SEGMENT 1

ELECTRICAL CONTROL SYSTEM BASICS

OBJECTIVE 1 DESCRIBE THE FUNCTION OF THREE TYPES OF ELECTRICAL CONTROL SYSTEMS AND GIVE AN APPLICATION OF EACH

A control system performs the same functions for a machine that the brain and the nervous system perform for the human body. The control system of a machine might perform functions such as start and stop operations, extend and retract actuators, sense and guide actuator motion, as well as turn motors on and off or even reverse them.

Electrical control systems are classified as:

- **Manual** - Manual control systems require an operator to command each operation (e.g. pushing a button, activating a switch, or changing the position of a lever). An example of a manual control system is a human being controlling a backhoe. The operator must continually make decisions and perform operations manually to accomplish any task.
- **Semiautomatic** - Semiautomatic control systems require a manual input to begin the operation. However, the machine operation requires no further manual input except possibly to stop the operation. Many motor control circuits fall into this category. An example of a semiautomatic control system is a washing machine, which, once started, automatically cycles through the wash, rinse, and spin operations.

- **Automatic** - Automatic control systems require no manual input to control the operation of a machine. Automatic control systems are operated by automatic input devices, often called pilot devices. Pilot devices react to conditions in a system. An example of an automatic control system is a heating/cooling system. A thermostat, like the one shown in figure 1, serves as the pilot device, which automatically monitors the room temperature and performs operations based on the information it gathers.

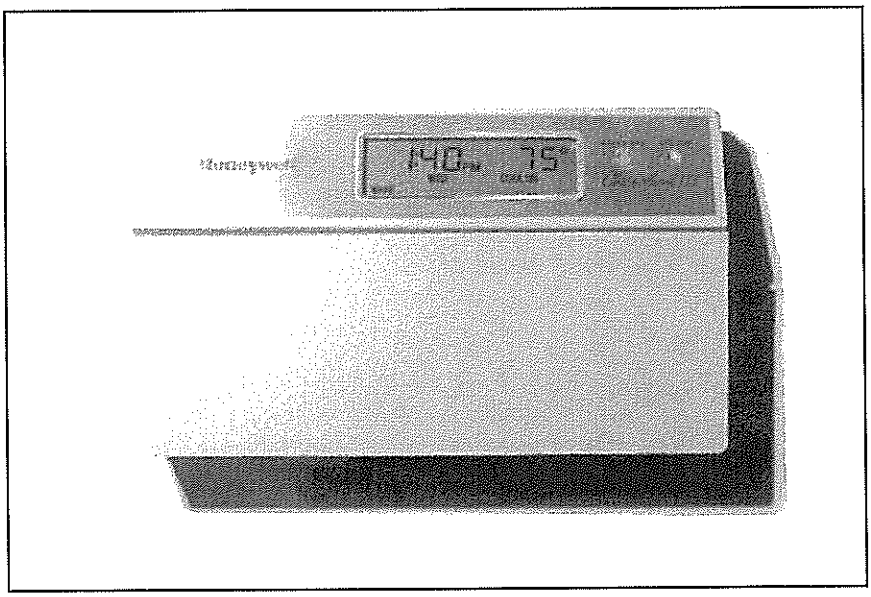


Figure 1. Electronic Thermostat

OBJECTIVE 2 DESCRIBE THE THREE STEPS OF A CONTROL PROCESS

The series of moves a machine has to make to perform a task is called a sequence of operation. Each move in the series is called a step. It does not matter whether a machine is manually, semiautomatically, or automatically controlled, it still must perform the same sequence of operation even though each type of control system performs this sequence in a different way.

For each step in a sequence, a control process consisting of three steps takes place. These three steps, shown in figure 2, are:

- **Input** - An input must be received to indicate that it is time to perform a step. The input for a manual system is usually a visual observation that the previous step has been completed. For semiautomatic and automatic systems, the input might be a sensor which senses that a step has been completed.
- **Logic** - Once the input is received, a decision must be made as to what action to take. This decision is made by the brain. In a manual system, the brain belongs to the human operator of the machine. The brain of a semiautomatic or automatic system consists of circuitry and components. It could be something as simple as an electromechanical relay or something as complex as a programmable logic controller (PLC).
- **Output** - Once the brain has decided what to do, the action must be carried out. If it is a manual system, the operator must perform another task (e.g. push a button, pull a lever, activate a switch). On the other systems, the brain must cause the action to be performed, for example, by changing the state of a set of contacts.

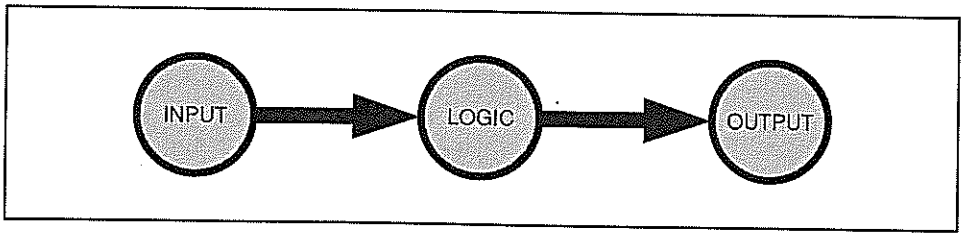


Figure 2. Control Process of a Step in a Sequence

As an example of a basic control process, study the sequence of operation in figure 3, which describes what an air conditioner must do to keep the room or building cool. For each step, there is a complete control process including input, logic, and output that takes place.

When there is a sequence of steps, the completion of one step by the output device is sensed by the input device for the next step.

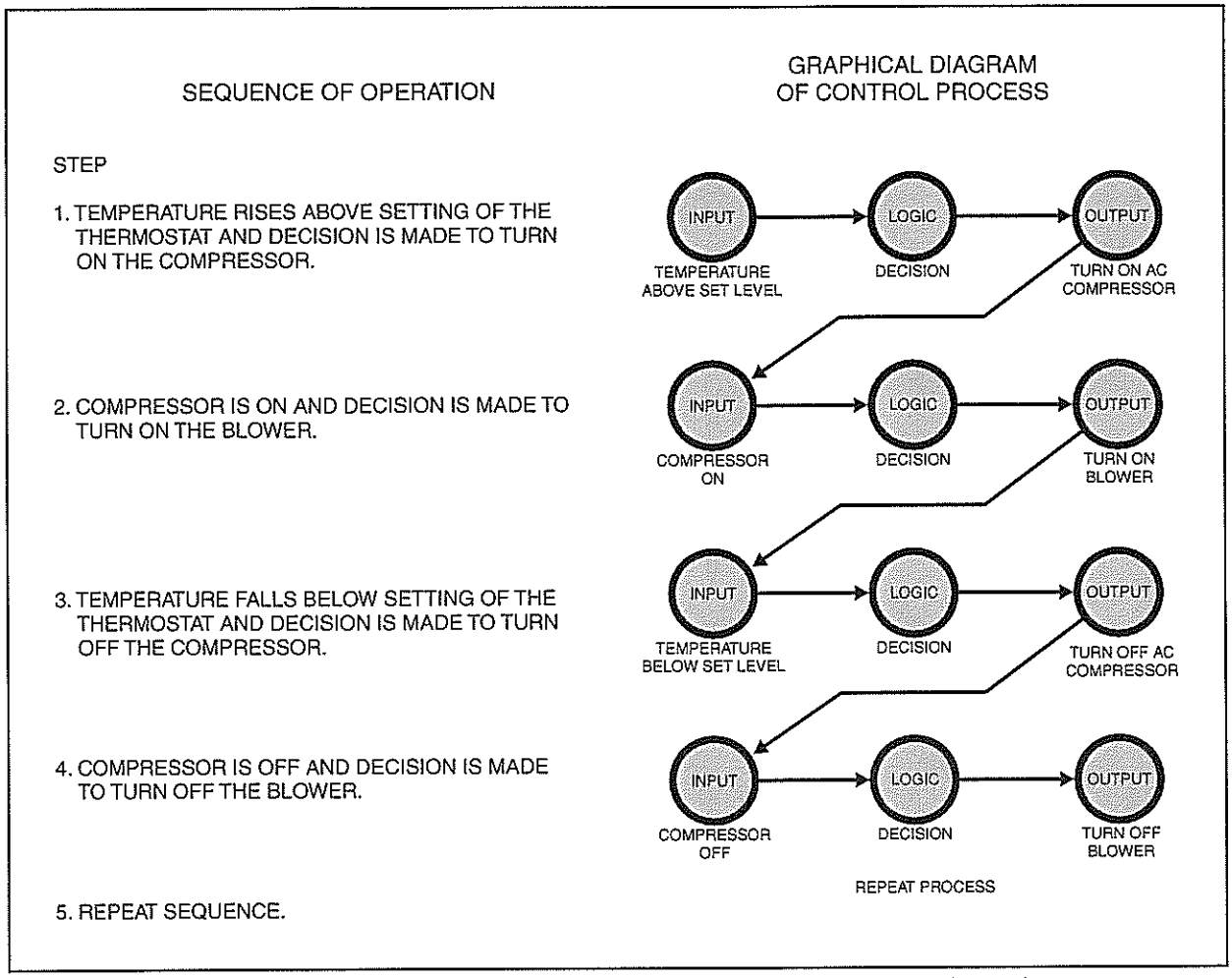


Figure 3. Graphical Diagram of a Control Process Compared to a Sequence of Operations

The sequence of operations described in figure 3 can be created by connecting electrical input devices, logic devices and output devices in certain combinations called logic. In this LAP, you will learn about the basic concepts of logic. Before you do this, you will learn about the basic input and output devices used in these circuits.

OBJECTIVE 3 DESCRIBE THE FUNCTION OF AN INDICATOR LAMP AND GIVE AN APPLICATION

The most basic output device is an indicator lamp. Although it is available in many sizes, shapes and types, the basic operation of all indicator lamps is the same: if it is receiving current, the lamp is on.

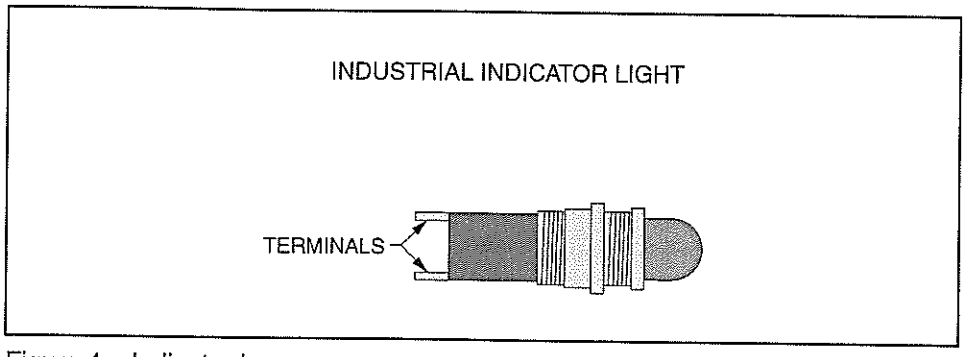


Figure 4. Indicator Lamp

The ladder diagram schematic symbol for an indicator lamp is shown in figure 5. The letter in the circle indicates the color of the lens.

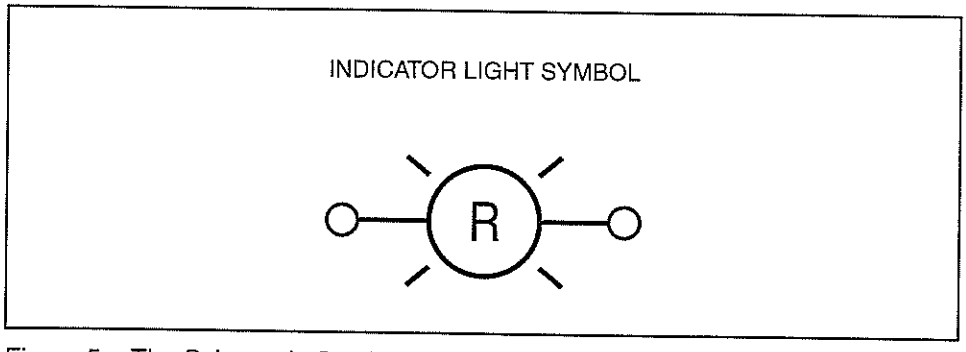


Figure 5. The Schematic Symbol for an Indicator Lamp

Indicator lamps are used in electrical control circuits to tell the operator at a glance the operating status of the machine. Indicator lamps have many industrial uses, including indicating that power to a machine is on, a cycle has begun or ended, a sensor has sensed an input, a dangerous condition exists, and so forth.

There are a variety of lens colors available for indicator lamps. Each color represents a different status, as the table in figure 6 shows.

COLOR	TYPICAL FUNCTION	EXAMPLE
Red	Danger, Abnormal Condition, Fault Condition	Voltage applied; cycle in automatic; faults in air, water, lubricating or filtering systems; ground detector circuits.
Amber (Yellow)	Attention	Motors running; machine in cycle; unit or head in forward position.
Green	Safe Condition (Security)	End of cycle; unit or head returned; motors stopped; motion stopped; contactors open.
White or Clear	Normal Condition	Normal pressure of air, water, lubrication

Figure 6. Indicator Lamp Lens Color Codes

Indicator lamps are available for both AC and DC control circuit voltages. Common types include 24 VDC and 120 VAC. The voltage rating of the indicator lamp is most often located on the base of the lamp assembly.

CAUTION

Be sure to check the voltage rating of an indicator lamp before you use it. Operating an indicator lamp on the wrong voltage will in most cases damage or destroy the lamp. For example, a 24 VDC lamp is not compatible with a 120 VAC circuit.

OBJECTIVE 4 DESCRIBE THE OPERATION OF A PUSHBUTTON SWITCH AND GIVE ITS SCHEMATIC SYMBOL

The most basic type of input device used in electrical circuits is a manual switch. There are several types of manual switches available. Two common switches used in electrical circuits, especially control circuits, are:

- Pushbutton Switches
- Selector Switches

Most switches, like the two listed above, are named for their operator. The operator is the part of the switch that causes the switch to activate by closing or opening the contacts. The contacts are the part of a switch that open or close the circuit path.

