SECTION 5

# Motor Controls

## Unit 26 Start-Stop Push-Button Control

### Objectives

After studying this unit, you should be able to:

- Place wire numbers on a schematic diagram.
- Place corresponding numbers on control components.
- Draw a wiring diagram from a schematic diagram.
- Define the difference between a schematic or ladder diagram and a wiring diagram.
- Connect a start-stop push-button control circuit.

In this experiment a schematic diagram of a start-stop push-button control will be converted to a wiring diagram and then connected in the laboratory. A schematic diagram shows components in their electrical sequence without regard for the physical location of any component (Figure 26-1). A wiring diagram is a pictorial representation of components with connecting wires. The pictorial representation of the components is shown in Figure 26-2.

**Helpful Hint**

A schematic diagram shows components in their electrical sequence without regard for the physical location of any component (Figure 26-1). A wiring diagram is a pictorial representation of components with connecting wires.

To simplify the task of converting the schematic diagram into a wiring diagram, wire numbers will be added to the schematic diagram. These numbers will then be transferred to the control components shown in Figure 26-2. The rules for numbering a schematic diagram are as follows:

1. A set of numbers can be used only once.
2. Each time you go through a component the number set must change.
3. All components that are connected together will have the same number.

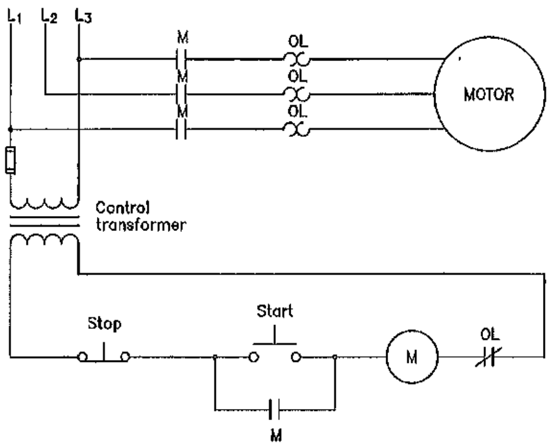


**Figure 26-1** Schematic diagram of a basic start-stop push-button control circuit.

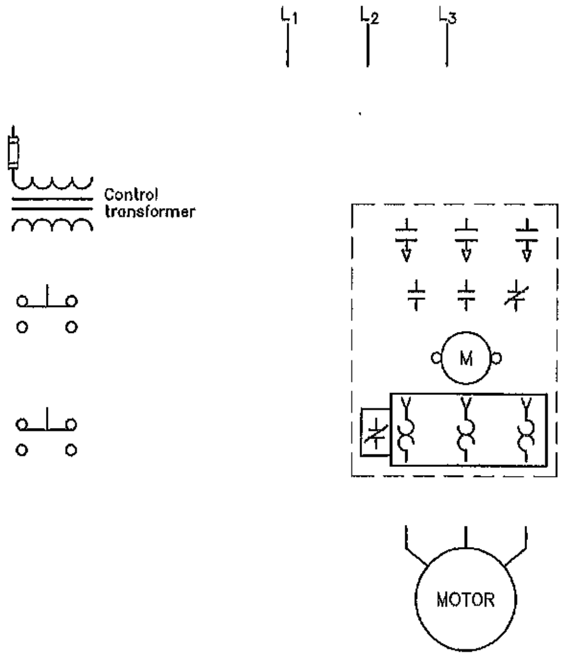


**Figure 26-2** Components of the basic start-stop control circuit.

To begin the numbering procedure, begin at Line 1 ($L_1$) with the number 1 and place a number 1 beside each component that is connected to $L_1$ (Figure 26-3). The number 2 is placed beside each component connected to $L_2$ (Figure 26-4), and a 3 is placed beside each component connected to $L_3$ (Figure 26-5). The number 4 will be placed on the other side of the M load contact that already has a number 1 on one side and on one side of the overload heater (Figure 26-6). Number 5 is placed on the other side of the M load contact, which has one side numbered with a 2, and a 5 will be placed beside the second overload heater. The other side of the M load contact, which has been numbered with a 3, will be numbered with a 6, and one side of the third overload heater will be labeled with a 6. Numbers 7, 8, and 9 are placed between the other side of the overload heaters and the motor T leads.

