating coil	
Three-phase induction motor	
Earth ground	
Red indicating light	
3-pole manual circuit breaker	

2. Write the designation letters of the devices listed below, by referring to Appendix B:

a. Time-delay opening contacts: _____

b. Overload: _____

c. Diode: _____

d. Circuit breaker: _____

e. Push button: _____

f. Ammeter: _____

g. Fuse: _____

h. Capacitor: _____

i. Pressure switch: _____

j. Transistor: _____

3. In the Figure 2-8 schematic diagram, identify each circled letter with the appropriate device name (see NEMA symbols table in Appendix B).

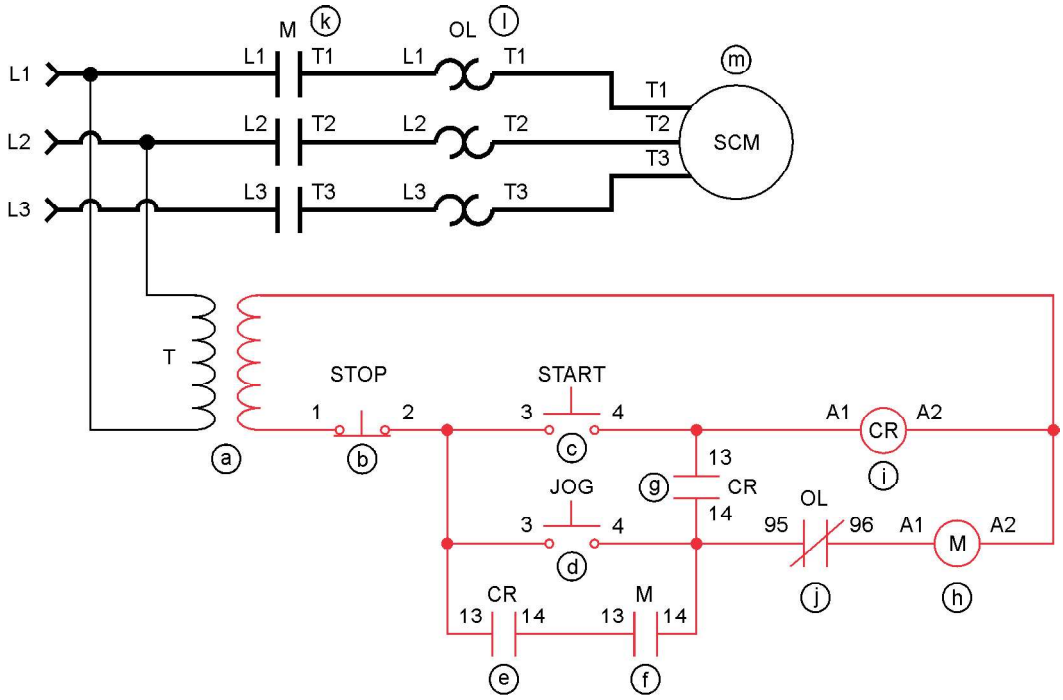


Figure 2-8. Schematic diagram.

a. _____ h. _____

b. _____ i. _____

c. _____ j. _____

d. _____ k. _____

e. _____ l. _____

f. _____ m. _____

g. _____

4. Draw in Figure 2-9 the schematic diagram of the wiring diagram shown in Figure 2-10.

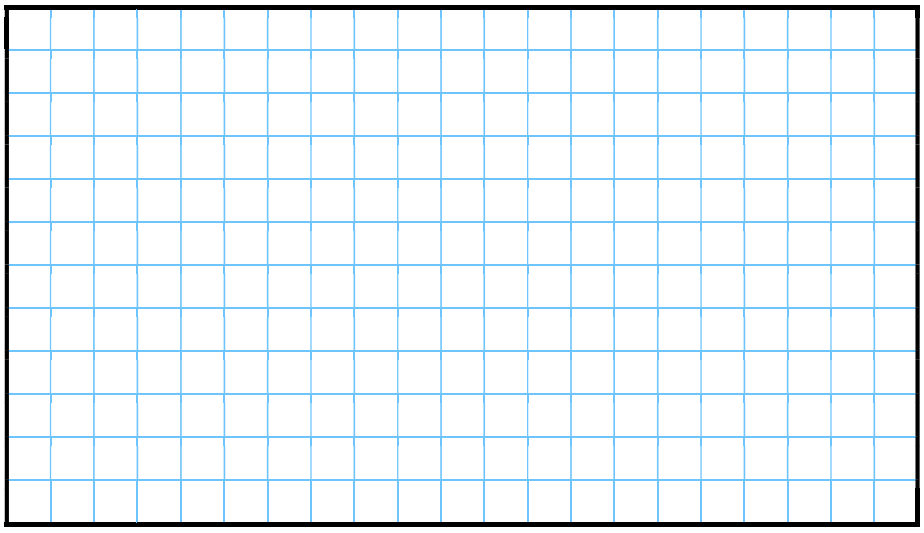


Figure 2-9. Schematic diagram of the Figure 2-10 wiring diagram.

