Introduction to Process Control

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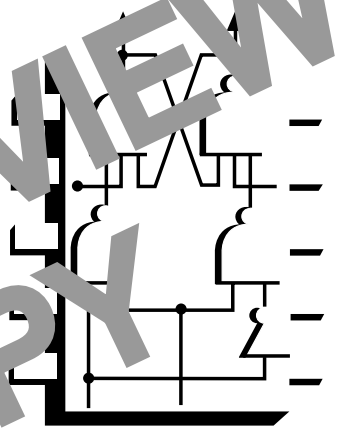
INTRODUCTION TO PROCESS CONTROL

Lesson Five

Using Symbols and Diagrams in Process Control



27105

TPC Training Systems

Lesson

5 Using Symbols and Diagrams in Process Control

TOPICS

Sequence of Operation
Flowchart
Switches
Relays
Motor Starters
Electrical Elementary Diagram
Pump System Schematic Diagram
Programmable Controller Diagram
Electronic Symbols

OBJECTIVES

After studying this lesson, you should be able to…

- Convert sequence-of-operation text to a flowchart.
- Read electrical and electronic control diagrams and drawings.
- Recognize symbols used on electrical and electronic diagrams, including those for PLCs and SAMA logic.
- Convert electrical diagrams to PLC diagrams.
- Discuss the role of computers in process control.

KEY TECHNICAL TERMS

Flowchart 5.03 a graphical description of the sequence of operation
SAMA 5.09 Scientific Apparatus Makers Association
Schematic 5.25 an electrical diagram showing the relationship of the components of a control system in the order that each should be energized
Run circuit 5.31 the line in the schematic that provides information about starting and stopping the motor

In today's complex process control systems, understanding what is happening and what should be happening is of primary importance to everyone involved in the process. Process designers prepare a sequence of operation to perform the tasks required to produce a high-quality finished product. Engineers then convert this sequence of operation to standard industrial symbols and diagrams in order to present the sequence in a logical form. To understand and work with the process, you must know how to read the symbols and diagrams.

This lesson will help you understand any process by showing you how to read electrical and electronic symbols and diagrams in particular. It will help you interpret schematics for SAMA logic, including that used for programmable logic controllers (PLCs) and other computers.

Sequence of Operation

5.01 The *sequence of operation* is a description in sentence form of how the controls in a process work. It is one of several methods for describing a process. The sequence of operation describes in detail what happens in what order in the process.

5.02 For example, the steps below might be part of the sequence of operation for a domestic water system. The system supplies water from a storage tank and pumps replacement water to the tank as the demand requires.

- If the pressure in the storage tank falls to a low level of 20 psi, and the pump is not running, start the pump.
- If the tank pressure reaches a high level of 60 psi, and the pump is running, stop the pump.

Flowchart

5.03 The *flowchart* is a graphical description of the sequence of operation. Figure 5-1 shows standard flowchart symbols. Once you become familiar with the shapes, you will be able to read flowcharts quite easily and rapidly.

5.04 Figure 5-2 on the following page shows a partial sequence of operation in flowchart form for the domestic water system discussed above. Flowcharts are arranged to be read from top to bottom or from left to right. Notice that each of the diamonds asks a question that can be answered with a "Yes" or a "No." A complete flowchart would show actions or further decisions for the alternate path from each decision diamond.

5.05 Following the sequence given above for the water-supply system, the first diamond asks the status of the pressure. You can trace the flow by fol-

Fig. 5-1. American standard flowchart symbols

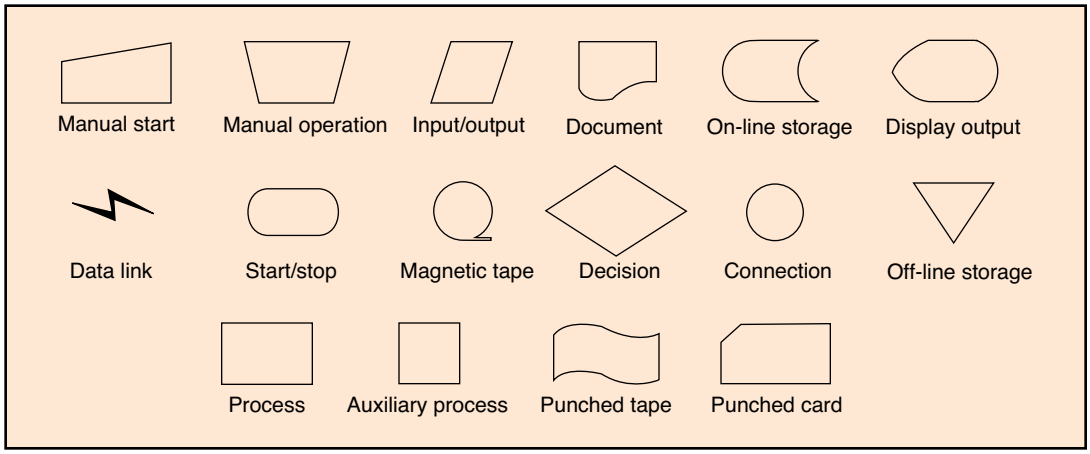
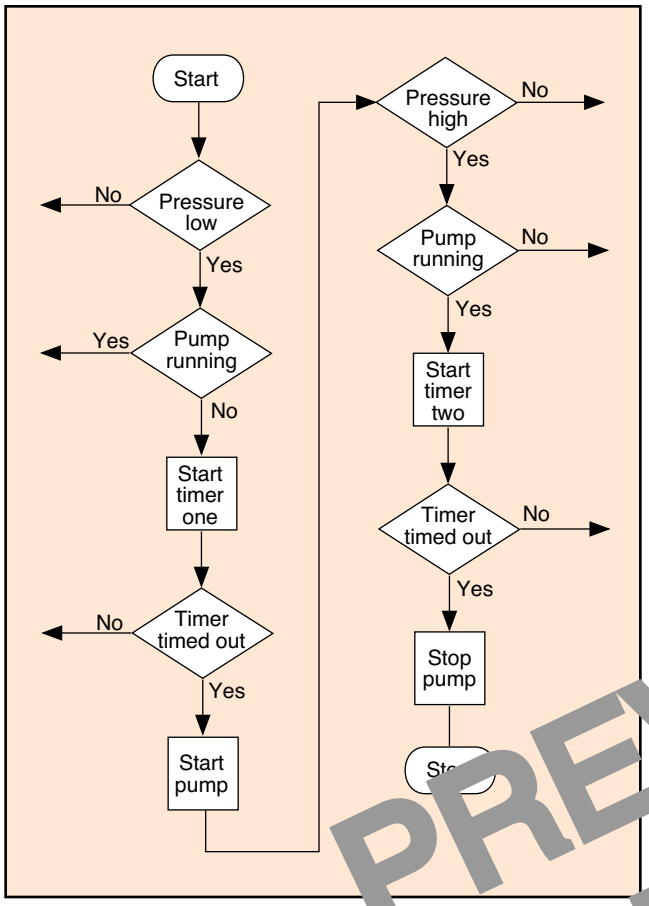