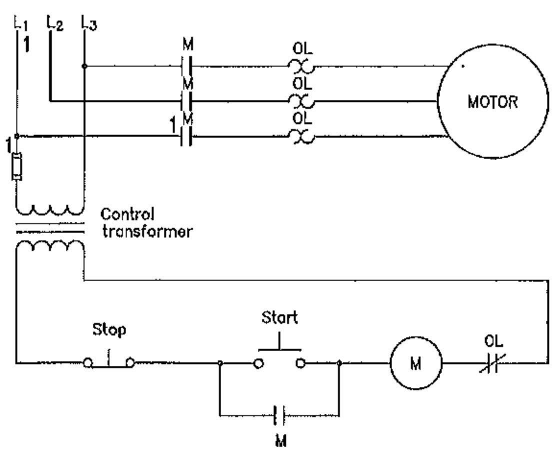


**Figure 26-3** The number 1 is placed beside each component connected to $L_1$.

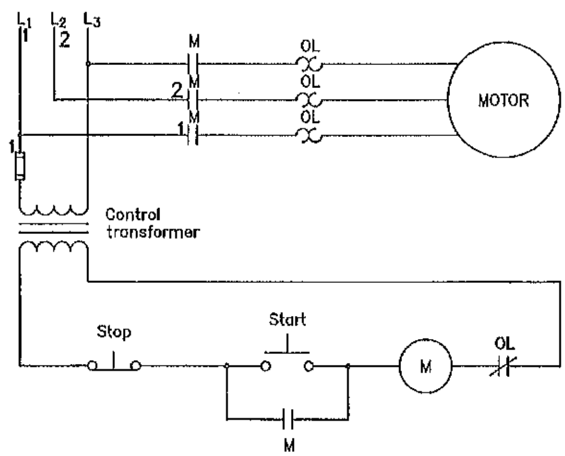


**Figure 26-4** A number 2 is placed beside each component connected to $L_2$.

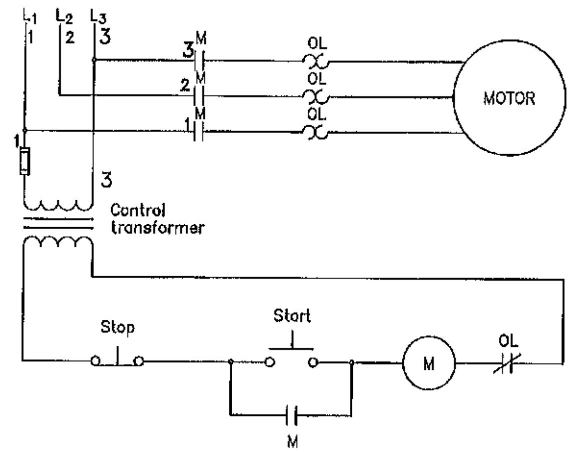


**Figure 26-5** A number 3 is placed beside each component connected to $L_3$.

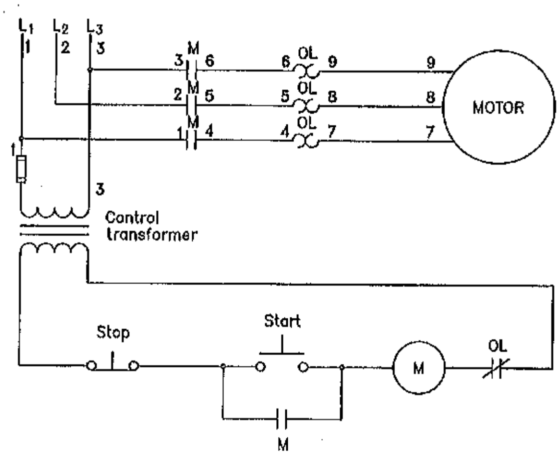


**Figure 26-6** The number changes each time you proceed across a component.

The number 10 will begin at one side of the control transformer secondary and go to one side of the normally closed stop push button. The number 11 is placed on the other side of the stop button and on one side of the normally open start push button and normally open M auxiliary contact. A number 12 is placed on the other side of the start button and M auxiliary contact and on one side of M coil. Number 13 is placed on the other side of the coil to one side of the normally closed overload contact. Number 14 is placed on the other side of the normally closed overload contact and on the other side of the control transformer secondary winding. See Figure 26-7.

## Numbering the Components

Now that the components on the schematic have been numbered, the next step is to place the same numbers on the corresponding components of the wiring diagram. The schematic diagram in Figure 26-7 shows that the number 1 has been placed beside $L_1$, the fuse on the control transformer, and one side of a load contact on M starter (Figure 26-8). The number 2 is placed beside $L_2$ and the second load contact on M starter (Figure 26-9). The number 3 is placed beside $L_3$, the third load contact on M starter, and the other side of the primary