The function of an input device such as a switch is to open or close the circuit path, as shown in figure 7. When the circuit path is closed, electricity flows through the path to turn on the output device. When this path is opened, flow stops and the output turns off.

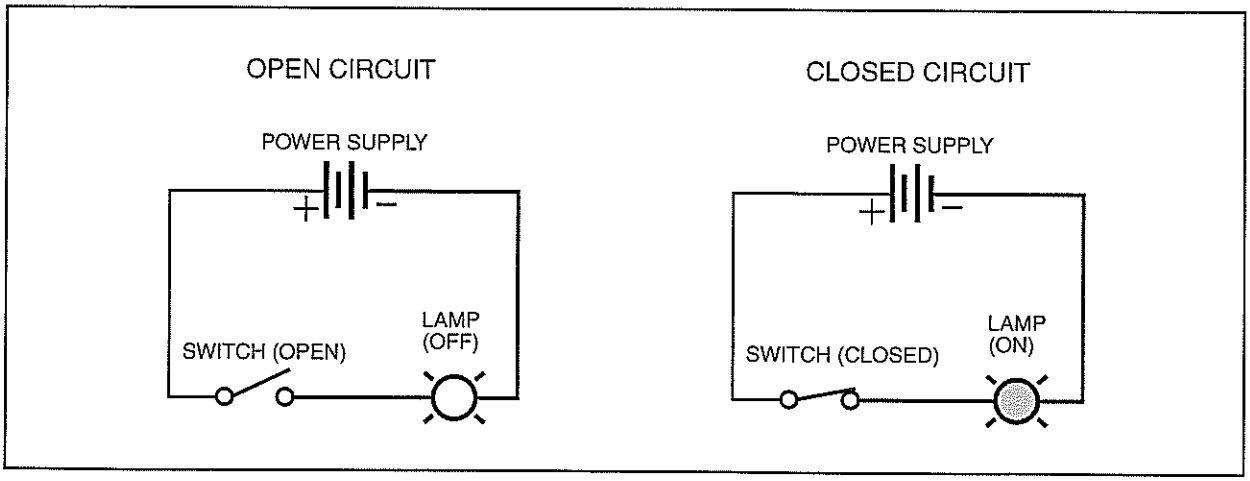


Figure 7. The Function of a Switch in a Circuit

A pushbutton switch is an input device which consists of a pushbutton-type operator and one or more sets of contacts, as shown in figure 8. Pushing the operator causes the contacts to open or close, depending on their normal state.

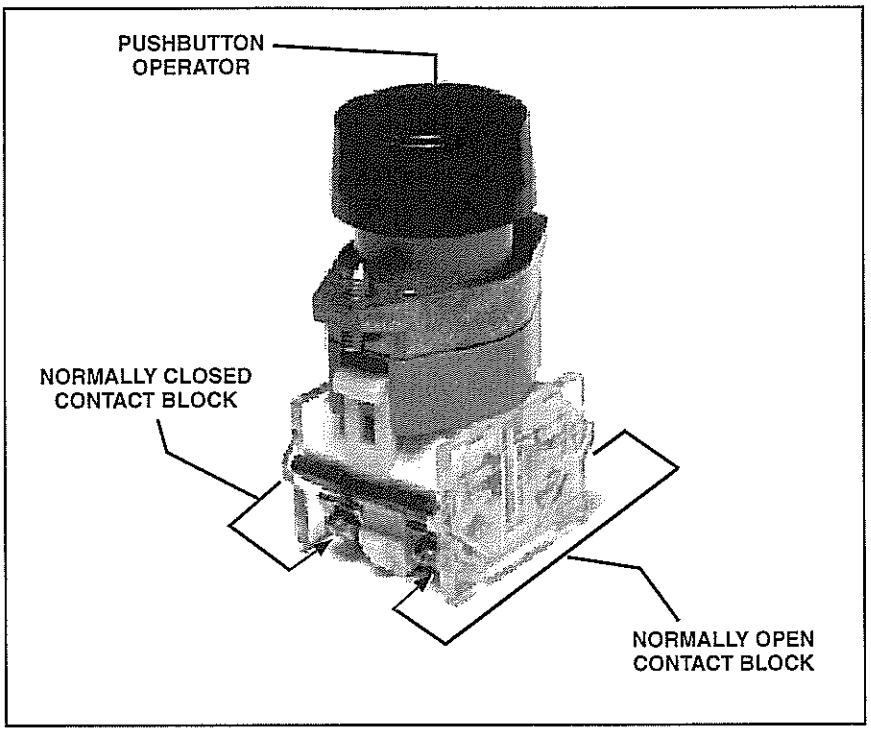


Figure 8. A Typical Pushbutton Switch

Many industrial pushbutton switches are designed to use interchangeable contact blocks. Pushbutton switches can have normally open (N.O.) contacts and/or normally closed (N.C.) contacts.

Figure 9 shows the schematic symbols for the normally open and normally closed contacts of a pushbutton.

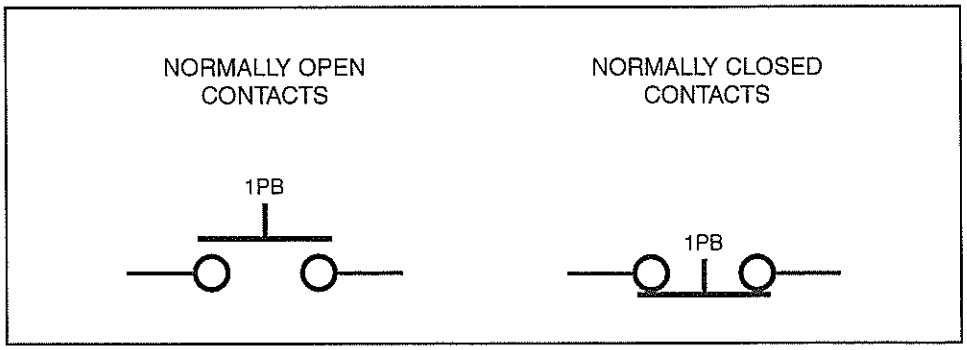


Figure 9. Normally Open and Normally Closed Contacts of a Pushbutton Switch

When a circuit is connected to the N.O. contacts, the normal (deenergized) state of the switch produces an open circuit. When the switch operator is activated (energized), the switch produces a closed circuit, as shown in figure 10.

NOTE

A switch which uses normally open (N.O.) contacts must be activated to allow current to flow. Therefore, the switch can be described as a normally open switch.

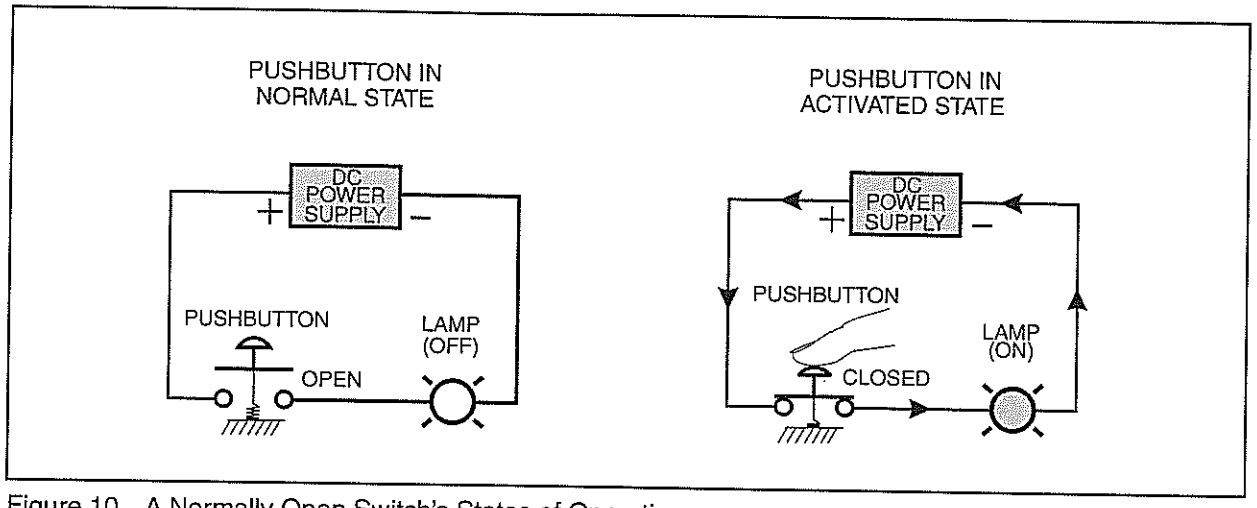


Figure 10. A Normally Open Switch's States of Operation

NOTE

Current flow shown in figures 10 and 11 is shown as *conventional flow* (positive to negative) instead of *electron flow* (negative to positive).

The opposite would be true for a switch with normally closed (N.C.) contacts, as shown in figure 11. The deenergized state produces a closed circuit, while the energized state produces an open circuit.

NOTE

A switch which uses normally closed (N.C.) contacts must be activated to stop the current flow. Therefore, the switch can be described as a normally closed switch.

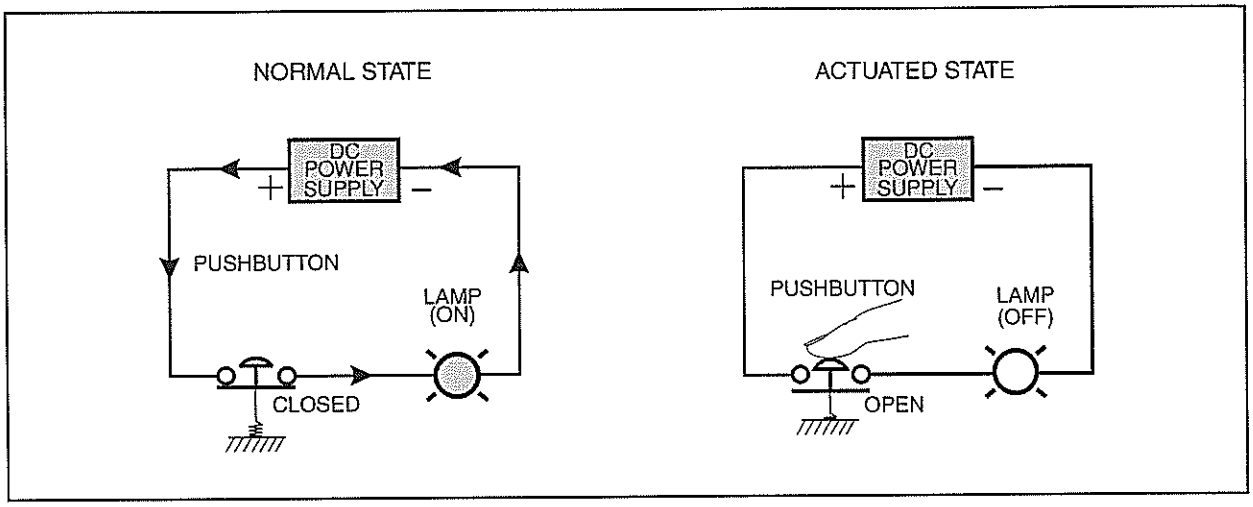


Figure 11. A Normally Closed Switch's States of Operation

NOTE

A common application for a normally closed pushbutton switch is an emergency stop pushbutton on a machine. This can be used to immediately stop the operation of a machine should a dangerous situation arise.

Switches can be either momentary or maintained. A ***momentary switch*** contains a spring that causes the operator to return to its original position and the contacts to return to their normal states once the operator is released by the user. One application of a momentary pushbutton switch is the horn on an automobile.

A ***maintained switch*** is a switch which holds its position once activated. The contacts will remain in their energized states until the operator is pressed again. One application of a maintained pushbutton switch is the Power On/Off button on a computer.

SKILL 1 CONNECT AND OPERATE A BASIC ELECTRICAL CONTROL CIRCUIT THAT USES A PUSHBUTTON SWITCH

Procedure Overview

In this procedure, you will connect a simple circuit which includes a pushbutton switch. You will then operate the circuit using the pushbutton switch to change conditions in the circuit.

☐ 1. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the station panels are arranged on the trainer, as shown in figure 12.