Fig. 5-2. Flowchart for pump sequence



lowing the lines from the Yes or the No. If the pressure is not low, the No path leads you to corrective action. If the pressure is low, the Yes line directs you to the second diamond.

5.06 The second diamond asks for the status of the pump. If the pump is running, you follow the Yes path. If the pump is not running, the arrowed No line directs you to the first square. A square is an instruction box. It indicates that an action of some kind is needed. In this case, the instruction is to start the first timer.

5.07 The third diamond asks for the status of the timer. If the timer has not timed out, you follow the No path. If the timer has timed out, the arrowed Yes line directs you to the second square. The second square is an instruction that tells you to start the pump. The first part of the sequence of operation above has now been satisfied.

5.08 The fourth diamond asks the pressure status. If the pressure is high (Yes), then the next diamond asks if the pump is running. If the pump is running (Yes), you are instructed to start the second timer. The last diamond asks if the timer has timed out. If the timer has timed out, you are instructed to shut off the pump. Now the second part of the sequence of operation has been satisfied.

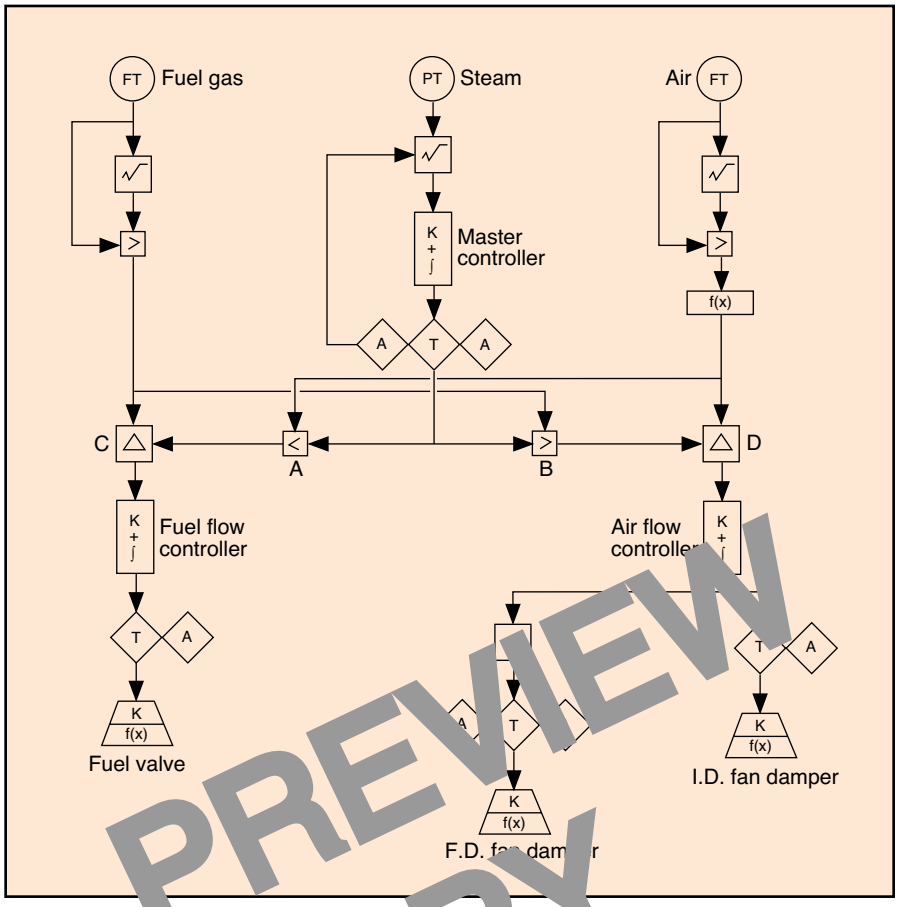
5.09 Figure 5-3 shows the flow for a combustion control system. This system is more complicated than the one just discussed, because it covers more kinds of information. This illustration shows a combination of pneumatic, liquid, steam, and electrical signals. The symbols are those of the *Scientific Apparatus Makers Association* (*SAMA*). Figure 5-4 lists and defines the SAMA symbols that are used for logic diagramming.

5.10 The purpose of the combustion control system is to provide the heat needed to maintain steam pressure. To accomplish this, fuel and air must be applied in the proper mixture. Note that the fuel transmitter and the air transmitter sense flow, while the steam transmitter senses pressure. Flow components include square root extractors and selector devices. The diagram shows you that all three controllers provide proportional and integral control.

5.11 The low selector at A and the high selector at B detect steam pressure and send the information to comparators in the fuel line (C) and in the air line (D). Comparators are devices that compare the signals from two inputs and send a signal based on the difference (Δ). If steam pressure is low, the system acts to increase it. If steam pressure is high, the system acts to reduce pressure.

5.12 Suppose the device at A in Fig. 5-3 sends a signal to the comparator at C indicating low steam pressure. The arrow from the comparator leads to the fuel controller, which sends a signal to the fuel valve, causing it to open. The comparator at D sends a signal to the air flow controller, which sends a signal to the dampers, causing them to open. The increase in fuel and air provide the heat needed to increase the steam pressure. Conversely, the device at B in Fig. 5-3 sends a signal to the comparator at D indicating high steam pressure, causing the system to reduce the flow fuel and close the air dampers, thus reducing steam pressure.