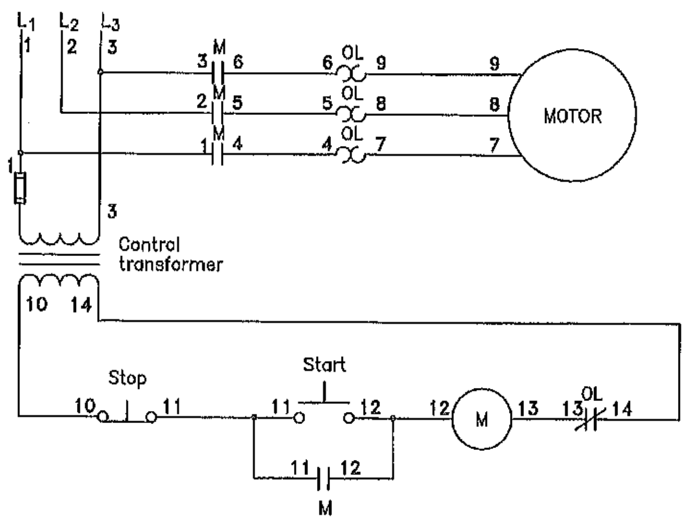


**Figure 26-7** Numbers are placed beside all components.

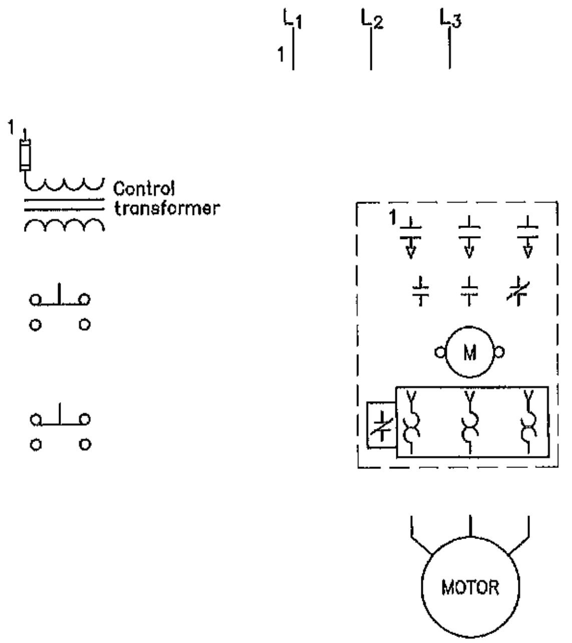


**Figure 26-8** A 1 is placed beside $L_1$, the control transformer fuse, and M load contact.

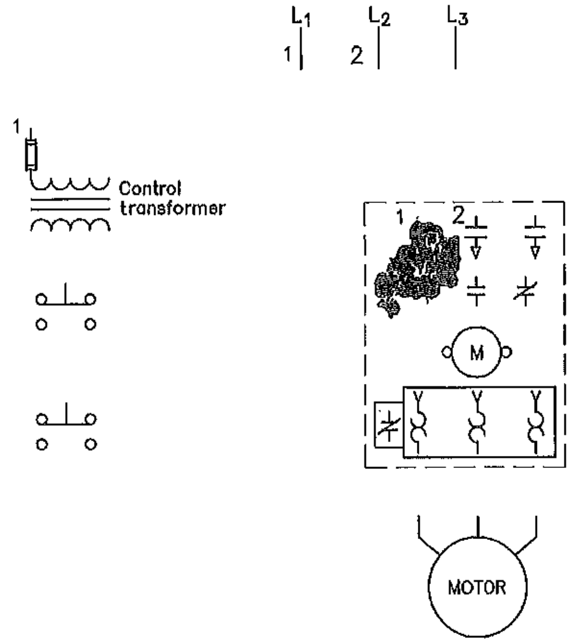


**Figure 26-9** The number 2 is placed beside $L_2$ and the second load contact on M starter.

winding on the control transformer. Numbers 4, 5, 6, 7, 8, and 9 are placed beside the components that correspond to those on the schematic diagram (Figure 26-10). Note on connection points 4, 5, and 6 from the output of the load contacts to the overload heaters, that these connections are factory made on a motor starter and do not have to be made in the field. These connections are not shown in the diagram for the sake of simplicity. If a separate contactor and overload relay are being used, however, these connections will have to

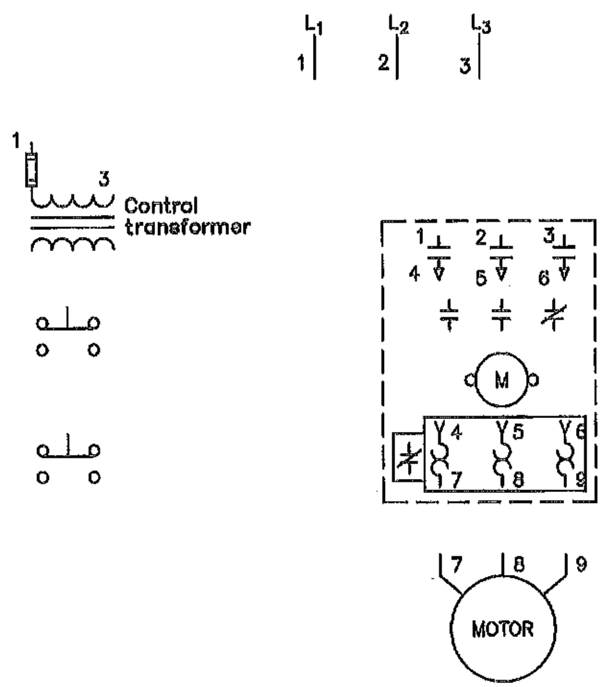


**Figure 26-10** Placing numbers 3, 4, 5, 6, 7, 8, and 9 beside the proper components.

be made. Recall that a contactor is a relay that contains load contacts and may or may not contain auxiliary contacts. A motor starter is a contactor and overload relay combined.

The number 10 starts at the secondary winding of the control transformer and goes to one side of the normally closed stop push button. When making this connection, care must be taken to make certain that connection is made to the normally closed side of the push button. Since this is a double-acting push button, it contains both normally closed and normally open contacts (Figure 26-11).

The number 11 starts at the other side of the normally closed stop button and goes to one side of the normally open start push button and to one side of a normally open M auxiliary contact (Figure 26-12). The starter in this example shows three auxiliary contacts: two normally open and one normally closed. It makes no difference which normally open contact is used.