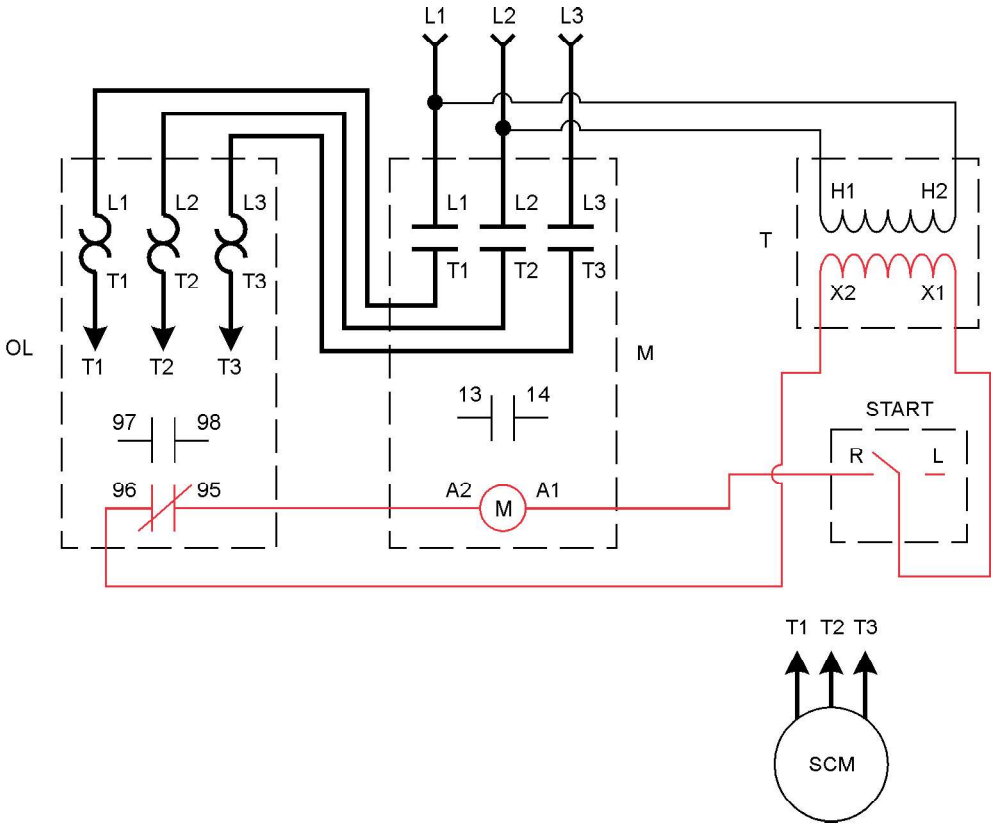


Figure 2-10. Wiring diagram.

CONCLUSION

Symbols are used in diagrams as a shorthand means of illustrating and defining elements and functions of electric circuits. Symbol functions can be defined with abbreviations (designations).

Schematic diagrams show simplified circuit connections and functions and are useful for troubleshooting purposes. Wiring diagrams show the circuits as they physically appear, making circuit construction easier.

Target tables are used to show the state of contacts on control devices.

REVIEW QUESTIONS

1. Which diagram represents the circuit as it appears physically?

   a. Wiring diagram

   b. Schematic diagram

   c. Elementary diagram

   d. One-line diagram

2. What term is a synonym for wiring diagrams?

   a. Elementary diagrams

   b. Connection diagrams

   c. Schematic diagrams

   d. Floor diagrams

3. What letter or combination of letters is used with graphic symbols to specify the function of a device?

   a. Written form

   b. Name code

   c. Indication

   d. Designation

4. What do narrower lines mean in diagrams?

   a. Future connections

   b. Control lines

   c. Power lines

   d. Standard-size cables

5. What is the meaning of a diamond-shaped symbol?

   a. The center of the circuit.

   b. An optional device.

   c. A diamond-shaped device.

   d. A solid-state device.

Unit Test

1. What is the meaning of this symbol? 

   a. NO limit switch
   b. NO limit switch, held closed
   c. NC limit switch
   d. NC limit switch, held open

2. What does the designation letter "X" stand for?

   a. Resistors
   b. Transistors
   c. Reactors
   d. Transformers

3. Which of the following symbols corresponds to a NO time-delay contact with a delay upon opening?

   a. 
   b. 
   c. 
   d. 

4. What term is a synonym for schematic diagrams?

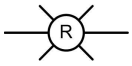
   a. Elementary diagrams
   b. Wiring diagrams
   c. Connection diagrams
   d. Isometric diagrams

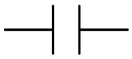
5. What is the purpose of target tables?

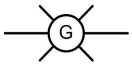
   a. Show the contacts required to reverse a motor using a cam switch.
   b. Show which contacts close depending on the control device operating mode.
   c. Indicate the control and power connections of a motor.
   d. Indicate abbreviations used to designate different devices.

6. What is the symbol for a green pilot lamp in electrical diagrams?

   a. 

   b. 

   c. 

   d. 

7. What term designates the maximum recommended temperature of the air surrounding the motor?

   a. Temperature rise
   b. Ambient temperature
   c. Intrinsic temperature
   d. None of the answers above is correct.

8. The "Duty" on a motor nameplate refers to the

   a. Locked rotor kVA input per hp.
   b. Heat rise above ambient temperature.
   c. Output of the motor in hp.
   d. Ratio of the time during which the motor runs to the time during which the motor is stopped.

9. Which of the following enclosures protects the motor from liquids of entry angles up to 100 degrees from vertical?

   a. Guarded
   b. Weather protected
   c. Drip proof
   d. Splash proof

10. Which type of device is designed with more reserve capacity to allow interchangeability?

    a. IEC-type devices
    b. CCC-type devices
    c. NEMA-type devices
    d. CSA-type devices