Fig. 5-3. A typical combustion control system



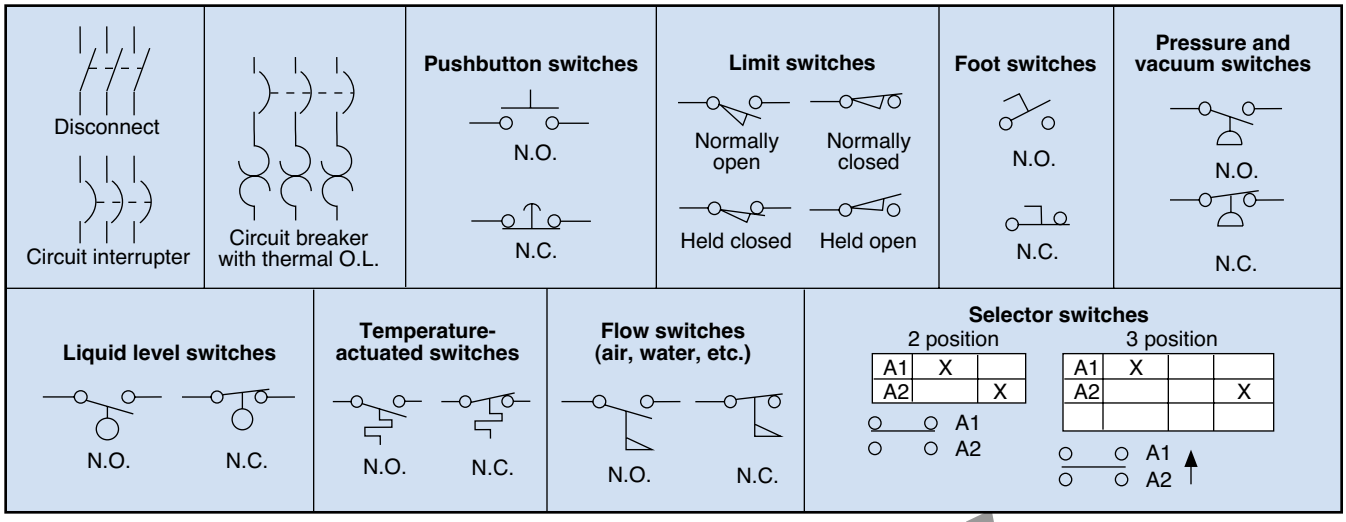
Switches

5.13 Many kinds of switches are available to perform control functions. Figure 5-5 on the following page shows the most common kinds of switches used in control circuits. Notice that each is shown as a normally open (N.O.) or a normally closed (N.C.) device. N.O. and N.C. indicate the state of the switch when it is de-energized—that is, when no pressure is applied to the switch arm.

Fig. 5-4. SAMA symbols

Symbols	Functions	Symbols	Functions	Symbols	Enclosures
Σ	Summing	f (t)	Time function	○	Measuring or readout
Σ / n	Averaging	>	High selecting	▭	Automatic signal processing
Δ	Difference	<	Low selecting	◇	Manual signal processing
K or P	Proportional	≯	High limiting	⏢	Final controlling
∫ or I	Integral	≮	Low limiting		
du/dx or D	Derivative	-K or -P	Reverse proportional		
X	Multiplying	V ≯	Velocity limiter		
÷	Dividing	+ or − or ±	Bias		
√	Root extracting	A	Analog signal generator		
X^n	Exponential	T	Transfer		
f (x)	Nonlinear or unspecified function	H/L or H//L	Signal monitor		

Fig. 5-5. Common switch symbols

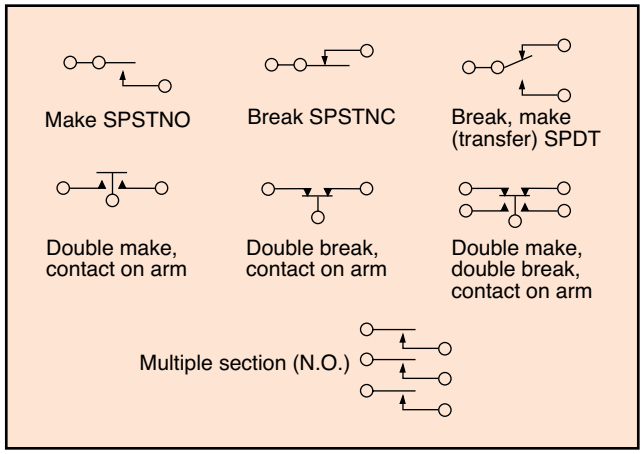


5.14 Here is a way to tell if a switch is N.O. or N.C., assuming the switch is drawn in the usual horizontal manner:

- Switches designated as N.C. are shown with the movable part of the switch above the contact.
- Switches designated as N.O. are shown with the movable part below the contact.

When the force holding the switch energized is removed, the movable part falls. The movable element of the N.O. switch falls downward away from the contact, *opening* the circuit. The movable element of the N.C. switch falls downward onto the contact, *closing* the circuit. Note that the opposite holds true for pushbutton and foot switches—downward movement closes the N.O. pushbutton switch and opens the N.C. pushbutton switch.

Fig. 5-6. Relay symbols



5.15 Starting at the upper left in Fig. 5-5, the first two boxes show kinds of main switches. The dotted line indicates a mechanical linkage. Each drawing indicates a three-phase switch.

- The first box shows a manual disconnect switch at the top. The circuit breaker (interrupter) shown at the bottom, disconnects when the current exceeds the rated value.
- The second box shows a circuit breaker with thermal overloads, which also disconnects when the current exceeds the rated value. This device includes heaters that heat up and open the contacts if the circuit current is excessive.

5.16 The third drawing shows switches that require manual operation and are mounted on the control panel. These can be pushbutton switches or rotary selector switches. All of the other switches depend on some kind of mechanical motion to change the state of the switch—that is, to open or close the contacts.