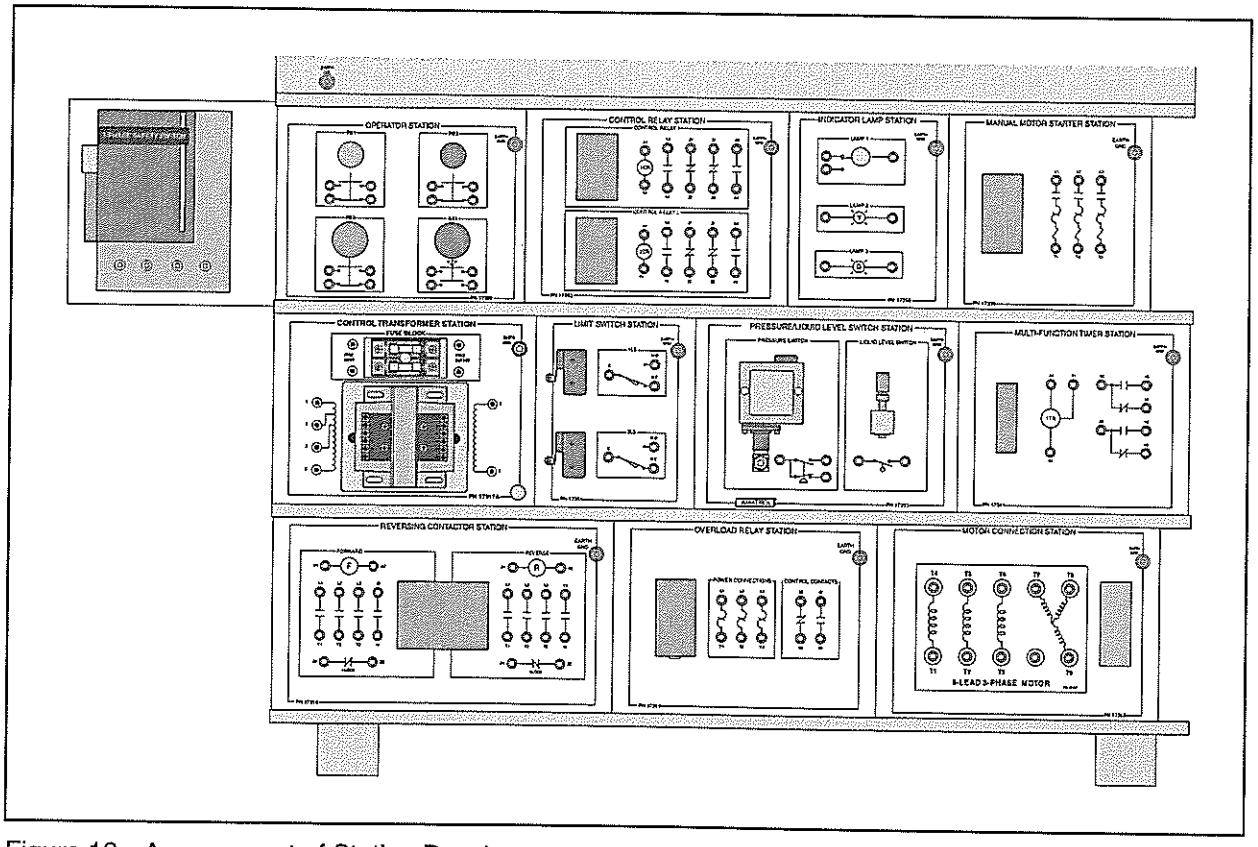


Figure 12. Arrangement of Station Panels

B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.

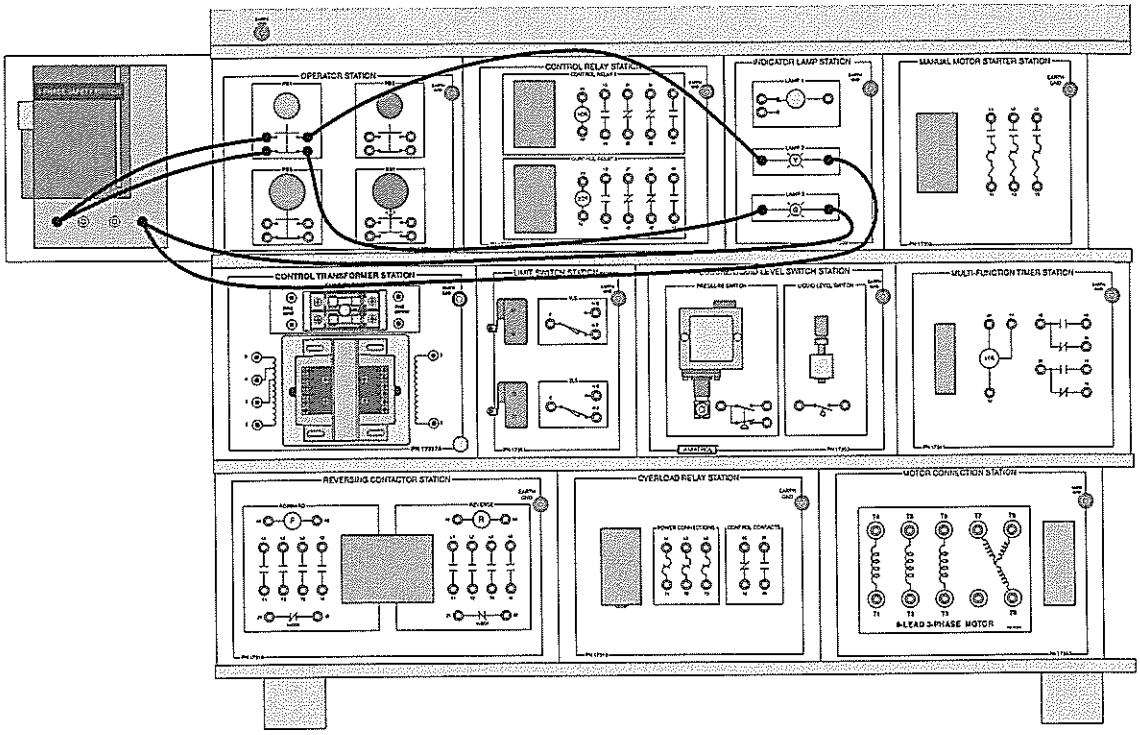
C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Use the green wires to ground all station panels to the equipment ground.

❑ 2. Connect two of the indicator lights to single-phase 120VAC through the contacts of a pushbutton switch, as shown in figure 13.



SCHEMATIC DIAGRAM

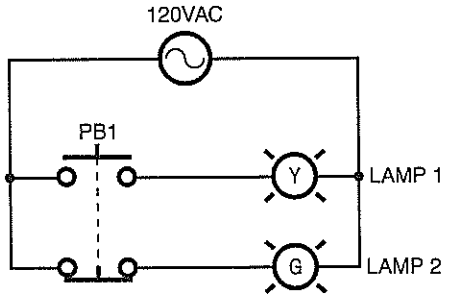


Figure 13. Pictorial and Schematic Diagrams to Connect Yellow and Green Indicator Lamps to 120 VAC Through the Contacts of a Pushbutton Switch (PB1)

NOTE

120VAC is available from the power supply between any of the three phases (L1,L2,L3) and neutral. In this skill, you are using L1 and neutral.

❑ 3. Perform the following substeps to test the operation of the circuit.

A. Make sure the 85-MT5 power cord is plugged into a 3-phase wall outlet.

B. Remove the lockout/tagout.

C. Turn on the safety switch to supply power to the circuit.

When you turn the safety switch on, you should notice that the green indicator lamp is on, while the yellow lamp is off. Since PB1 is not activated or energized (not being pressed), the N.O. and N.C. contacts are in their normal states. That is to say, the N.O. contacts are open, while the N.C. contacts are closed.

Since the N.O. contacts are open, the circuit path for the yellow indicator lamp is not complete (the circuit is open). Therefore, no current can flow through the yellow indicator lamp and it remains off.

Since the N.C. contacts of the switch are closed, the circuit path for the green indicator lamp is complete (the circuit is closed). This allows current to flow through the N.C. contacts to cause the green indicator lamp to illuminate.

D. Press and hold **PB1** while observing the yellow and green indicator lamps.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

The yellow indicator should now be on and the green indicator should be off. The pushbutton switch has now been activated or energized, and the contacts have now changed states. The N.O. contacts are now closed and the N.C. contacts are now open. Therefore, the yellow indicator lamp circuit is now complete (closed), and the green indicator lamp circuit is no longer complete (open).

E. Release **PB1** and observe the yellow and green indicators again.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

Once again, the yellow indicator should be off and the green indicator should be on, which are their original conditions. The lamps have returned to their original conditions because the contacts of the switch returned to their normal states when the operator of the momentary switch was released.

❑ 4. Perform the following substeps to shut down the 85-MT5 system.

A. Turn off the safety switch.

B. Perform a lockout/tagout.

C. Disconnect all circuit leads except for green ground lead connections.

D. Remove the lockout/tagout equipment. If this is your last activity for the day, return the equipment to your instructor. If not, continue.

OBJECTIVE 5 DESCRIBE THE OPERATION OF A SELECTOR SWITCH AND GIVE ITS SCHEMATIC SYMBOL

A selector switch is an input device which consists of a rotary-type operator and one or more sets of contacts, as shown in figure 14. Rotating the operator into a position will cause the contacts to be opened or closed.

Again, many industrial selector switches are designed to accept interchangeable contact blocks.

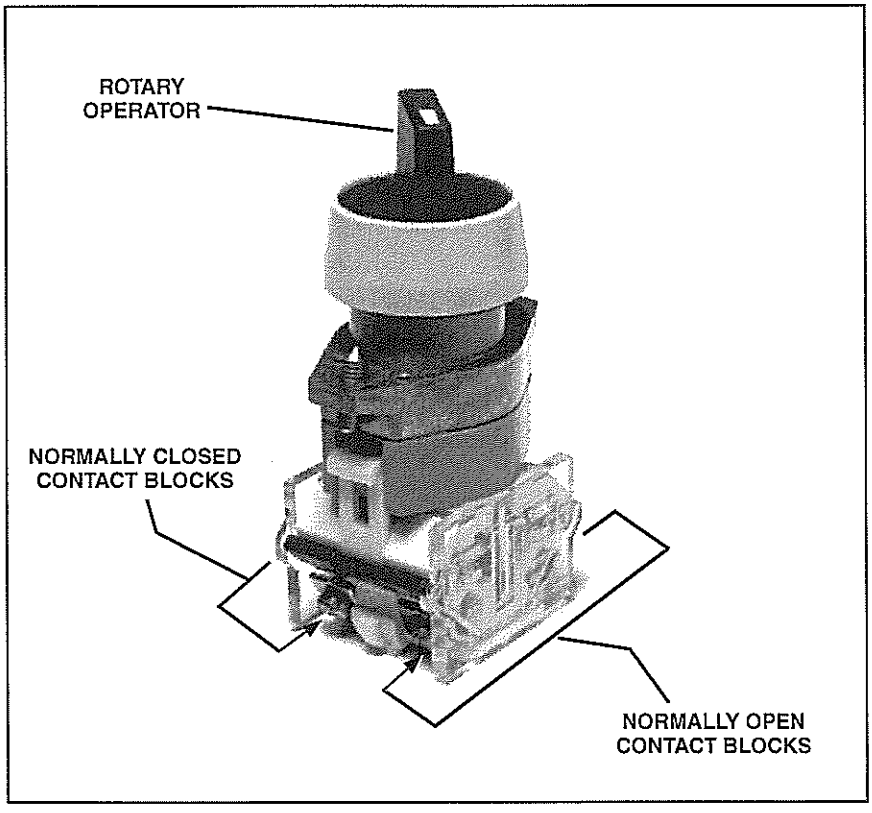


Figure 14. A Typical Selector Switch

NOTE

The selector switch on the operator station panel of the 85-MT5 has two N.O. contact blocks, one for the left-hand position and one for the right-hand position, as shown in figure 15. The center position does not operate any contacts. If the selector switch is set to the center position, both sets of contacts are in their normal state, open.

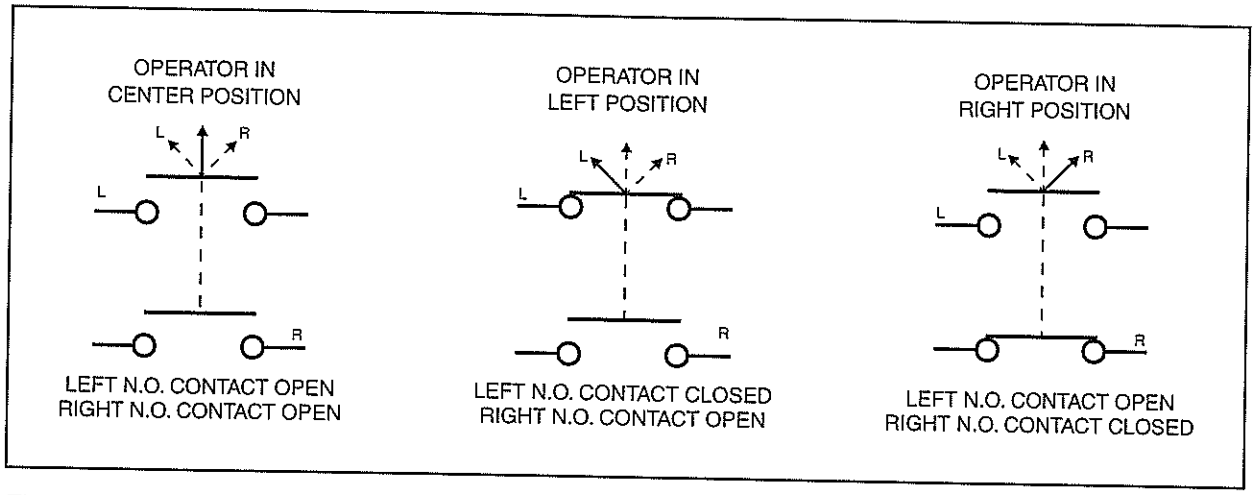


Figure 15. Schematic Diagram of the Three-Position Selector Switch on the 85-MT5 Operator's Station

Selector switches have a number of different operator types available including knob, lever, and keylock, which are all shown in figure 16. These operators are available with two, three, or four positions.