This same procedure is followed until all circuit components have been numbered with the number that corresponds to the same component on the schematic diagram (Figure 26-13).

## Connecting the Wires

Now that numbers have been placed beside the components, wiring the circuit becomes a matter of connecting numbers. Connect all components labeled with a number 1 together (Figure 26-14). All components numbered with a 2 are connected together (Figure 26-15). All components numbered with a 3 are connected together (Figure 26-16). This procedure is followed until all the numbered components are connected together, with the exception of 4, 5, and 6, which are assumed to be factory connected (Figure 26-17).

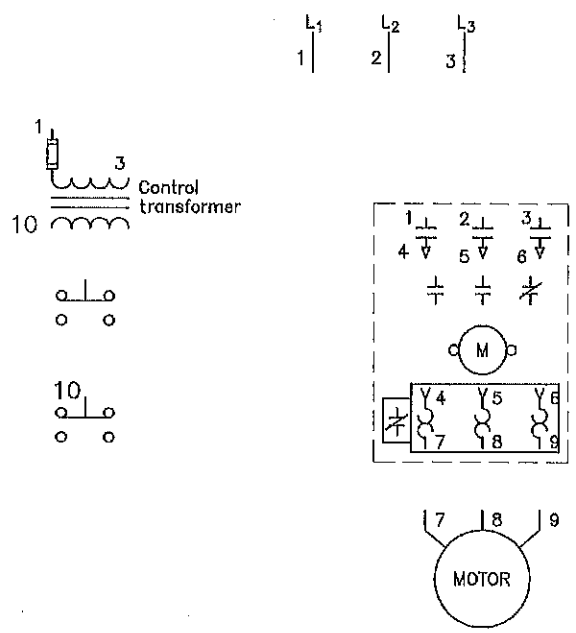


**Figure 26-11** Wire number 10 connects from the transformer secondary to the stop button.

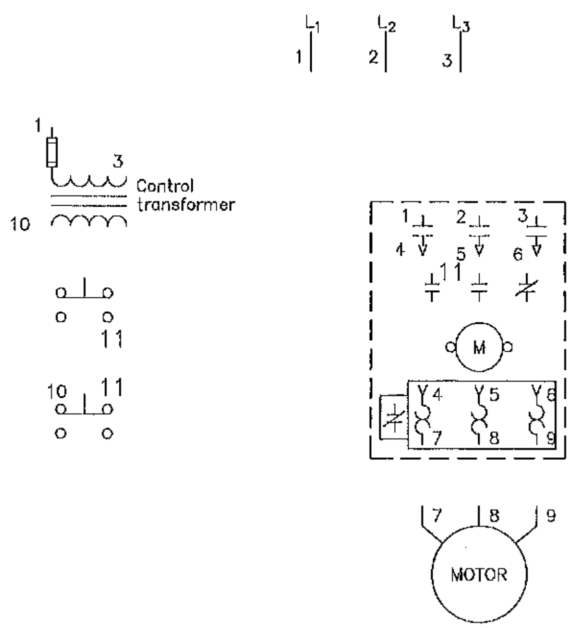


**Figure 26-12** Number 11 connects to the stop button, start button, and holding contact.

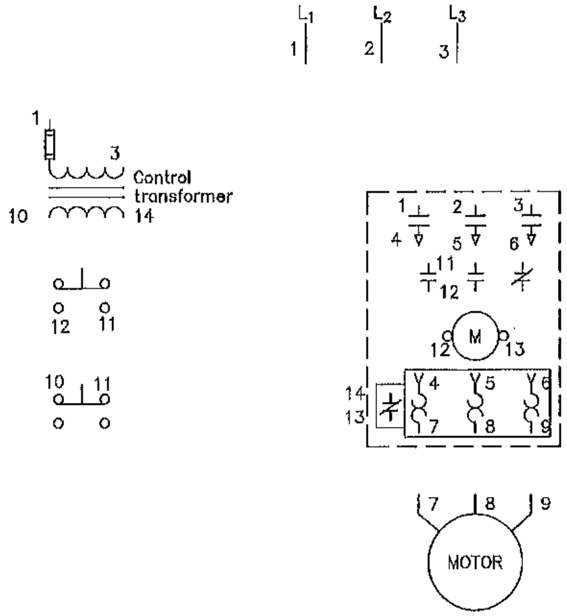


**Figure 26-13** All components have been numbered.

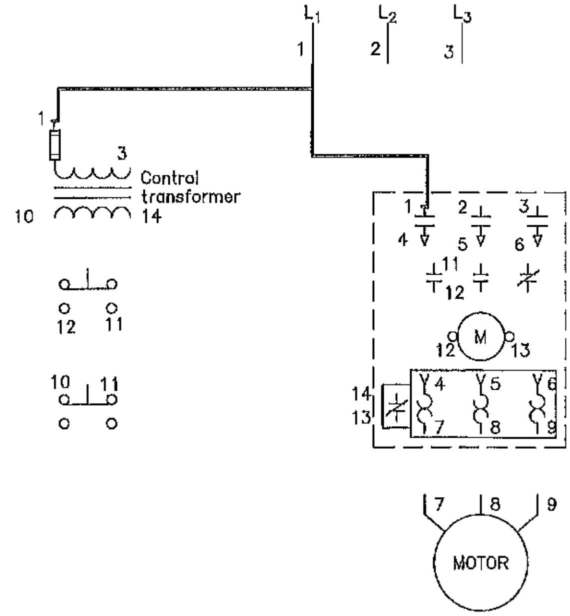


**Figure 26-14** Connecting all components numbered with a 1 together.

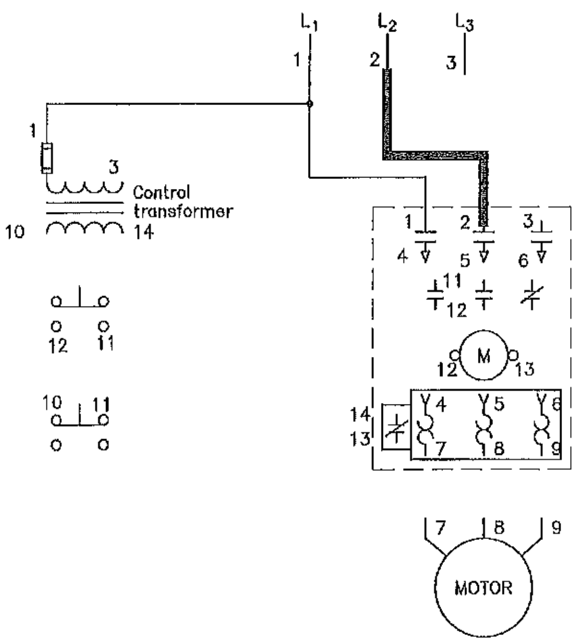


**Figure 26-15** Connecting all components numbered with a 2 together.

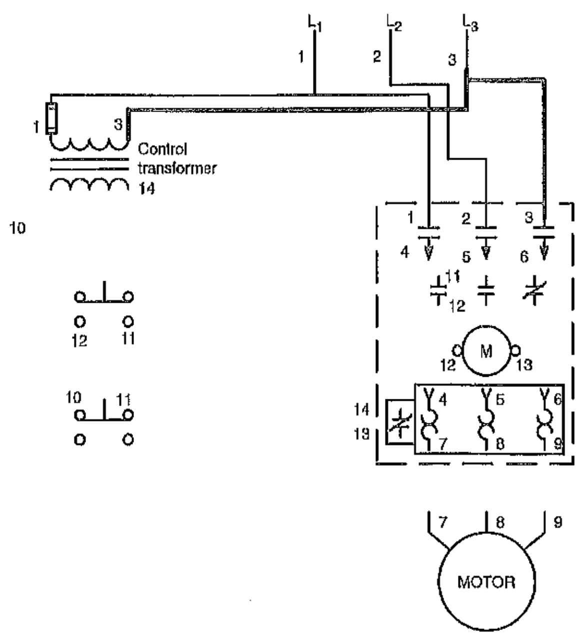


**Figure 26-16** Connecting all components numbered with a 3 together.

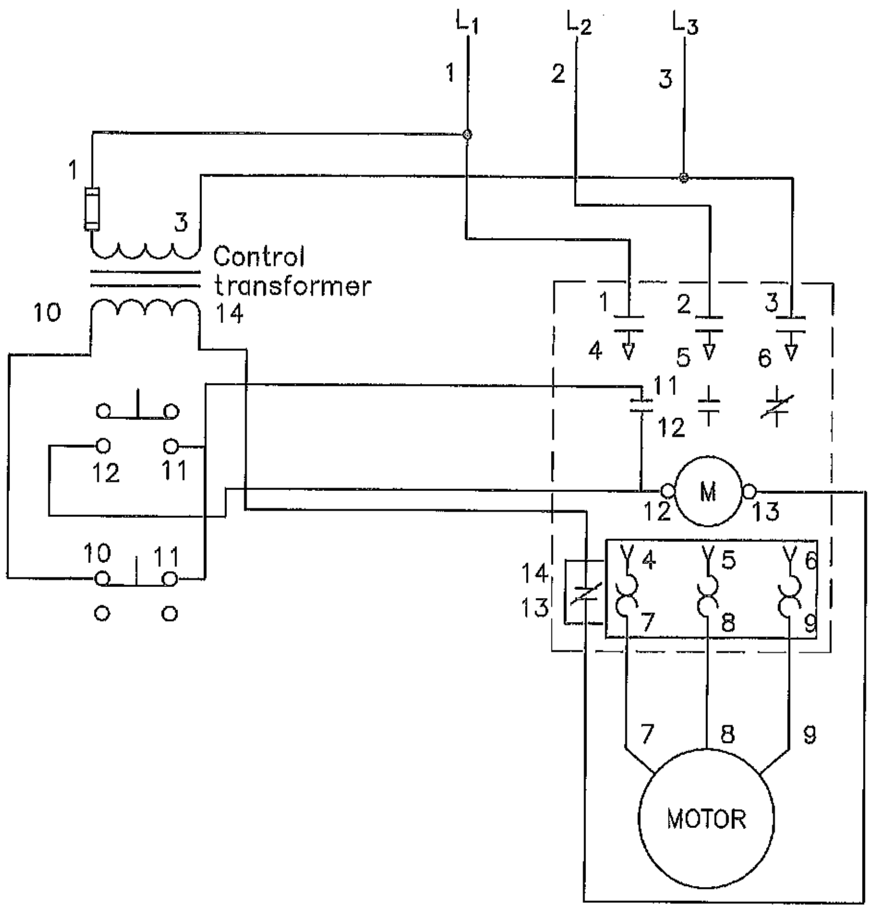


**Figure 26-17** Completing the wiring diagram.

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

### Materials Required

Three-phase power supply

Three-phase squirrel cage induction motor or simulated load

2 double-acting push buttons (N.O./N.C. on same button)

Three-phase motor starter or contactor with overload relay containing three load contacts and at least one normally open auxiliary contact

Control transformer

### Connecting a Start-Stop Push-Button Control Circuit

To connect the control circuit, follow the same procedure that was used to develop the wiring diagram. Use the schematic diagram shown in Figure 26-7. It is sometimes helpful to use a highlighter to mark the diagram as connections are made.

1. Connect all components that are labeled with a number 1. Make certain to connect to a load contact on the starter or contactor.
2. Connect all components labeled with a number 2. Again make sure to connect to a load contact on the starter or contactor.
3. Connect all components labeled with a 3.
4. Wire connections 4, 5, and 6 may or may not have to be made depending on whether you are using a starter or a contactor and separate overload relay.