Relays

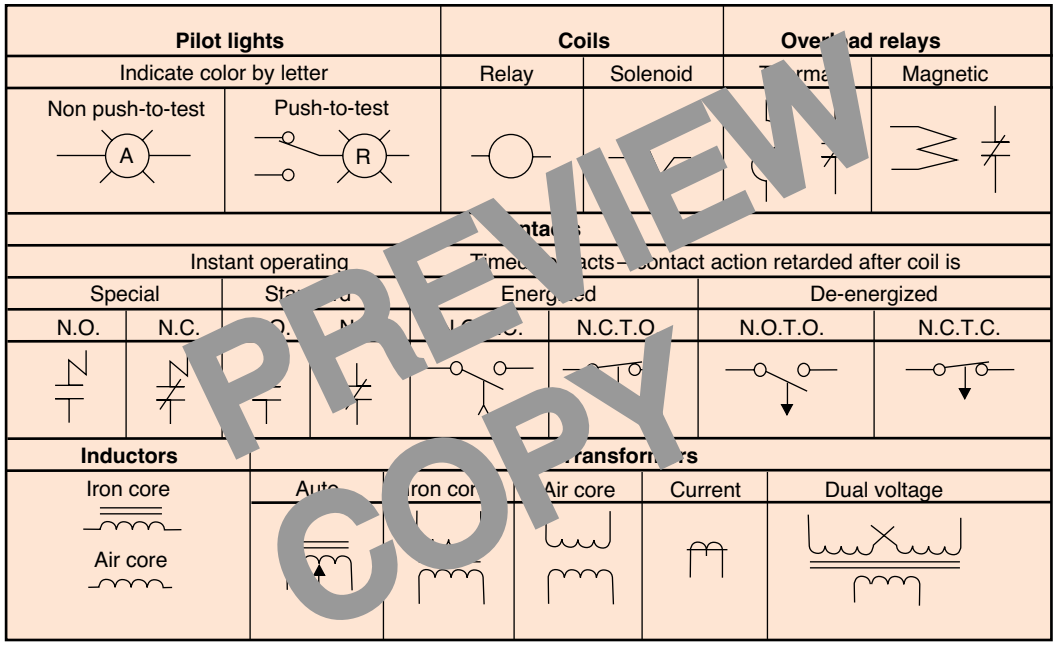
5.17 Many relays are used in control circuits. The *control relay* is an electromagnetic device.

That is, a magnetic field is created as voltage is applied to the coil. When power is applied to the coil, the relay's magnetic system causes the contacts to open (break) or close (make). The contacts are wired in an electrical circuit to perform the control action.

5.18 Figure 5-6 shows several basic relay contact configurations, although there are many others. Multiple-contact relays are very common. The most common is the single-pole, double-throw (SPDT) relay. This relay is normally shown as in Fig. 5-7 under the heading of Standard Instant-Operating Contacts. Figure 5-7 also shows the symbol for a control relay coil under the Coils heading, as well as many other symbols you will often see on drawings.

5.19 Relay contacts operate somewhat differently from switch contacts. Because electromagnetic action pulls the movable part of a direct-acting relay switch down when the relay is energized, normally closed contacts would move up when the relay is de-energized. Springs are used in relays to provide a counter force to the magnetic pull.

Fig. 5-7. Standard elementary wiring diagram symbols



5-1. The _____ is a description in sentence form of how the controls in a process work.	5-1. SEQUENCE OF OPERATION Ref: 5.01
5-2. A(n) _____ is a graphical description of the steps in a sequence of operation.	5-2. FLOWCHART Ref: 5.03
5-3. The shape that indicates a decision in a flowchart is a(n) _____, and a(n) _____ indicates an instruction.	5-3. DIAMOND; SQUARE Ref: 5.04, 5.06
5-4. SAMA symbols are those developed by the _____.	5-4. SCIENTIFIC APPARATUS MAKERS ASSOCIATION Ref: 5.09
5-5. N.O. and N.C. indicate the state of a switch when it is _____.	5-5. DE-ENERGIZED Ref: 5.13
5-6. Switches designated as N.C. are shown with the movable part of the switch _____ the contact.	5-6. ABOVE Ref: 5.14
5-7. A circuit breaker with thermal overloads includes _____ that open the circuit if current exceeds a specified value.	5-7. HEATERS Ref: 5.15
5-8. The control relay is a(n) _____ device.	5-8. ELECTROMAGNETIC Ref: 5.17

Motor Starters

5.20 Magnetic motor starters may be considered a special kind of relay. A typical three-phase motor starter includes contacts and overload heater elements, as well as a pushbutton station that contains an N.O. pushbutton START switch and an N.C. STOP switch.

5.21 Figure 5-8 shows the wiring for a magnetic starter. The heavy black lines show the three-phase power circuit. L1, L2, and L3 are the lines of supply. T1, T2, and T3 are motor leads. The control circuit is shown in light lines and consists of the START/STOP pushbuttons, the holding interlock, magnetic starter coil (M), and the overload relay contacts (OL) with a terminal of X2.

5.22 Pushing the START button energizes the coil (M). The magnetic action closes all four contacts and the motor starts. The interlock contact keeps the motor running, because it is in parallel with the START button. Pushing the STOP button de-energizes the circuit. The coil drops out, opening all four contacts, and the motor stops. Because the interlocking contact dropped out when the coil dropped out, the motor is prevented from restarting until the START button is pressed again.

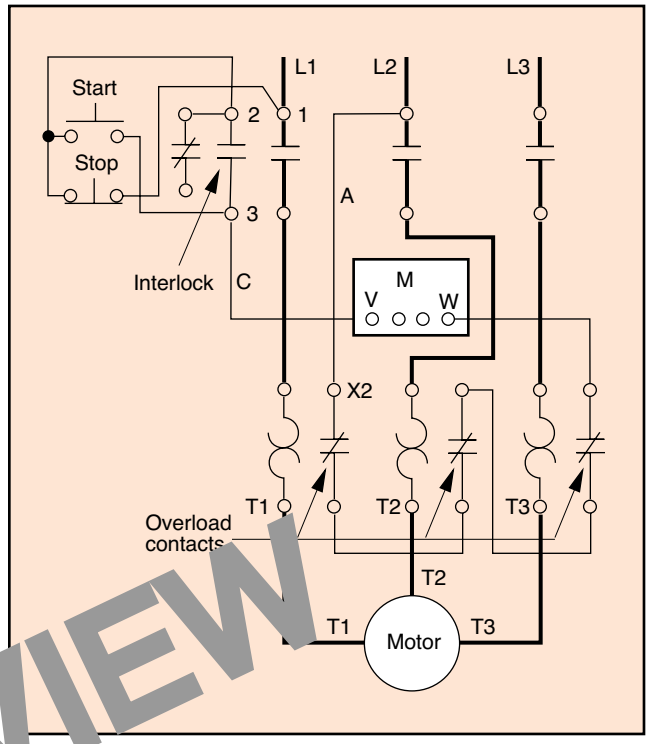
5.23 The overload heater elements are protective devices. Excessive current in the motor leads will cause the overload elements to heat up. If a certain temperature is reached, the overload relay contacts will open, de-energizing the coil and stopping the motor.