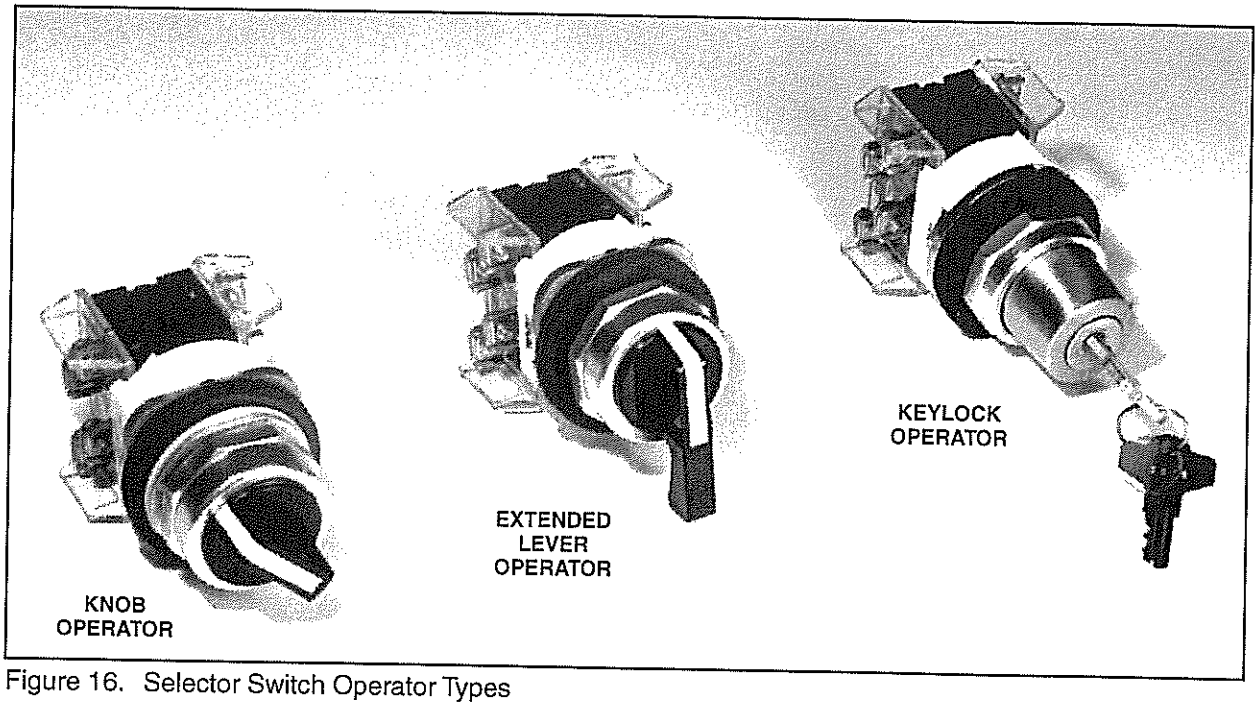


Figure 16. Selector Switch Operator Types

Selector switches are often used to change the mode of operation of a machine. Typical applications include On/Off, Manual/Automatic, Run/Jog and Forward/Reverse. Each position of the selector switch will cause the machine to change to a different mode of operation. In most cases, the selector switch will be mounted with a legend to identify the function of each position, as shown in figure 17.

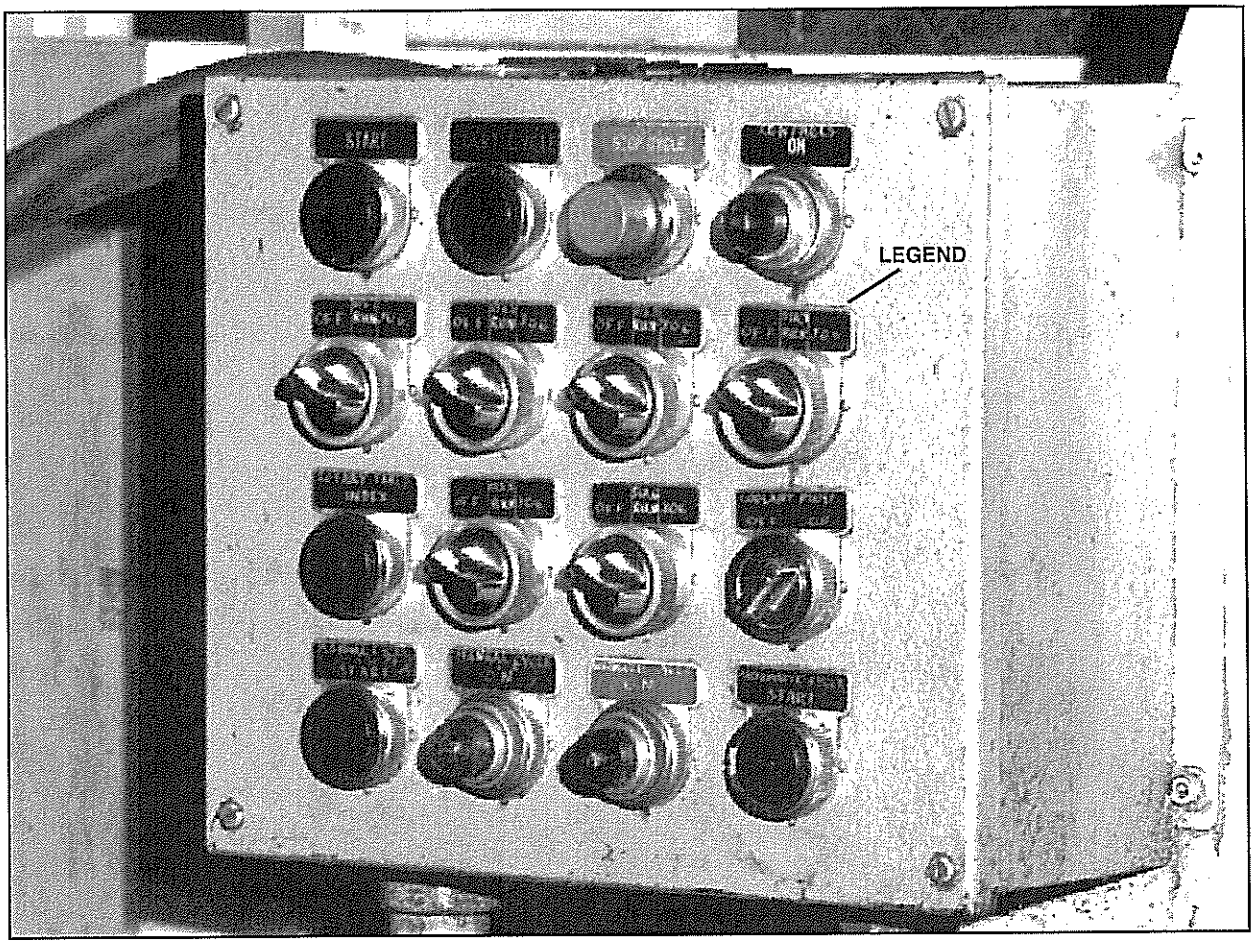


Figure 17. Selector Switches with Legends Indicating the Function of Each Position

Selector switches can be momentary or maintained, like pushbutton switches. One example of a momentary selector switch is an ignition switch on an automobile. An example of a maintained selector switch is the Hot/Warm/Cold temperature selector on a washing machine.

SKILL 2 CONNECT AND OPERATE A BASIC ELECTRIC CONTROL CIRCUIT USING A SELECTOR SWITCH

Procedure Overview

In this procedure, you will connect a simple circuit that includes a selector switch. You will then operate the circuit using the selector switch to change conditions in the circuit.

☐ 1. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the stations are still arranged on the trainer, as shown in figure 12.

B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.

C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Make sure the green ground wires are still connected to all station panels and equipment ground.

❑ 2. Connect two indicator lamps to 120 VAC through the contacts of a three-position selector switch, as shown in figure 18.

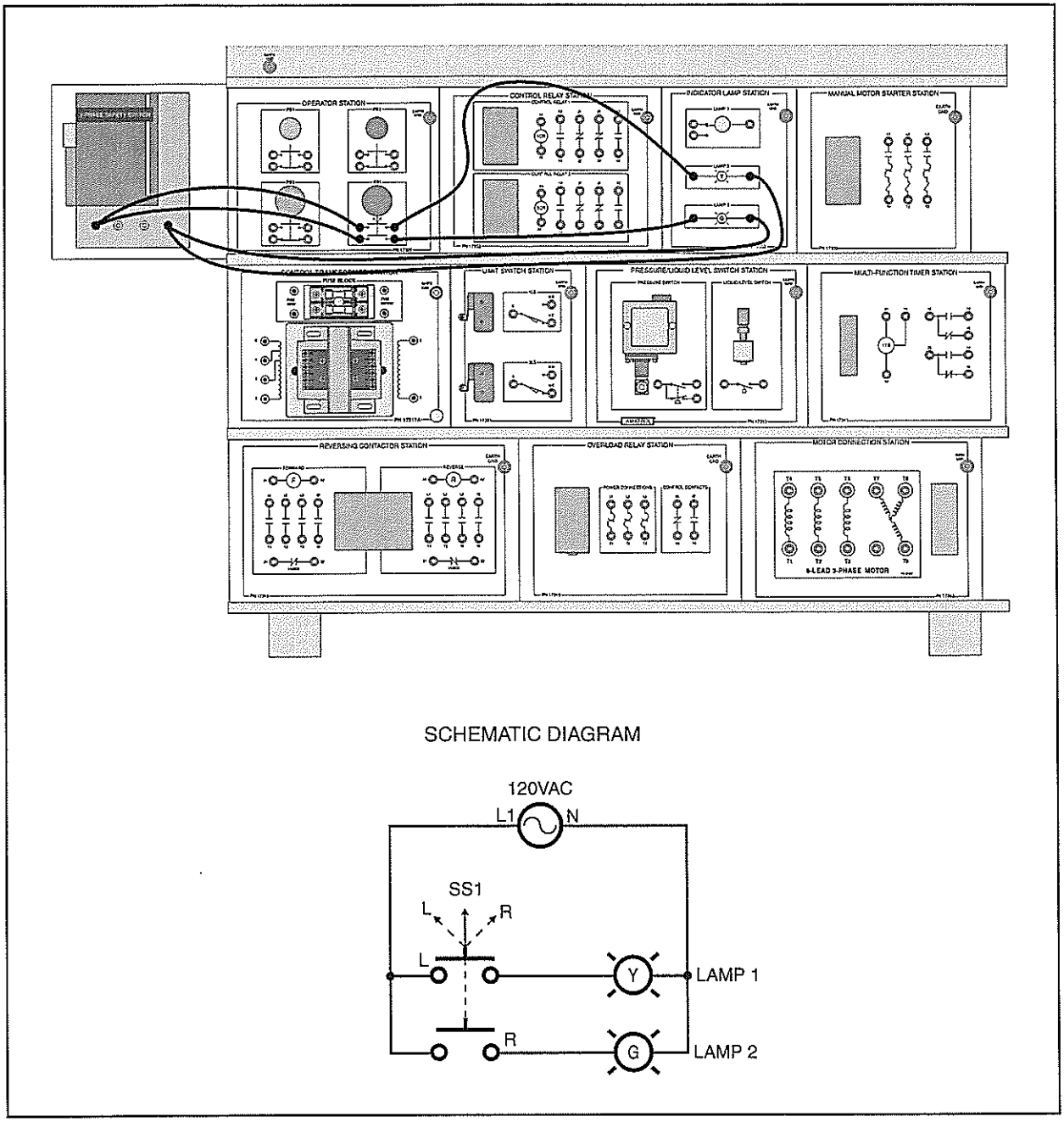


Figure 18. Pictorial and Schematic Diagrams of Indicator Lights Connected to 120 VAC through the Contacts of the Selector Switch SS1

☐ 3. Perform the following substeps to test the operation of the circuit.

A. Make sure that the selector switch SS1 is in the center position.

When you turn on the safety switch, neither lamp should be on. This is because there are no contacts in the center position. The center position basically serves as an off position.

B. Make sure the 85-MT5 power cord is plugged into a 3-phase wall outlet.

C. Remove the lockout/tagout.

D. Turn on the safety switch to supply power to the circuit.

E. Rotate **SS1** to the left-hand position, release the operator, and observe the indicator lights.

Green Indicator Status _____(On/Off)

Yellow Indicator Status _____(On/Off)

The yellow indicator lamp should come on because the N.O. contacts for the left-hand position are now being held closed. The green indicator lamp should still be off.

Also, you should notice that the selector switch stays in the left-hand position. This indicates that the selector switch is a maintained switch.

F. Now rotate **SS1** to the right-hand position and observe the indicator lamps.

Green Indicator Status _____(On/Off)

Yellow Indicator Status _____(On/Off)

The green indicator should now be on and the yellow indicator should be off. The N.O. contacts for the right-hand position are now being held closed.

G. Rotate **SS1** back to the center position and observe the indicator lights.

Green Indicator Status _____(On/Off)

Yellow Indicator Status _____(On/Off)

Once again, neither lamp should be on.

☐ 4. Perform the following substeps to shut down the system.

A. Turn off the safety switch.

B. Perform a lockout/tagout on the safety switch.

C. Remove all the lead wires.

D. Remove the lockout/tagout equipment. If this is your last activity for the day, return the equipment to your instructor. If not, continue.

SEGMENT 1 SELF REVIEW

1. The three types of electrical control systems are manual, semiautomatic, and _____.
2. The three steps of a control process are _____, logic, and output.
3. If an indicator lamp is receiving current, the lamp is ____.
4. A switch which uses _____ contacts must be activated to allow current to flow.
5. A switch which uses _____ contacts must be activated to stop the current flow.
6. A switch which returns to its normal position once it is released is called a _____ switch.
7. A switch which remains in its energized position once it is activated is called a _____ switch.
8. A _____ switch is an input device which consists of a rotary-type operator and one or more sets of contacts.

SEGMENT 2

LADDER DIAGRAM BASICS

OBJECTIVE 6 — DESCRIBE THE FUNCTION OF A LADDER DIAGRAM

Ladder, or line, diagrams are used to represent electrical control circuits in a way that makes them easier to read. The ladder diagram method "unravels" the wires of a circuit and allows it to be read in an orderly fashion. This type of circuit diagram arranges the conductors in straight horizontal lines, like rungs on a ladder, with inputs and outputs located on each of these rungs. The power source is represented with vertical lines, like the "side rails" of the ladder. A basic ladder diagram is shown in figure 19.