5. Wires 7, 8, and 9 connect from the output of the heaters on the overload relay(s) to the motor T leads. Your circuit may contain a single three-phase overload relay or three separate overload relays if you are using a contactor and separate overload relay(s).
6. Wire number 10 connects from the secondary winding of the control transformer to one side of the normally closed push button used for the stop button. If using a double-acting push button, make certain to connect to the closed side.
7. Wire number 11 connects from the other side of the normally closed push button to the normally open push button used for the start button. If a double-acting push button is being used, make certain to connect to the open side. Wire number 11 also connects to a normally open auxiliary contact on M starter. Auxiliary contacts are smaller than the load contacts and are used as part of the control circuit. Make certain to connect to one side of an open contact.
8. Wire number 12 connects from the other side of the normally open start button to the other side of the normally open auxiliary contact and to one side of the coil on M starter.
9. Wire number 13 connects from the other side of the coil on M starter to one side of the normally open contact located on the overload relay. If a three-phase motor starter is being used, or if a separate three-phase overload relay is being used, there will be only one overload contact. Note the number of contacts on the overload relay. Some overload relays contain both normally open and normally closed contacts, and some do not. Make certain that connection is made to the normally closed contact if the relay contains more than one contact. If three separate single-phase overload relays are being used, each overload relay contains an overload contact. These three contacts will have to be connected in series so that if one opens, the circuit will be broken.
10. Wire number 14 connects from the other side of the normally closed overload contact to the other side of the secondary winding on the control transformer.
11. Check with your instructor before turning on the power.
12. Test the circuit for proper operation.
13. If the circuit works properly, **turn off the power** and disconnect the circuit. Return the wires and components to their proper place.

## Review Questions

1. Refer to the circuit shown in Figure 26-7. If wire number 11 were disconnected at the normally open auxiliary M contact, how would the circuit operate?