Electrical Elementary Diagram

5.24 Electrical and electronic symbols show the devices in a de-energized state—that is, no voltage is applied to the circuit. A *circuit* consists of a combination of devices that work together to accomplish a specific task. A *control circuit*, then, is a combination of devices that work together to control one or more specific tasks.

5.25 Figure 5-9 shows the elementary wiring diagram, also referred to as the *schematic*, for the motor starter circuit just discussed. The schematic shows you that the control circuit is a series circuit. Therefore, if any device changes state from open to closed or closed to open, the state of the entire circuit will be affected.

Fig. 5-8. Motor starter wiring diagram



Pump System Schematic Diagram

5.26 Figure 5-10 on the following page shows the electrical schematic diagram for the pump system discussed at the beginning of this lesson. The following paragraphs will analyze this drawing line by line.

5.27 In general, power circuits are not covered in this course. The power circuit is shown at the top of

Fig. 5-9. Motor starter schematic

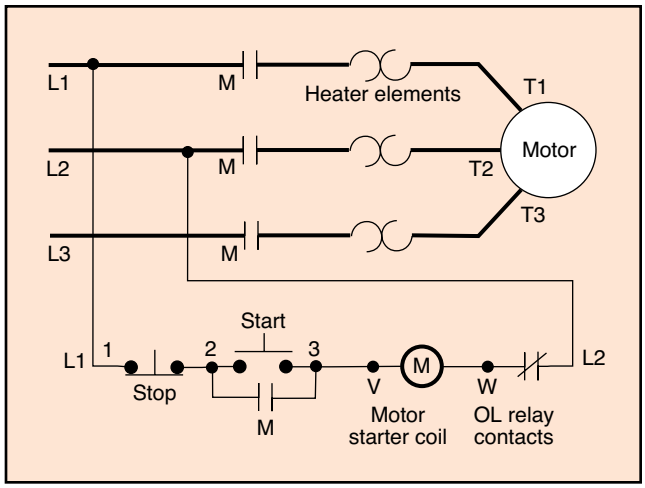
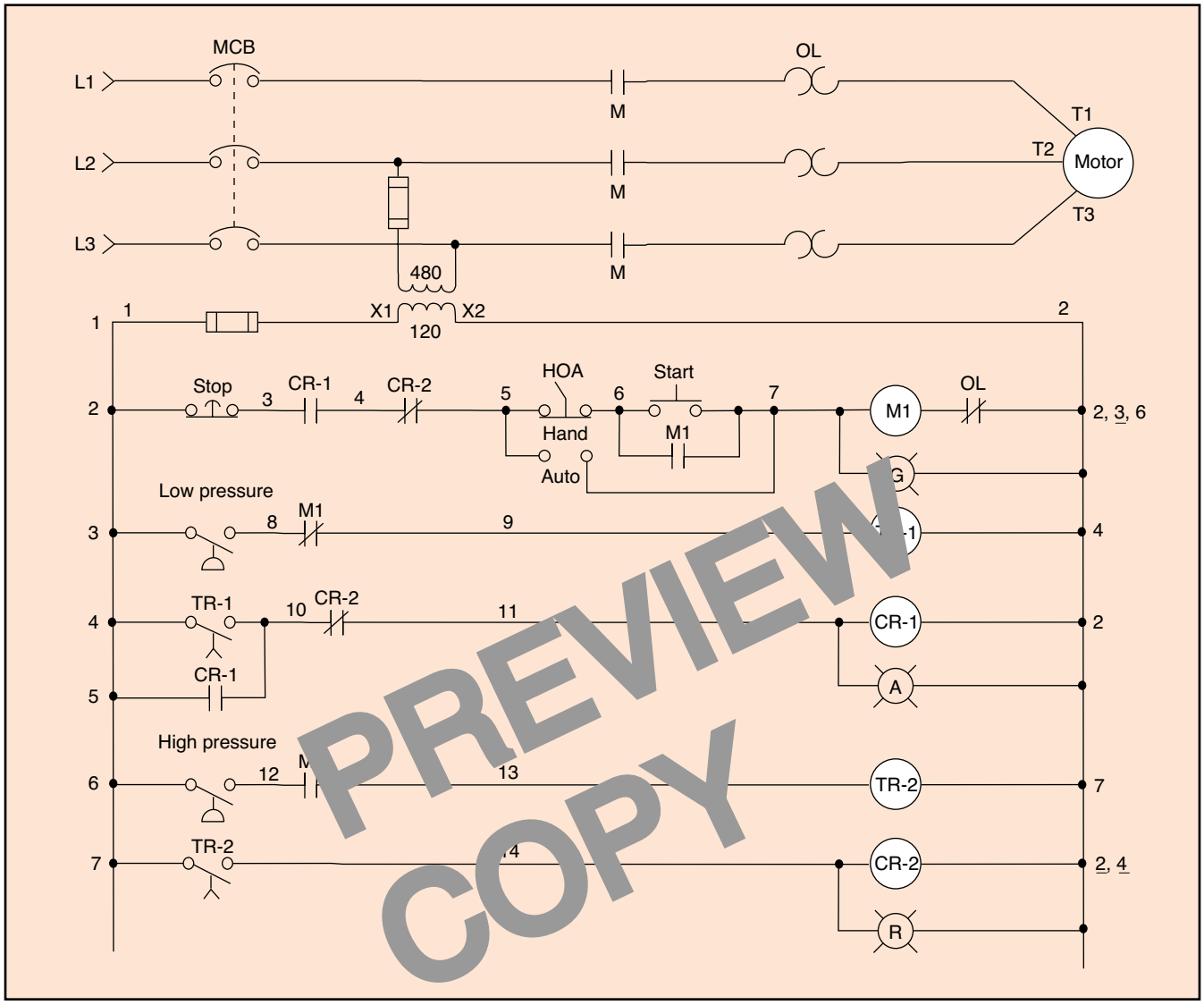


Fig. 5-10. Pump system schematic



the page to help explain the relationship between the starter (M1) and the power connection for the motor.