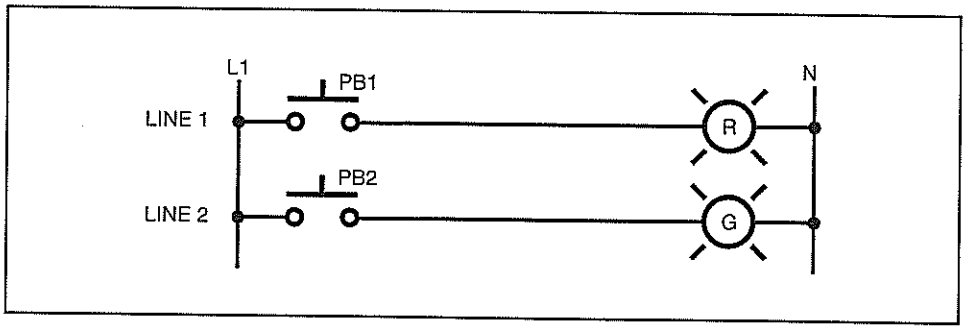


Figure 19. Ladder Diagram Schematic

OBJECTIVE 7 DESCRIBE THE FUNCTION OF FOUR COMPONENTS OF A LADDER DIAGRAM

The four components of a ladder diagram are:

- Power Supply
- Conductors
- Input Devices
- Output Devices

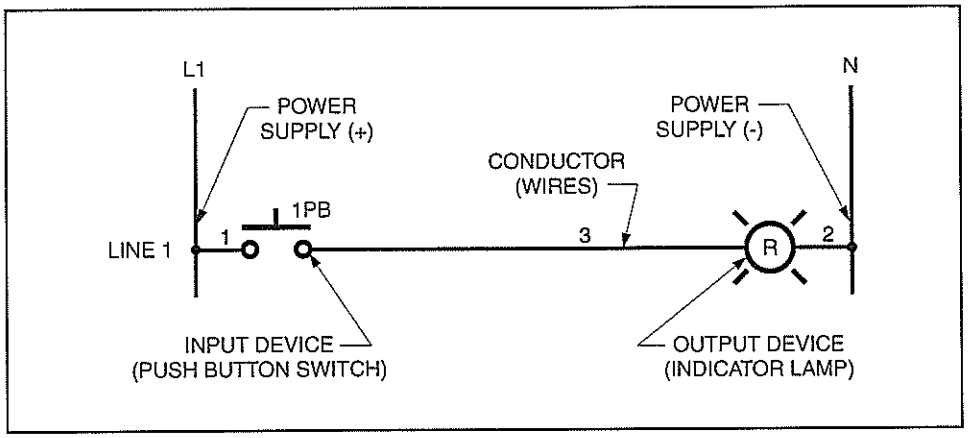


Figure 20. The Basic Components of a Ladder Diagram

Power Supply

All electrical circuits must have a power supply to allow the control logic circuit to energize the output devices. The power supply in a ladder diagram is represented by the two vertical lines, or ladder side rails. The vertical line on the left is the hot or positive side of the power supply and is sometimes labeled L1. The vertical line on the right is the ground or return side of the power supply and is often labeled N or L2. On an AC supply, the supply rails can either come from a control transformer or directly from the main power lines. If the supply is from a control transformer, the rails are often labeled X1 and X2.

Conductors

Conductors are the electrical wires that connect the control circuit. They form the lines of the ladder running between the power rails. The input and output device symbols are placed on these lines.

Input Devices

All input devices, such as switches, are used to perform the logic functions that control the outputs. Input devices are usually connected between the positive side of the power supply and the output devices. The various symbols for input devices, some of which are shown in figure 21, are usually located on the left side or towards the middle of the lines in a ladder diagram.

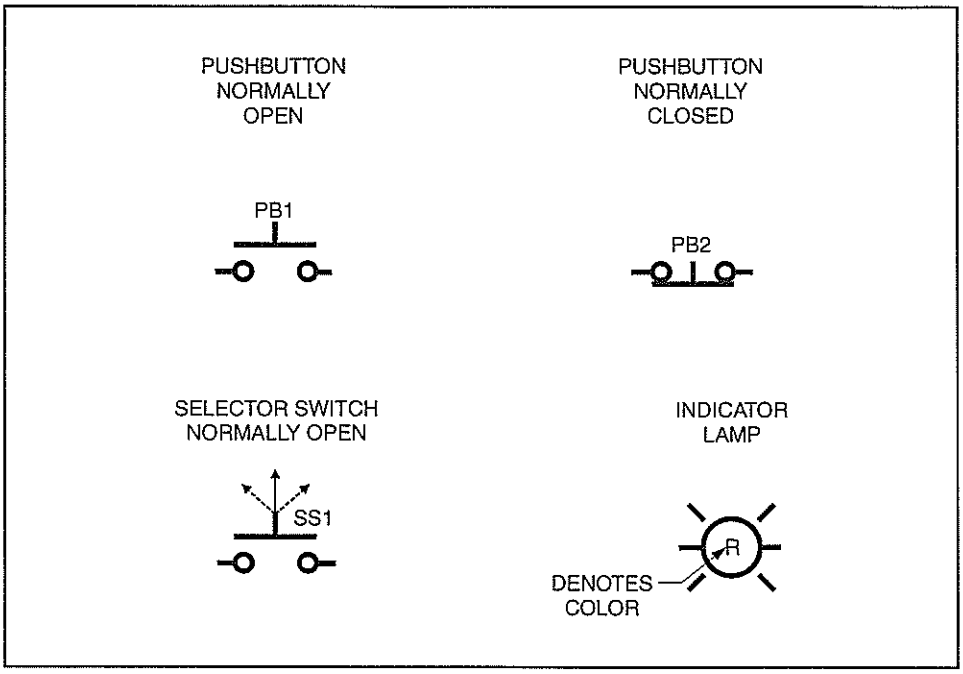


Figure 21. Ladder Diagram Symbols

Output Devices

Output devices are the components that perform the machine operation. Output devices are usually connected between the input devices and the return side of the power supply. The various symbols for output devices are always located on the right side of the lines of a ladder diagram.

OBJECTIVE 8 DESCRIBE SIX RULES OF DRAWING A LADDER DIAGRAM

There are six basic rules that determine how a ladder diagram is drawn:

- **All Components Labeled** - Each component in a ladder diagram should be labeled with its function (e.g. start) and an abbreviation identifying what it is (e.g. PB1).
- **All Conductors (wires) Numbered** - The wires connecting the components should be numbered left to right and top to bottom. Typically, wires connected to the left powerrail will be numbered 1 and all wires connected to the right powerrail will be numbered 2. This is due to the fact that all wires connected to a diagram's side rail are actually joined at a common connection, the power supply terminal. Also, conductors that are joined together directly within the diagram will have the same numbers.

NOTE

More complex ladder diagrams may not follow the convention that wires connected to the left powerrail are numbered 1 and wires connected to the right powerrail are numbered 2. However, in this series of LAPs, we will observe this convention for all ladder diagrams.

- **All Lines Numbered** - Any horizontal level where conductors in the circuit run is considered a line.

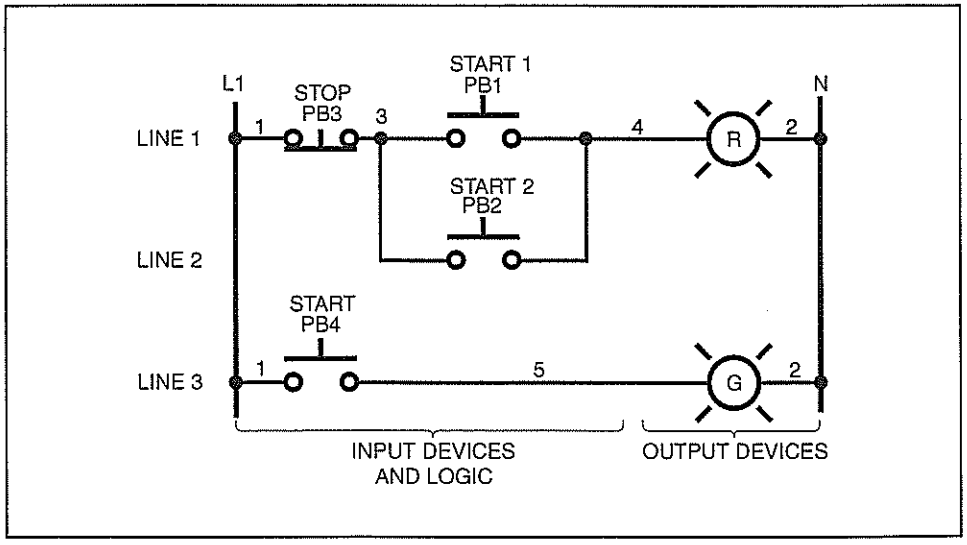


Figure 22. The Structure of a Ladder Diagram

- **Control Devices Only** - A ladder diagram shows only control devices such as switches, solenoids, indicator lamps, and relays. It does not show power devices such as valves, motors and cylinders. These are shown on a separate diagram, usually a power diagram.
- **Only One Load Per Line** - A load is an output device such as an indicator lamp or relay coil. Loads should never be wired in series on the same line. As you should recall, connecting loads in series causes a portion of the supply voltage to be "dropped" across each of the loads. All of the loads in a control circuit are designed to operate on the same voltage (e.g. 120 VAC). They will not operate or will operate erratically on less than the required voltage.

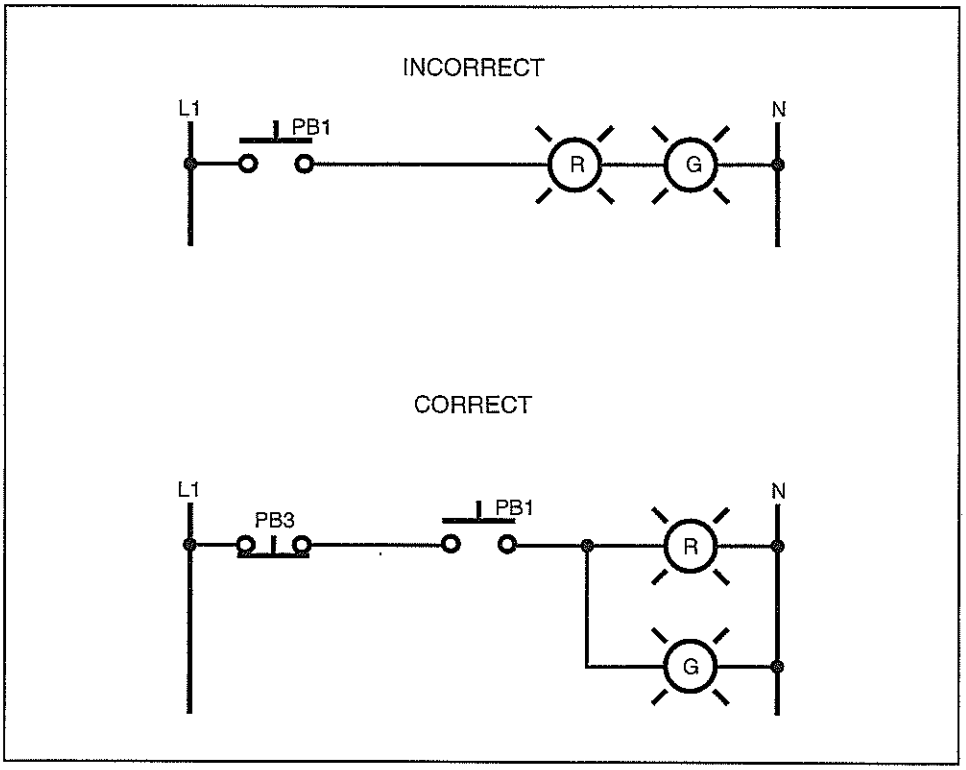


Figure 23. Wiring of Multiple Loads

- **Output Devices Located on Right** - Output devices such as solenoids, lamps, relay coils, and contactor coils should always be located on the right side of the ladder line with one terminal connected directly to the right power rail.

SKILL 3 DRAW A LADDER DIAGRAM OF A CONTROL CIRCUIT

Procedure Overview

In this skill, you will draw the ladder diagram of the circuit you connected in a previous skill. This will demonstrate the orderly layout of components in a ladder diagram.

❑ 1. Study the circuit diagram in figure 24. Identify the power supply, any input devices, any output devices, and the conductors.

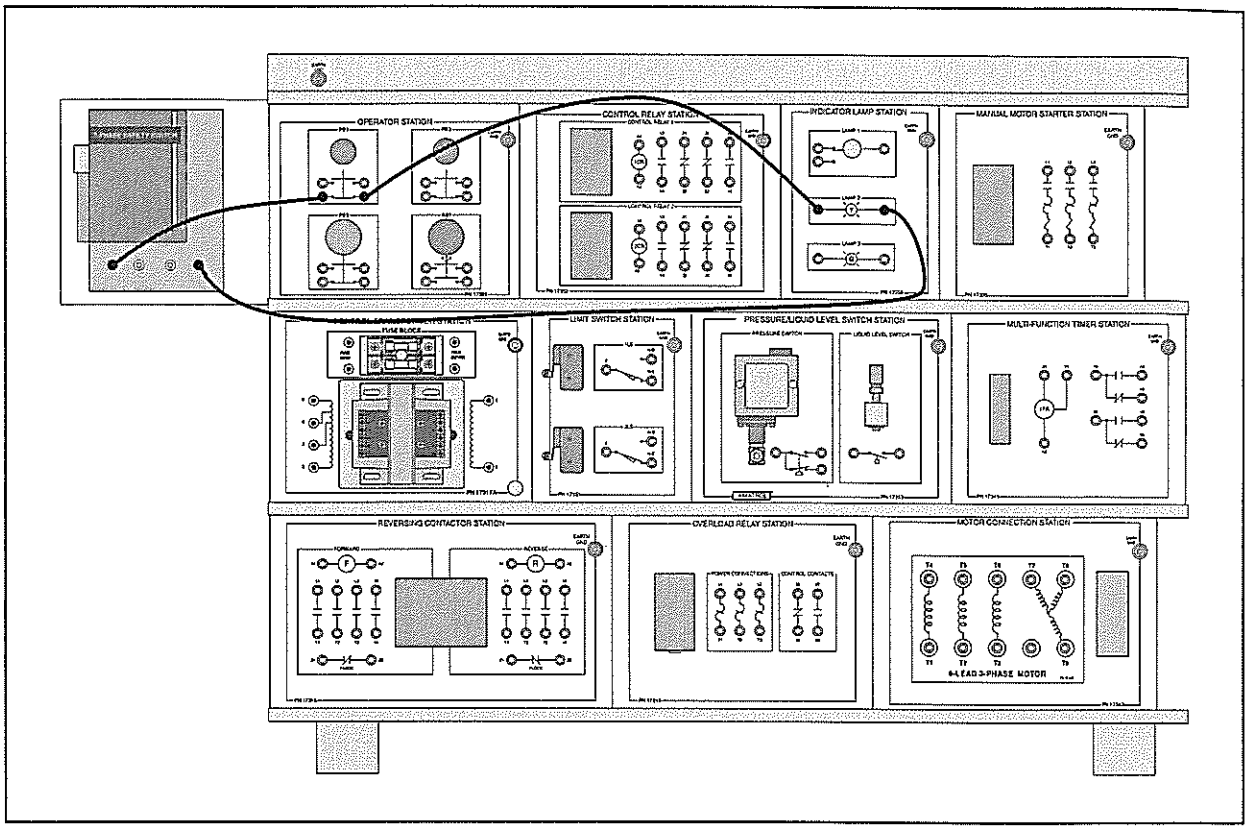


Figure 24. Pictorial Circuit Diagram for Skill 1

❑ 2. On a separate sheet of paper, perform the following substeps to draw the ladder diagram symbol for a power supply.