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2. Assume that when the start button is pressed, M starter does not energize. List seven possible causes for this problem:

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

   e. ______________________________

   f. ______________________________

   g. ______________________________

3. Explain the difference between a motor starter and a contactor.

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   ______________________________

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4. Refer to the schematic in Figure 26-7. Assume that when the start button is pressed, the control transformer fuse blows. What is the most likely cause of this trouble?

   ______________________________

   ______________________________

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5. Explain the difference between load and auxiliary contacts.

   ______________________________

   ______________________________

   ______________________________

# Unit 30 Jogging Controls

## Objectives

After studying this unit, you should be able to:

- Describe the difference between inching and jogging circuits.
- Discuss different jogging control circuits.
- Draw a schematic diagram of a jogging circuit.
- Discuss the connection of an 8-pin control relay.
- Connect a jogging circuit in the laboratory using double-acting push buttons.
- Connect a jogging circuit in the laboratory using an 8-pin control relay.

Jogging or inching control is used to help position objects by permitting the motor to be momentarily connected to power. Jogging and inching are very similar and the terms are often used synonymously. Both involve starting a motor with short jabs of power. The difference between jogging and inching is that when a motor is jogged, it is started with short jabs of power at full voltage. When a motor is inched, it is started with short jabs at reduced power. Inching circuits require the use of two contactors, one to run the motor at full power and the other to start the motor at reduced power (Figure 30-1). The run contactor is generally a motor starter that contains an overload relay while the inching contactor does not. In the circuit shown in Figure 30-1, if the inch push button is pressed, a circuit is completed to S contactor coil causing all S contacts to close. This connects the motor to the line through a set of series resistors used to reduce power to the motor. Note that there is no S holding contact in parallel with the inch push button. When the push button is released, S contactor