5.28 Closing the circuit breaker energizes L1, L2, and L3. When the starter coil (M1) is energized, the M1 contacts close, thus energizing T1, T2, and T3 and allowing the motor to start. The transformer provides the control voltage for this system. However, control voltage could be provided by a separate power supply.

5.29 All control drawings show line numbers on the far left. These numbers are used as references in troubleshooting. The numbers on the far right refer to the control line where the contacts of the output device are located. For example, the numbers 2, 3, and 6 in line 2 refer to the contacts of coil M1. A line under the number on the far right indicates a N.C. contact. You see that the M1 contacts in lines 2 and 6 are N.O., but the contact in line 3 is N.C.

5.30 Line 1 in Fig. 5-10 is the beginning of the control part of the drawing and provides control power information. In this example, the control voltage is 120 V ac. The numbers on each side of each device are wire numbers, essential information for troubleshooting or wiring the circuit.

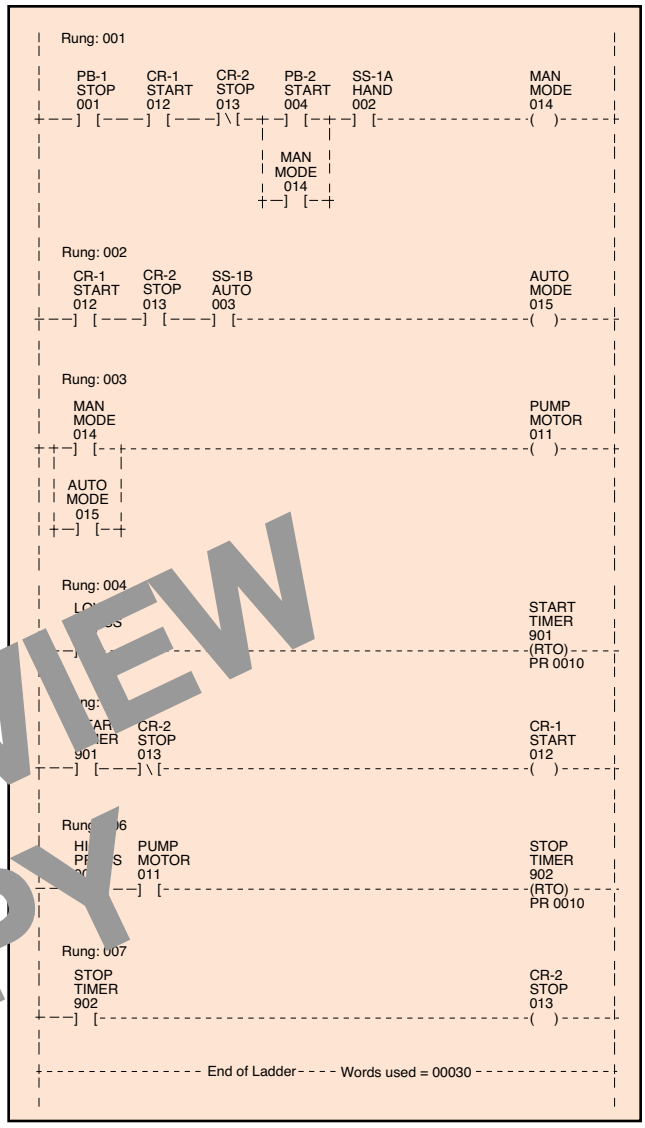
5.31 Line 2 in this example is referred to as the *run circuit*. It provides information about starting

and stopping the motor. The STOP button, CR-2, the switch (marked HOA), and OL are all N.C. devices and are shown in the normally closed position. You see that CR-1 and the START button are N.O. devices. Therefore, for the motor to start—that is, for M1 to be energized, first the START pushbutton must be depressed, energizing the circuit. CR-1 must be energized, and all devices except the START pushbutton and CR-1 must be closed (de-energized).

5.32 Line 4 tells you that control relay CR-1 must be energized to close contact CR-1 in line 2. Line 4 also shows that the start timer (TR-1) N.O. switch must be closed to energize relay CR-1. Line 3 shows that the low-pressure switch must be energized to close the circuit and start TR-1 timing. When TR-1 times out, switch TR-1 will close, energizing relay CR-1 and lighting the amber (A) ready-to-start light. Depressing the START button will then start the motor and light the green (G) pump-on light.

5.33 The motor can be stopped manually by depressing the STOP button or turning the selector switch to the OFF position. The motor will stop automatically if the OLs open due to an overload condition. When the pressure is high, relay CR-2 will be energized and open the CR-2 contacts. Lines 6 and 7 show the sequence to energize the CR-2 relay.

Fig. 5-11. Pump system PLC ladder diagram



Programmable Controller Diagram

5.34 Programmable controllers (PLCs) are actually computers that were originally developed to replace electromechanical relays. Symbols for indicating the control circuit program that resides in a PLC memory were developed from standard electrical symbols to enable electricians to follow the circuitry. Basically, a PLC consists of a rack holding the computer and the input/output boards needed to perform the control.

5.35 The PLC control diagram is referred to as a *ladder diagram*. Figure 5-11 shows the circuitry of Fig. 5-10 in ladder diagram form. You will notice many similarities between the two drawings.

5.36 Different kinds of PLCs use different numbering systems. The one used here is typical but by no means the only possible system. Each device in the circuit is assigned a specific number that is used in the programming of the PLC. This number represents the input or the output according to the particular board to which the device is wired.