A. Draw two vertical lines about 2 inches long and 3 inches apart.

B. Label the left-hand line L1.

C. Label the right-hand line N.

- ❑ 3. Perform the following substeps to draw the inputs.
  - A. Draw the symbol for a N.C. pushbutton switch to the right of L1 on your diagram.
  - B. Label the symbol PB1.
- ❑ 4. Draw the symbol for a yellow indicator lamp to the left of N on your diagram.
- ❑ 5. Perform the following substeps to draw the conductors.
  - A. Draw a straight horizontal line from L1 to the pushbutton symbol.

    Label this line 1.
  - B. Draw a straight horizontal line from the indicator lamp symbol to N.

    Label this line 2.
  - C. Draw a straight horizontal line from the pushbutton symbol to the indicator lamp symbol.

    Label this line 3.

    Your ladder diagram should match figure 25.

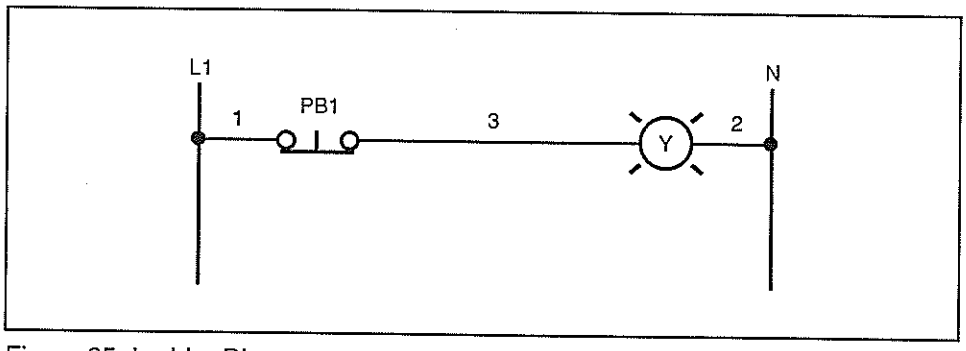


Figure 25. Ladder Diagram

- ❑ 6. Show your ladder diagram to your instructor.

  This is part of your skill assessment.
- ❑ 7. Now, add another load (the green indicator lamp) to the ladder so it also is energized through the contacts of PB1.

NOTE

Remember, do not put loads in series.

OBJECTIVE 9 DESCRIBE HOW TO DETERMINE THE OPERATION OF A CIRCUIT GIVEN A LADDER DIAGRAM

The best method for reading a ladder diagram is to start at the upper left of the diagram at the first input on the first line. Then, work your way across that line before moving down to the first input on the next line. This is true whether you want to determine the sequence of operation of the circuit represented or construct an actual circuit from the diagram. This is shown in figure 26.

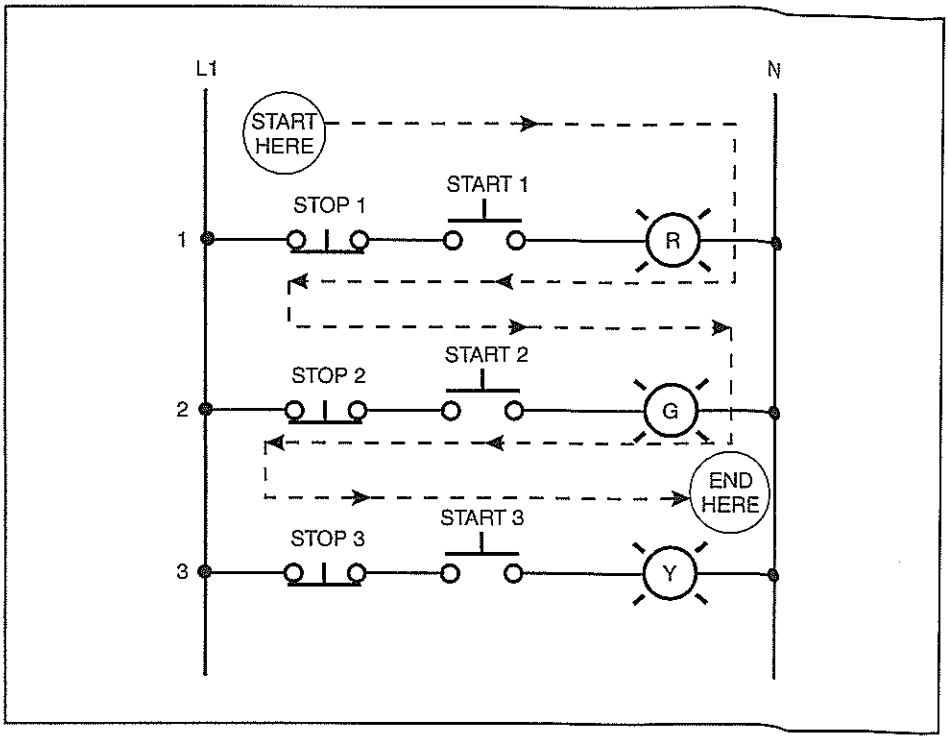


Figure 26. Method for Reading a Ladder Diagram

When determining the sequence of operation of a circuit using a ladder diagram, first determine the state of all outputs when all inputs are in their de-activated, or normal, states. Keep in mind that in order for an output to be energized, there must be a complete circuit from the left power rail, through any inputs, through the output, and on to the right power rail.

Start with line 1 and trace the circuit from left to right to determine if any outputs on that line are energized. Then move along any branches to determine if there is a complete circuit along line 1 to any outputs on lower lines. Continue to the next line, checking outputs on this line first, then moving up or down any branches.

Once you have determined the initial state of all the outputs on the diagram, the next step is to determine the states of all outputs as each of the inputs is energized. For example, determine which indicator lamps come on or go off as each of the buttons are pressed.

SKILL 4 DETERMINE THE OPERATION OF A CONTROL CIRCUIT GIVEN A LADDER DIAGRAM

Procedure Overview

In this procedure, you will use a ladder diagram to determine the operation of a control circuit.

❑ 1. Study ladder diagram in figure 27. Identify the two inputs and the two outputs.

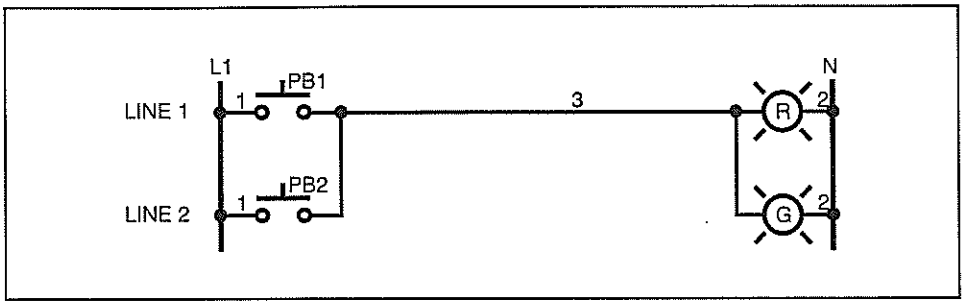


Figure 27. First Ladder Diagram for Skill 4

❑ 2. Determine the initial status of each lamp, before any pushbuttons are pressed.

Red Indicator Status _____(On/Off)

Green Indicator Status_____(On/Off)

The red lamp will be off, because there is not a complete circuit between L1 and N, through this lamp. The green lamp will also be off, since there is not a complete circuit through this lamp.

❑ 3. Determine the status of the red lamp if **PB1** is pressed.

Red Indicator Status _____(On/Off)

The red lamp will be on as long as the button is held because pressing PB1 completes the circuit between the power rails, allowing current to flow through the red output lamp.

❑ 4. Determine the status of the green lamp if **PB1** is pressed.

Green Indicator Status_____(On/Of

The green lamp will also be on as long as the button is held, since pressir PB1 completes the circuit between L1 and N, allowing the current to flo through the green output lamp. Notice that the red and green lamps are wire in parallel in this circuit.

❑ 5. Repeat steps 3 and 4 if **PB2** is pressed.

Red Indicator Status _____(On/Of

Green Indicator Status_____(On/Of

Both lamps will come on if PB2 is pressed, since the circuit paths a completed between L1 and N, through each of the lamps.

❑ 6. Perform the following substeps to determine the operation of a circuit usir the ladder diagram in figure 28.

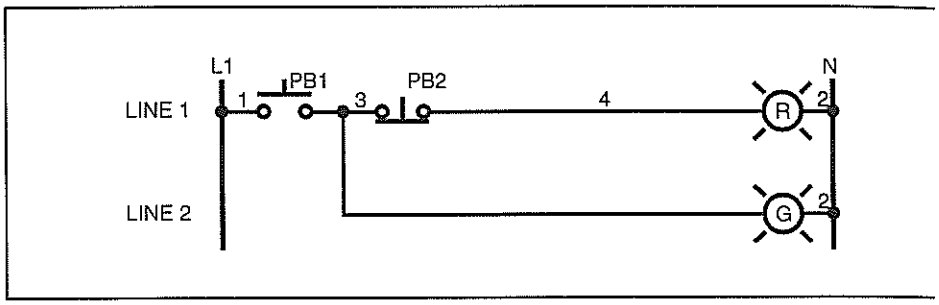


Figure 28. Second Ladder Diagram for Skill 4

A. Determine the initial status of the red indicator lamp.

Red Indicator Status_____(On/O

B. Determine the initial status of the green indicator lamp.

Green Indicator Status _____(On/O

C. Determine the status of the red lamp if **PB1** is pressed.

Red Indicator Status_____(On/O

D. Determine the status of the green lamp if **PB1** is pressed.

Green Indicator Status _____(On/O

E. Determine the status of the red and green lamps if **PB1** is pressed and he and **PB2** is also pressed.

Red Indicator Status_____(On/O

Green Indicator Status _____(On/O

SKILL 5 CONNECT AND OPERATE A CONTROL CIRCUIT GIVEN A LADDER DIAGRAM

Procedure Overview

In this procedure, you will determine the operation of a circuit given the ladder diagram. You will then connect the circuit using only the ladder diagram as a reference.

❑ 1. Perform the following substeps to determine the operation of a circuit given the ladder diagram in figure 29.

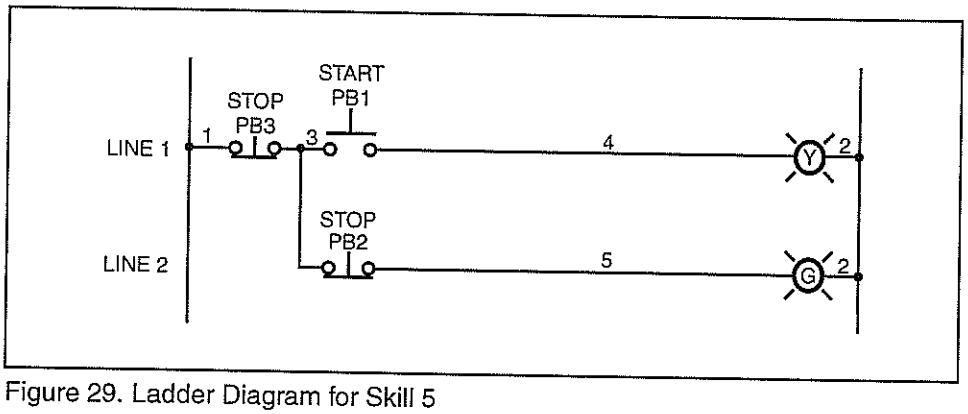


Figure 29. Ladder Diagram for Skill 5

A. Determine the initial status of the indicator lamps.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

B. Determine the status of the lamps if only **PB1** is pressed.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

C. Determine the status of the lamps if only **PB2** is pressed.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

D. Determine the status of the lamps if **PB3** is pressed and held and PB1 is pressed.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

E. Determine the status of the lamps if **PB3** is pressed and held and PB2 is pressed.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

❑ 2. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the station panels are still arranged on the trainer, as shown in figure 12.

B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.

C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Make sure the green ground wires are still connected to all station panels and the equipment ground.

❑ 3. Connect the circuit as shown in figure 29.

NOTE

When wiring a circuit from a ladder diagram, always work from left to right and top to bottom. First connect a wire from the power source (L1) to the first input on line 1. Work across the line to the right, one wire at a time. Mark off wires as you go, for example with a red pen. This helps you keep track of which components you have completed. Once line 1 is connected, begin on line 2.

❑ 4. Perform the following substeps to test the operation of the circuit.

A. Make sure the 85-MT5 power cord is plugged into a 3-phase wall outlet.

B. Remove the lockout/tagout.

C. Turn on the safety switch to supply power to the circuit.

When you turn the safety switch on, you should notice that the yellow lamp is off, while the green indicator lamp is on. PB3, the stop push-button, is not activated, so its N.C. contacts are closed. Since PB1 is not activated, its N.O. contacts are open, and the circuit is not complete through the yellow lamp. Since PB2 is not activated, its N.C. contacts are closed, allowing current to flow through the green lamp. This should agree with what you determined in substep 1A.