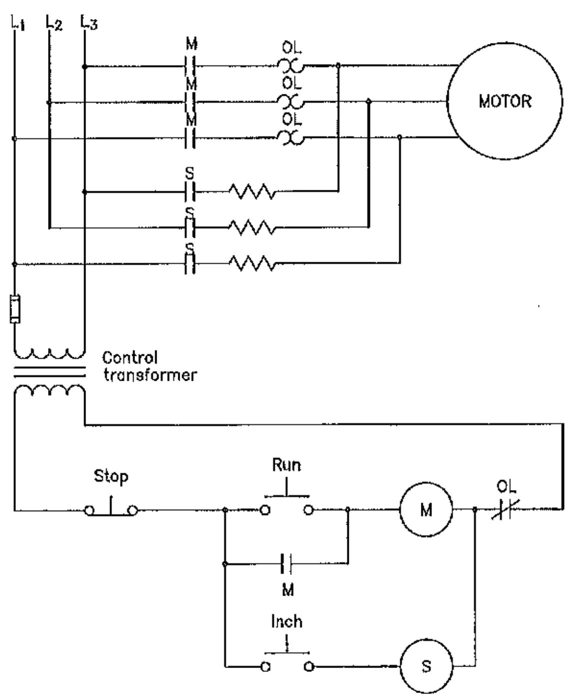



**Figure 30-1** Inching control circuit.

de-energizes and all S contacts reopen and disconnect the motor from the power line. If the run push button is pressed, M contactor energizes and connects the motor directly to the power line. Note the normally open M auxiliary contact connected in parallel with the run push button to maintain the circuit when the button is released.

## Other Jogging Circuits

Like most control circuits, jog circuits can be connected in different ways. One method is shown in Figure 30-2. In this circuit a simple single-pole switch is inserted in series with the normally open M auxiliary contact connected in parallel with the start button. When the switch is open, it is in the *jog* position and prevents M holding contact from providing a complete path to M coil. When the start button is pushed, M coil will energize and connect the motor to the power line. When the start button is released, M coil will de-energize and disconnect the motor from the line. If the switch is closed, it is in the *run* position and permits the holding contact to complete a circuit around the start button.

Another method of constructing a run-jog control is shown in Figure 30-3. This circuit employs a double-acting push button as the jog button. The normally closed section of the jog push button is connected in series with the normally open M auxiliary holding contact. If the jog button is pressed, the normally closed section of the button opens to disconnect the