5.37 Inputs, indicated by reversed brackets, are shown on the left side of the ladder. Outputs, indicated by parentheses, are shown on the right side of the ladder. A diagonal line within the reversed brackets indicates normally closed contacts, and the absence of a diagonal line indicates normally open contacts. For example, in Fig. 5-11 contacts of CR-1 (device 012), located on rungs 001 and 002, are shown normally open, but contacts of CR-2 (device

Fig. 5-12. PLC ladder inputs and outputs

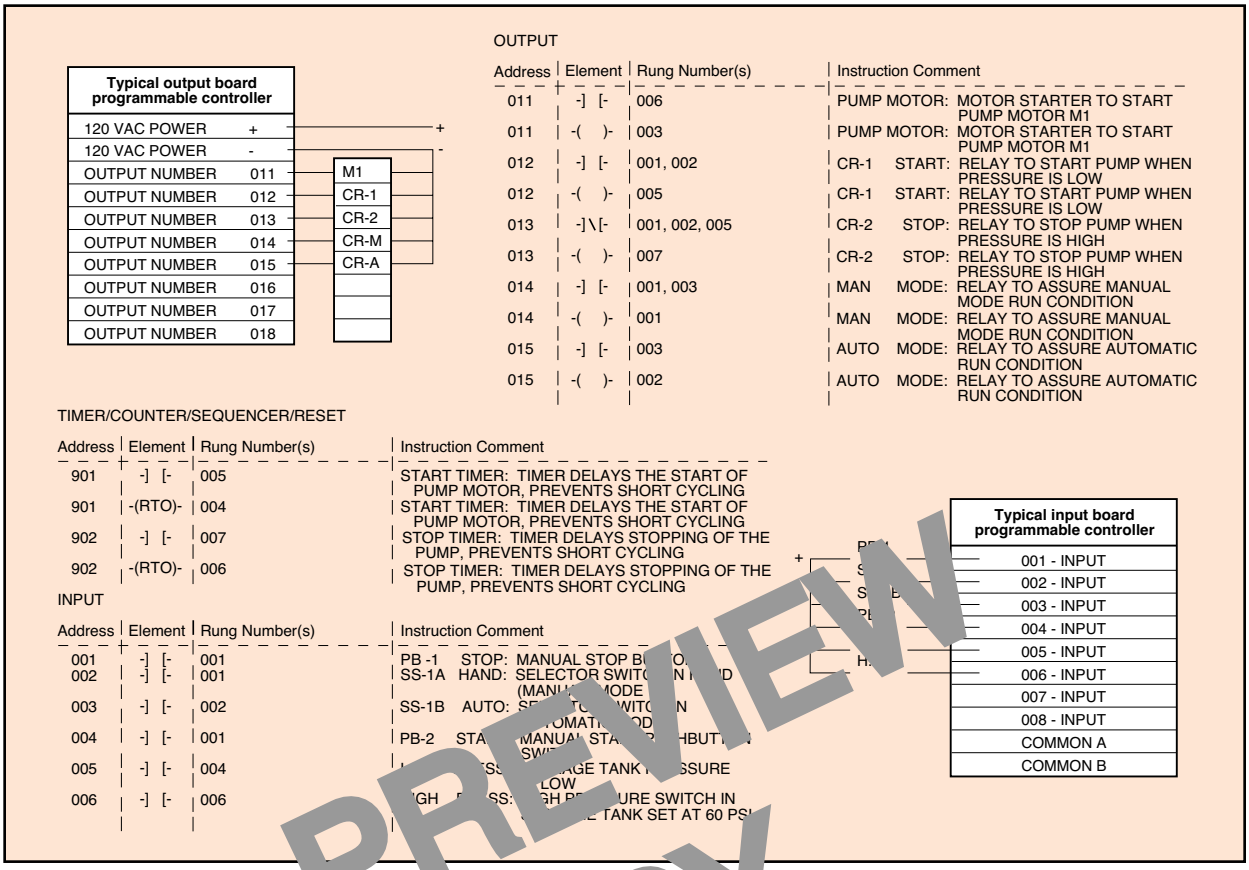
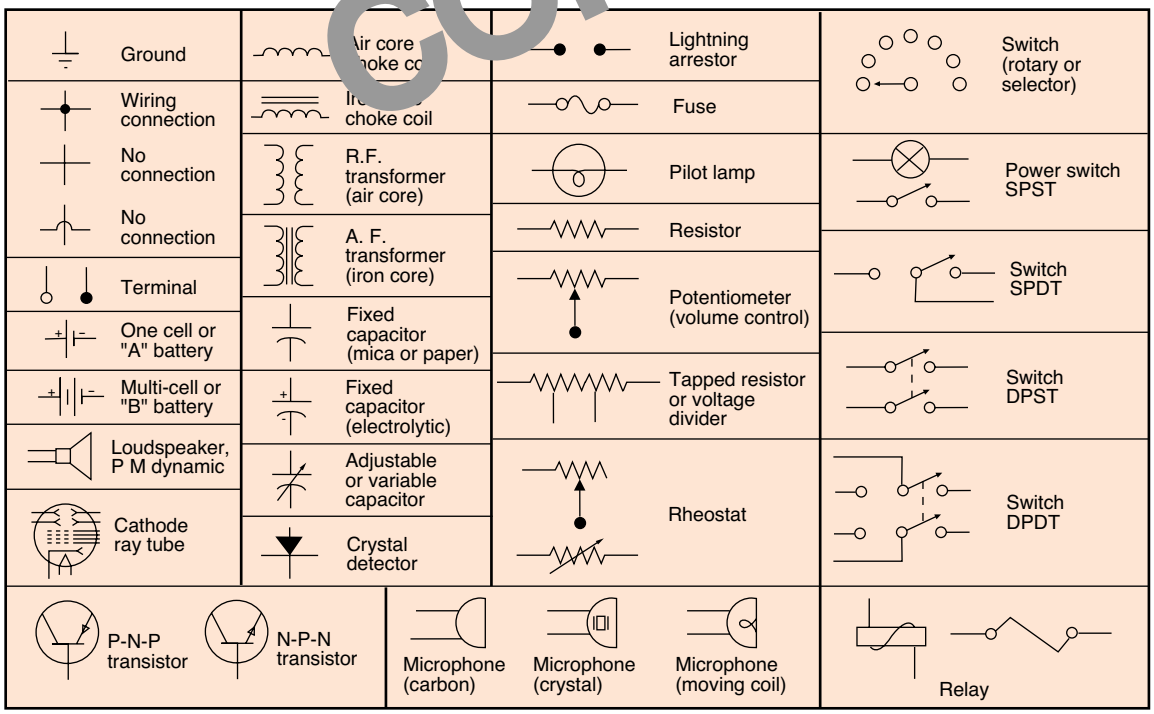


Fig. 5-13. Electronic schematic symbols



013), located on rungs 001, 002, and rung 005, are shown normally closed.

5.38 Figure 5-12 shows an input board with numbers from 001 to 008 and an output board with numbers from 011 to 018. Information in Fig. 5-12 acts as a reference to provide an explanation of each device represented by a numbered contact in Fig. 5-11. One of the advantages of using a PLC for control is that all of the information relating to the ladder diagram can be stored in the memory.