D. Press and hold **PB1** and observe the yellow and green indicator lamps.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

Compare your answer to that of substep 1B. Your answers should agree.

E. Release **PB1** and press and hold **PB2**. Observe the yellow and green indicators again.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

Compare your results to those in substep 1C. They should agree.

F. Release **PB2**. Hold down **PB3** while pressing **PB1**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

Compare your results to those in substep 1D. Again, they should agree.

G. Release **PB1**. Hold down **PB3** while pressing **PB2**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

Compare your results to those in substep 1E. They should also agree.

☐ 5. Perform the following substeps to shut down the 85-MT5 system.

A. Turn off the safety switch.

B. Perform a lockout/tagout.

C. Disconnect all circuit leads except for green ground lead connections.

D. Remove the lockout/tagout equipment. If this is your last activity for the day, return the equipment to your instructor. If not, continue.

SEGMENT 2

SELF REVIEW

1. A _____diagram arranges the conductors in straight horizontal lines, with inputs and outputs located on each of these lines.
2. The four components of a ladder diagram are: power supply, conductors, input devices and _____ devices.
3. The "side rails" of the ladder diagram represent the _____.
4. _____ devices are used to perform the logic function that controls the outputs.
5. _____ devices are the components that perform the machine operation.
6. Ladder diagrams show only _____ devices such as switches, solenoids, and relays.
7. When wiring a circuit from a ladder diagram, always work from top to bottom and left to _____.

SEGMENT 3

LOGIC ELEMENTS 1

OBJECTIVE 10 LIST SIX ELEMENTS OF CONTROL LOGIC

There are six ways of connecting switches (input devices) in a circuit. These "elements" form the logic that controls the operation of the outputs. A control logic circuit uses these elements to perform operations in automation and motor control.

The six elements of control logic are:

- AND
- OR
- NOT
- NOR
- NAND
- MEMORY

OBJECTIVE 11 DESCRIBE THE OPERATION OF AND LOGIC AND GIVE AN APPLICATION

AND logic requires that all input devices on a line be activated before the output device receives current. An AND logic circuit can be made of two or more normally open (N.O.) switches wired in series. The term ***series*** means that the components are connected so that electricity must flow through the first component before it can flow to the next one.

In the AND circuit in figure 30, both N.O. switch "A" and N.O. switch "B" must be activated (e.g. pressed) to make the output (e.g. a lamp) energize. If only one switch is activated, the output will not be energized.

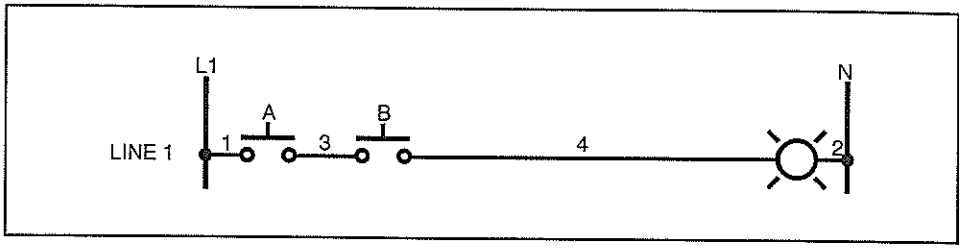


Figure 30. A Basic AND Logic Circuit

An application of an AND logic circuit is the "TWO HAND CIRCUIT". This circuit requires that both hands must be used to start the machine by having each hand activate a separate switch at the same time. The purpose is to protect the operator from getting a hand caught in the machine during its operation. The machine will stop if either hand is removed from one of the start switches.

WARNING

FIGURE 30 DOES NOT SHOW A COMPLETE TWO HAND CIRCUIT. THE CONNECTION OF AN OSHA APPROVED TWO HAND CIRCUIT HAS ADDITIONAL COMPONENTS TO INSURE THE SAFETY OF THE OPERATORS.

SKILL 6 CONNECT AND OPERATE AN AND LOGIC CIRCUIT

Procedure Overview

In this procedure, you will connect and operate an AND logic control circuit that controls an indicator lamp.

❑ 1. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the station panels are still arranged on the trainer, as shown in figure 12.

B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.

C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Make sure the green ground wires are still connected to all station panels and the equipment ground.

❑ 2. Connect the AND logic circuit as shown in the ladder diagram in figure 31.

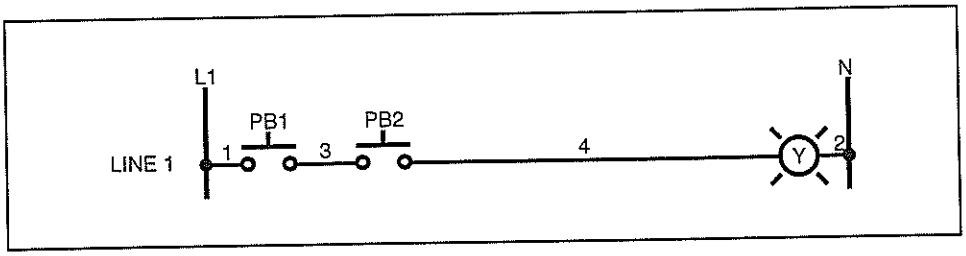


Figure 31. The AND Logic Circuit for Skill 6

❑ 3. Perform the following substeps to operate the circuit.

A. Remove the lockout/tagout from the safety switch.

B. Turn on the safety switch.

Since neither pushbutton is actuated, when you turn the power disconnect on the indicator lamp should be off.

C. Press and hold the pushbutton labeled **PB1**.

Indicator Status _____(On/Off)

You should notice that the indicator lamp does not come on because AND logic requires both pushbuttons to be pressed.

D. Release **PB1**.

E. Press and hold the pushbutton labeled **PB2**.

Indicator Status _____(On/O

You should notice that the indicator lamp does not come on because AN logic requires both pushbuttons to be pressed.

F. Now press and hold **PB1** again while continuing to press **PB2**.

Indicator Status _____(On/O

The indicator lamp should now come on. When both PB1 AND PB2 a pressed the circuit is complete.

G. Release either **PB1** or **PB2**.

Indicator Status _____(On/O

The indicator lamp will now go off because the circuit has been broker

H. Release the other pushbutton.

I. Repeat steps C through H to familiarize yourself with the operation of AND circuit.

❑ 4. Perform the following substeps to disconnect this circuit and prepare for t next skill.

A. Turn off the safety switch.

B. Lockout/tagout the safety switch.

C. Disconnect all lead wires except for the grounding wires.

OBJECTIVE 12 DESCRIBE THE OPERATION OF OR LOGIC AND GIVE AN APPLICATION

OR logic does not allow current to flow to the output device until either one input device or another input device is activated. An OR logic circuit can be formed by two or more normally open (N.O.) switches wired in parallel. The term parallel means that the components are connected so that the flow of electricity can "branch" through one component or the other. With the OR logic circuit in figure 32, the output (lamp) will be energized (lighted) as soon as either the N.O. switch "A" or the N.O. switch "B" is pressed.

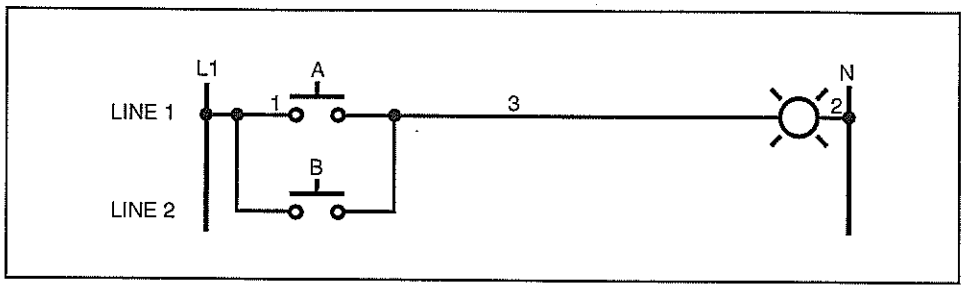


Figure 32. A Basic OR Logic Circuit

OR logic in a control circuit can be used to connect a remote start switch for a machine. In some industries, there may be reasons why you would want to start a machine from a remote position. For example, a paint room may have hazardous fumes that could prove dangerous to an operator. Therefore, you would connect a remote start switch to avoid the area.

SKILL 7 CONNECT AND OPERATE AN OR LOGIC CIRCUIT

Procedure Overview

In this procedure, you will connect a circuit using OR logic to provide a remote start pushbutton to turn on the output device. The output device for this procedure will be an indicator lamp.

❑ 1. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the station panels are still arranged on the trainer, as shown in figure 12.

B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.

C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Make sure the green ground wires are still connected to all station panels and the equipment ground.

❑ 2. Connect the OR logic circuit as shown the ladder diagram in figure 33.

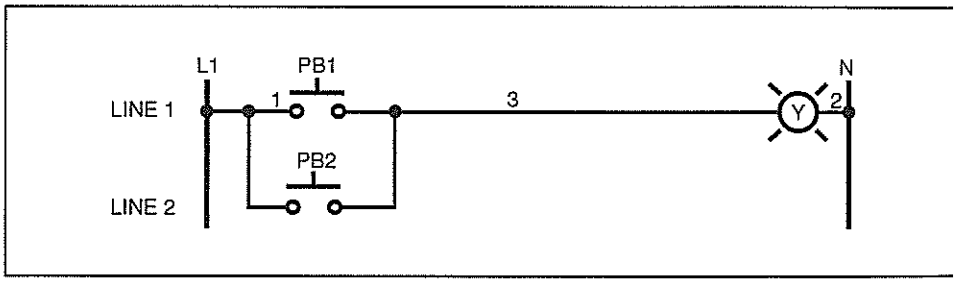


Figure 33. The OR Logic Circuit for Skill 7

❑ 3. Perform the following substeps to operate the circuit.

A. Remove the lockout/tagout from the safety switch.

B. Turn on the safety switch.

C. Since neither pushbutton is actuated, the indicator lamp should be off.

D. Press and hold pushbutton **PB1**.

Indicator Status _____(On/Off)

The lamp should come on because OR logic requires only one pushbutton to be pressed.

E. Release **PB1**.

Indicator Status _____(On/Off)

The lamp should now be off.

F. Press and hold pushbutton **PB2**.

Indicator Status _____(On/Off)

The lamp should come on because once again only one pushbutton is required to be pressed when OR logic is used.

G. Release **PB2**.

Indicator Status _____(On/Off)

The lamp will once again be off.

H. Repeat steps D through G to familiarize yourself with an OR circuit.

❑ 4. Perform the following substeps to disconnect this circuit.

A. Turn off the safety switch.

B. Lockout/tagout the safety switch.

C. Disconnect all lead wires except for the grounding wires.

D. Remove the lockout/tagout equipment. If this is your last activity for the day, return the equipment to your instructor. If not, continue.

SEGMENT 3

SELF REVIEW

1. The six elements of control logic are: AND, _____, NOT, NOR, NAND and MEMORY.

2. With _____ logic, all input devices must be activated before the output device receives current.

3. A _____ circuit requires that both hands be used to start a machine.

4. The term _____ means that the components are connected so that the electricity must flow through the first component before it can flow to the next one.

5. With _____ logic, activating either input device will allow current to flow to the output device.

6. The term _____ means that the components are connected so that the flow of electricity can "branch" through one component or the other.

SEGMENT 4

LOGIC ELEMENTS 2

OBJECTIVE 13 — DESCRIBE THE OPERATION OF NOT LOGIC AND GIVE AN APPLICATION

NOT logic requires that the single input device ***not*** be activated in order for current to flow through the output device. NOT logic can be formed by the use of a single normally closed (N.C.) switch. The output is energized as long as the input N.C. switch is NOT activated. Likewise, as soon as the input switch is pressed, the circuit is broken and the output goes off, as shown in figure 34.

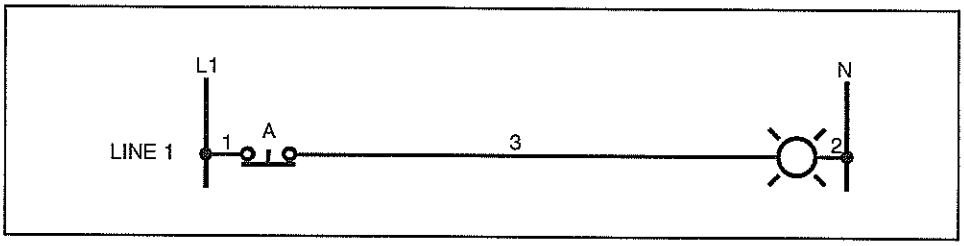


Figure 34. NOT Logic is Formed by a Single Normally Closed Input Switch

A common use of NOT logic is the stop pushbutton. It is a standard practice to use a normally closed pushbutton switch to stop a machine. When the stop pushbutton is actuated, it opens the circuit and deenergizes the output.

SKILL 8 CONNECT AND OPERATE A NOT LOGIC CIRCUIT

Procedure Overview

In this procedure, you will connect an electrical control circuit using NOT logic with a normally closed switch to provide a stop button.

❑ 1. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the station panels are still arranged on the trainer, as shown in figure 12.

B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.

C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Make sure the green ground wires are still connected to all station panels and the equipment ground.

❑ 2. Connect the circuit shown in the ladder diagram in figure 35.

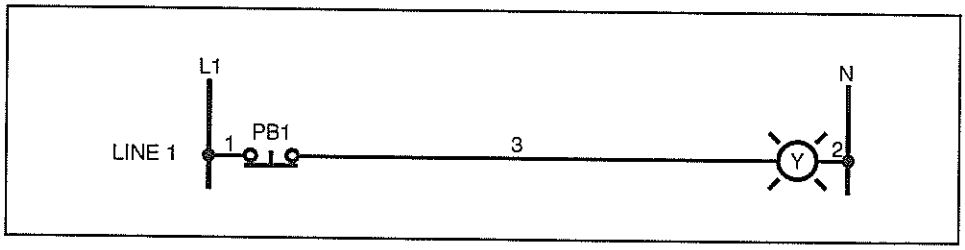


Figure 35. The NOT Logic Circuit for Skill 8

❑ 3. Perform the following substeps to operate the circuit.

A. Remove the lockout/tagout from the safety switch.

B. Turn on the safety switch.

C. Since the pushbutton is NOT being pressed, the indicator lamp should be on.

D. Press and hold **PB1**.

Indicator Status _____(On/Off)

The lamp should go off because NOT logic is used to open the circuit when the pushbutton is pressed.

E. Release **PB1**.

Indicator Status _____(On/Off)

The lamp should come back on because releasing the pushbutton allowed the switch to return to its normal position, which completed the circuit and allowed electricity to flow through the lamp.

F. Repeat steps B through E to familiarize yourself with the NOT circuit.

❑ 4. Perform the following substeps to disconnect this circuit and prepare for the next skill.

A. Turn off the safety switch.

B. Lockout/tagout the safety switch.

C. Disconnect all lead wires except for the grounding wires.

OBJECTIVE 14 DESCRIBE THE OPERATION OF NOR LOGIC AND GIVE AN APPLICATION

NOR logic allows current to flow through to the output device only if none of the input devices on a line are activated. NOR logic can be made of two or more normally closed (N.C.) switches wired in series. In order for the output to be energized in figure 36, neither input switch "A" NOR input switch "B" can be actuated. As soon as one of the switches is pressed, the circuit is broken and the output goes off.

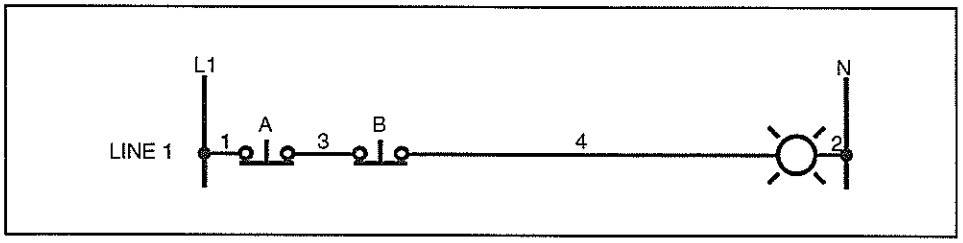


Figure 36. Circuits with Multiple Stop Pushbuttons Use NOR Logic

NOR logic is often used to provide multiple stop pushbuttons for the control circuits of machines in factories. These remote stop pushbuttons provide safer operation by allowing all machine processes to be halted from any of several locations. An assembly line is a good example.

SKILL 9 CONNECT AND OPERATE A NOR LOGIC CIRCUIT

Procedure Overview

In this procedure, you will connect a control circuit using NOR logic to provide a remote stop pushbutton.

☐ 1. Perform the following substeps to set up the 85-MT5 trainer.

A. Make sure the station panels are still arranged on the trainer, as shown i figure 12.

B. If you are using the 890-FTS1 Fault Troubleshooting System make sur the power switch on the power supply is off.

C. Make sure all fault terminals on the back of each of the panels have eithe a fault cable or a standard jumper plug attached.

D. Perform a lockout/tagout on the safety switch.

E. Perform an electrical safety check.

F. Make sure the green ground wires are still connected to all station panel and the equipment ground.

☐ 2. Connect the circuit shown in the ladder diagram in figure 37.

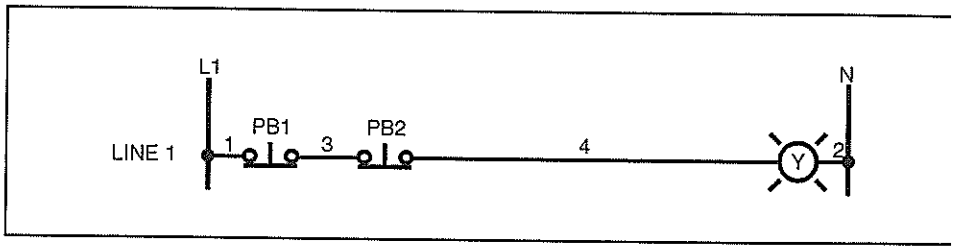


Figure 37. The NOR Logic Circuit for Skill 9

☐ 3. Perform the following substeps to operate the circuit.

A. Remove the lockout/tagout from the safety switch.

B. Turn on the safety switch.

C. Since neither pushbuttons are being pressed, the indicator lamp should be on.

D. Press and hold **PB1**.

Indicator Status _____(On/Off)

The lamp should go off because NOR logic requires only one pushbutton to be pressed to open the circuit path.

E. Release **PB1**.

Indicator Status _____(On/Off)

The light should come back on.

F. Press and hold **PB2**.

Indicator Status _____(On/Off)

The lamp should go back off again because only one pushbutton has to be pressed to open the circuit path in NOR logic.

G. Release **PB2**.

Indicator Status _____(On/Off)

The lamp should come back on.

H. Repeat steps D through G to familiarize yourself with the NOR circuit.

☐ 4. Perform the following substeps to disconnect this circuit and prepare for the next skill.

A. Turn off the safety switch.

B. Lockout/tagout the safety switch.

C. Disconnect all lead wires except for the grounding wires.

OBJECTIVE 15 DESCRIBE THE OPERATION OF NAND LOGIC AND GIVE AN APPLICATION

With **NAND** logic, the first input device must be activated ***and*** all other input devices must be activated in order for the output device to ***not*** be energized. NAND logic can consist of two or more normally closed (N.C.) input switches wired in parallel. For example, the output in the circuit of figure 38 will stay on until all the N.C. input switches are pressed.

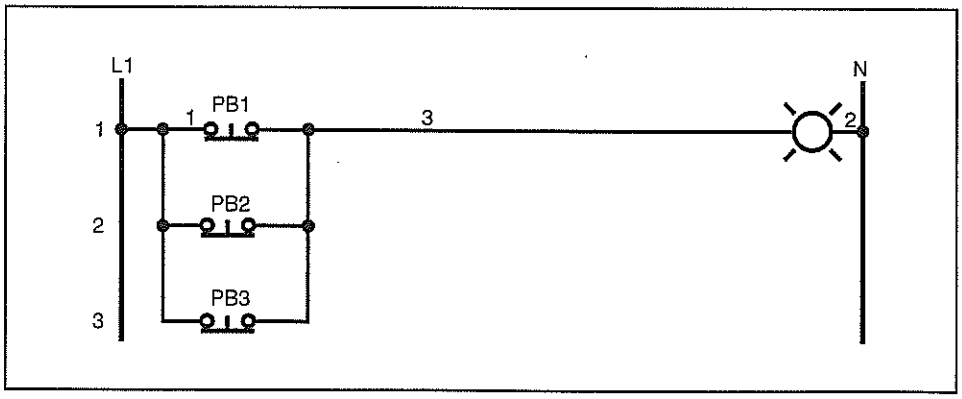


Figure 38. Normally Closed Switches in Parallel Must All be Actuated to Turn Off the Output

A good example of NAND logic is the interior light circuit in a car. Each door on a car has a switch connected to the interior light. When the doors are open, the switches are not being actuated and the light is on. Closing one door will actuate one switch, but the light will continue to stay on. All the doors must be closed before the light will go off.

SKILL 10 CONNECT AND OPERATE A NAND LOGIC CIRCUIT

Procedure Overview

In this procedure, you will connect a control circuit which requires two pushbuttons to be pressed to provide a "stop" to the output device. The output device will be an indicator lamp.

- ❑ 1. Perform the following substeps to set up the 85-MT5 trainer.
  - A. Make sure the station panels are still arranged on the trainer, as shown in figure 12.
  - B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.
  - C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.
  - D. Perform a lockout/tagout on the safety switch.
  - E. Perform an electrical safety check.
  - F. Make sure the green ground wires are still connected to all station panels and the equipment ground.
- ❑ 2. Connect the circuit shown in the ladder diagram in figure 39.

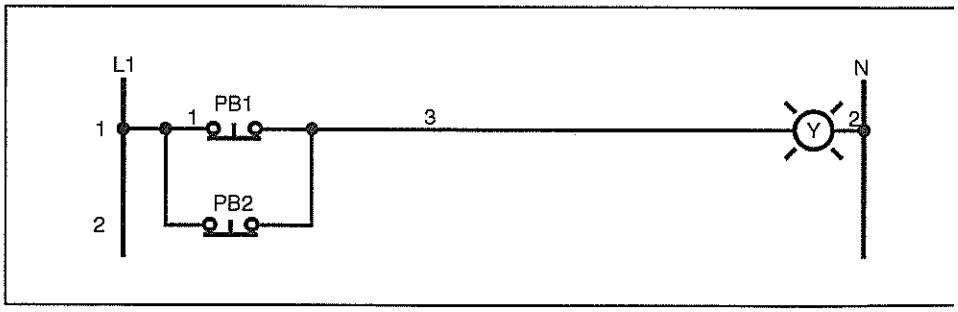


Figure 39. The NAND Logic Circuit for Skill 10

- ❑ 3. Perform the following substeps to operate the circuit.
  - A. Remove the lockout/tagout from the safety switch.
  - B. Turn on the safety switch.
  - C. The lamp should come on when the power is applied because you have connected two normally closed switches in parallel which provide a closed circuit to energize the lamp.

D. Press and hold **PB1**.

Indicator Status _____(On/Off)

This simulates closing one of the doors on a car.

The lamp should remain on because NAND logic requires that all pushbuttons must be pressed to block the flow of electricity in a circuit.

Pushbutton PB2 is providing a path for the electricity to flow around switch PB1 which is now open.

E. Press and hold **PB2** while continuing to press **PB1**.

Indicator Status _____(On/Off)

This simulates closing all the car's doors.

The lamp should go out because NAND logic is used to block the flow of electricity in a circuit when all the pushbuttons are pressed.

F. Release the pushbuttons.

Indicator Status _____(On/Off)

The lamp will come back on as the electrical path is restored.

G. Repeat steps D through F to familiarize yourself with NAND logic.

❑ 4. Perform the following substeps to shut down the system.

A. Turn off the safety switch.

B. Lockout/tagout the safety switch.

C. Disconnect all lead wires except for the grounding wires.

SKILL 11 DESIGN A MULTIPLE START/STOP PUSHBUTTON STATION CONTROL CIRCUIT

Procedure Overview

In this procedure, you will design a control circuit which uses multiple switches and indicator lamps to simulate the operation of a machine in both automatic and manual modes.

- ❑ 1. Perform the following substeps to set up the 85-MT5 trainer.
  - A. Make sure the station panels are still arranged on the trainer, as shown in figure 12.
  - B. If you are using the 890-FTS1 Fault Troubleshooting System, make sure the power switch on the power supply is off.
  - C. Make sure all fault terminals on the back of each of the panels have either a fault cable or a standard jumper plug attached.
  - D. Perform a lockout/tagout on the safety switch.
  - E. Perform an electrical safety check.
  - F. Make sure the green ground wires are still connected to all station panels and the equipment ground.
- ❑ 2. Design and draw the ladder diagram of a control circuit which will perform the following logic functions:
  - "Manual" mode is selected by SS1 being in the left-hand position. Pressing PB1 while in manual mode starts the "machine", indicated by the yellow lamp. The yellow indicator lamp will come on only if PB1 is pressed AND the selector switch SS1 is in the left-hand position.
  - "Automatic" mode is selected by SS1 being in the right-hand position. Pressing PB2 while in automatic mode starts the "machine", indicated by the green lamp. The green indicator lamp will come on only if PB2 is pressed AND SS1 is in the right-hand position.
  - Pressing the stop pushbutton, PB3, stops the machine regardless of the mode selected. That is to say, the circuit will operate only if PB3 is NOT pressed.
- ❑ 3. Show your instructor your ladder diagram.
- ❑ 4. After receiving permission from your instructor, connect the circuit you have designed.
- ❑ 5. Perform the following substeps to operate the circuit.
  - A. Remove the lockout/tagout from the safety switch.
  - B. Turn on the safety switch.
  - C. When the power is turned on, neither lamp should be illuminated.

D. Rotate the selector switch to the left-hand position. The machine is now in the "manual" mode. Press **PB1**. This begins manual operation of the machine.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

The yellow lamp should come on. The green should stay off.

E. While holding **PB1**, press **PB3**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

PB3 is the stop button, so the yellow lamp should go off.

F. Release **PB3**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

The yellow lamp should come back on.

G. Release **PB1**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

Both lamps should now be off, since no buttons are being pressed.

H. Rotate **SS1** to the right-hand position. This switches the machine to "automatic" mode. Press **PB2**. This begins automatic operation of the machine.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

The green lamp should now be on and the yellow lamp should be off.

I. While holding **PB2**, press **PB3**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

PB3 is the stop button, so the green lamp should go off.

J. Release **PB2** and **PB3**. Now press **PB1**.

Yellow Indicator Status _____(On/Off)

Green Indicator Status _____(On/Off)

No lamps should be on, since you are pressing PB1 while SS1 is in the wrong mode.

❑ 6. Perform the following substeps to shut down the system.

A. Turn off the safety switch.

B. Perform a lockout/tagout on the safety switch.

C. Remove all the lead wires.

D. Remove the lockout/tagout equipment. Return the lockout, the tagout tag, and the padlock to your instructor.

SEGMENT 4

SELF REVIEW

1. With _____ logic, the output device stops being energized if the single input device is activated.
2. With _____ logic, the output device stops being energized if any of the two or more input devices is activated.
3. NOR logic can be made of two or more N.C. switches wired in _____.
4. With _____ logic, the output device stops being energized only when all the input devices are activated.
5. NAND logic can be made of two or more N.C. switches wired in _____.