5.39 The instructions referring to inputs, outputs, and timers shown in the drawings are just a few of the instructions available for use in programming. As with numbering systems, instructions for PLC control vary from manufacturer to manufacturer.

5.40 Computers are being used more and more to provide automatic control of industrial processes. One use is in computer-integrated manufacturing (CIM), in which the computer acts as the main controller for PLCs, microprocessors, recorders, and other control instruments. The symbols used for computer-controlled devices follow the guidelines for PLCs.

Electronic Symbols

5.41 Figure 5-13 shows many of the more common electronic symbols. Some of them are identical to those you have studied for electrical circuits—for example, transformers and switches. Electronic symbols are also an attempt to show graphically what the device does or how it is put together.

5.42 You may notice a considerable lack of consistency in electronic symbols. Figure 5-14 shows examples of different ways electronic devices may be shown on drawings. Until standard symbols are in use throughout industry, you may have to rely on a legend defining the symbols for each drawing.

Fig. 5-14. Comparison of electronic symbols

Usual electronic circuit symbols		Industrial electronic symbols
	Resistor	R or
	Potentiometer	R or
	Capacitor	
L	Inductor	x or x
	Battery	+ −
	Fuse	
	Relay coil	
	Relay contacts normally open (N.O.)	
	Relay contacts normally closed (N.C.)	

5-9. The elementary wiring diagram is also referred to as the _____.	5-9. SCHEMATIC Ref: 5.25
5-10. The control circuit for a magnetic motor starter is a(n) _____ circuit.	5-10. SERIES Ref: 5.25
5-11. Line power is available to a typical pump system when the circuit beaker is .	5-11. ENERGIZED Ref: 5.28
5-12. If a number in the right-hand margin of a schematic is underlined, the referenced contacts are _____.	5-12. NORMALLY CLOSED Ref: 5.29
5-13. The numbers on each side of each device are _____ numbers.	5-13. WIRE Ref: 5.30
5-14. The line in the schematic that provides information about starting and stopping the motor is referred to as the _____.	5-14. RUN CIRCUIT Ref: 5.31
5-15. A PLC control diagram is referred to as a(n) _____.	5-15. LADDER DIAGRAM Ref: 5.35
5-16. PLC ladder diagrams show _____ on the left and _____ on the right.	5-16. INPUTS; OUTPUTS Ref: 5.37

Answer the following questions by marking an "X" in the box next to the best answer.

5-1. Which of the following provides a sentence-by-sentence description of the controls in a process?

- ☐ a. Flowchart
- ☐ b. Ladder diagram
- ☐ c. Schematic
- ☐ d. Sequence of operation

5-2. Which of the following uses a diamond with a Y and N to indicate decisions?

- ☐ a. Flowchart
- ☐ b. SAMA logic
- ☐ c. Schematic
- ☐ d. Sequence of operation

5-3. A SAMA flowchart

- ☐ a. includes only electronic symbols
- ☐ b. indicates the flow of liquids only
- ☐ c. is used for logic diagramming
- ☐ d. is used with digital devices only

5-4. If a switch is shown with the movable arm above the contact, it is

- ☐ a. N.C. and opens on being de-energized
- ☐ b. N.C. and opens on being energized
- ☐ c. N.O. and closes on being de-energized
- ☐ d. N.O. and closes on being energized

5-5. In relays, a counter force to the magnetic pull is provided by a(n)

- ☐ a. bellows
- ☐ b. diaphragm
- ☐ c. opposing magnet
- ☐ d. spring

5-6. A motor starter may be de-energized manually by the STOP button or automatically by the

- ☐ a. interlock pole
- ☐ b. OL heater elements
- ☐ c. START button
- ☐ d. terminal leads

5-7. In electrical schematics, numbers

- ☐ a. next to devices are schematic line references
- ☐ b. on the far left are wire numbers
- ☐ c. on the far right show where relay contacts appear
- ☐ d. that are underlined refer to N.O. contacts

5-8. Which of the following best describes where to find wire numbers on an electrical schematic?

- ☐ a. On each side of each device
- ☐ b. On the left of each device
- ☐ c. On the right of each device
- ☐ d. On the run circuit

5-9. In PLC ladder diagrams, inputs are shown

- ☐ a. on the left, as parentheses
- ☐ b. on the left, as reversed brackets
- ☐ c. on the right, as parentheses
- ☐ d. on the right, as reversed brackets

5-10. Instructions for PLC control

- ☐ a. are read from left to right
- ☐ b. are standardized by ISA
- ☐ c. are standardized by SAMA
- ☐ d. vary from manufacturer to manufacturer

SUMMARY

The sequence of operation describes in sentence form how the controls in a process work. The flowchart presents the circuit logic of the sequence of operation in graphical form.

Three common kinds of electrical control devices are switches, relays, and motor starters. If the movable part of a switch is shown above the contact, the switch is N.C.—otherwise it is N.O. The control relay is an electromagnetic device. The motor starter is a special kind of relay.

The elementary wiring diagram, also referred to as a schematic, shows the relationships between electrical devices. All devices are shown in a de-energized state. Line numbers are shown on the left and line references for relay contacts are shown on the right. An underlined contact number is N.C.

SAMA symbols are used for logic diagramming involving PLCs and other computers. PLCs provide automatic control of the system. The computer is becoming the main controller for process control systems. The PLC control diagram is referred to as a ladder diagram. Each device is assigned a number that represents a specific input or output. Inputs are shown on the left and outputs on the right. Some electronic devices may be indicated in more than one way.

Answers to Self-Check Quiz

5-1. d. Sequence of operation. Ref: 5.01

5-2. a. Flowchart. Ref: 5.04

5-3. c. Is used for logic diagramming. Ref: 5.09

5-4. b. N.C. and opens on being energized. Ref: 5.13, 5.14

5-5. d. Spring. Ref: 5.19

5-6. b. OL heater elements. Ref: 5.23

5-7. c. On the far right show where relay contacts appear. Ref: 5.29

5-8. a. On each side of each device. Ref: 5.30

5-9. b. On the left, as reversed brackets. Ref: 5.37

5-10. d. Vary from manufacturer to manufacturer. Ref: 5.39