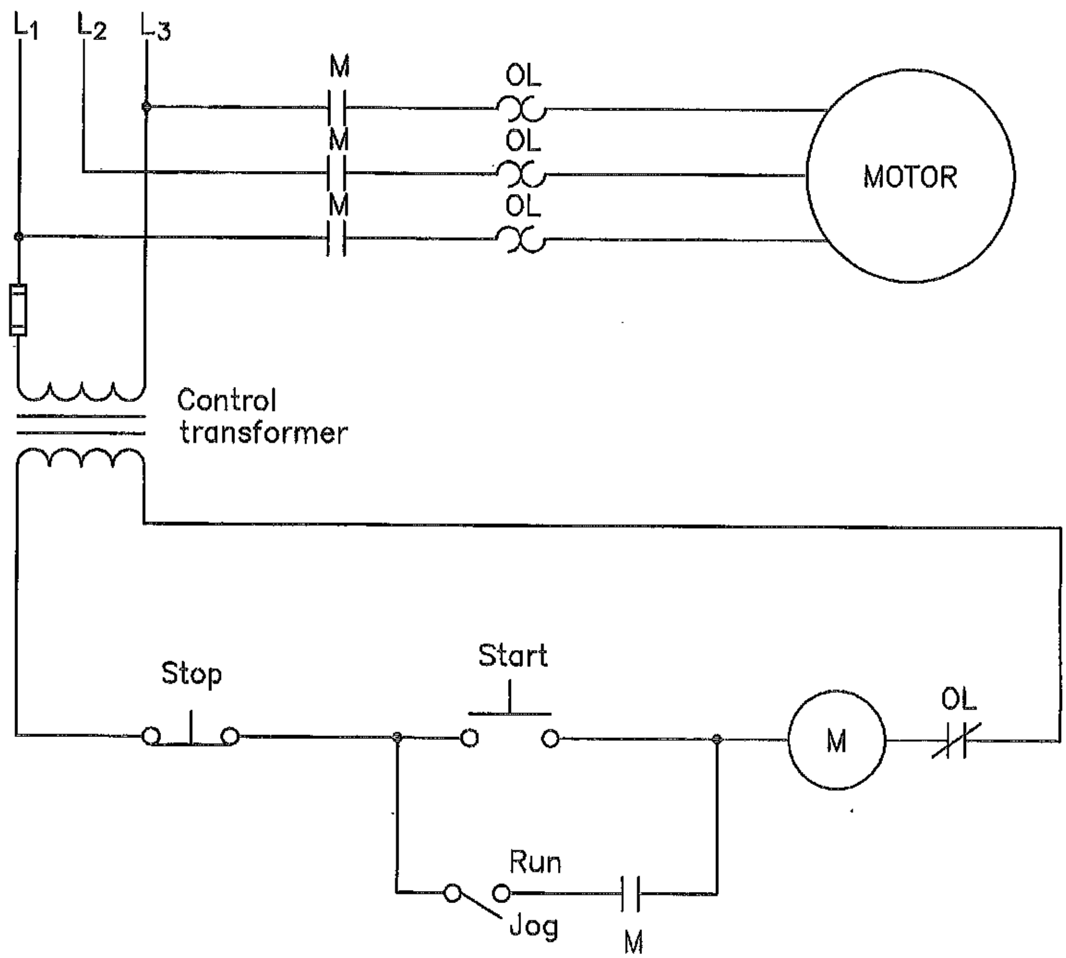



**Figure 30-2** Run-jog controls using a single-pole switch.

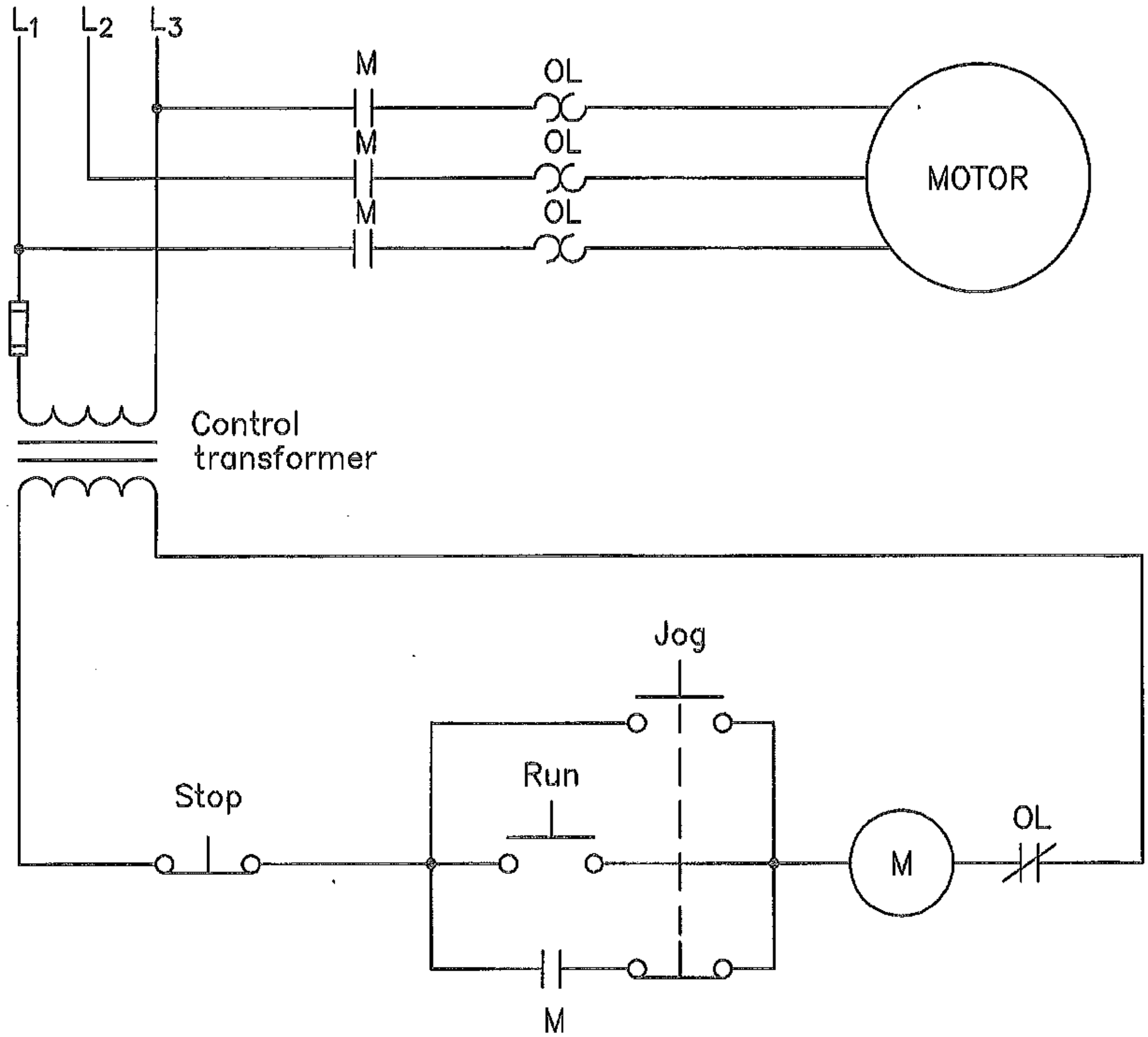



**Figure 30-3** Jogging control using a double-acting push button.

holding contacts before the normally open section of the button closes. Although M auxiliary contact closes when M coil energizes, the now open jog button prevents it from completing a circuit to the coil. When the jog button is released, the normally open section reopens and breaks contact before the normally closed section can reclose.

Although a double-acting push button can be used to construct a run-jog circuit, it is not generally done because there is a possibility that the normally closed section of the jog button could reclose before the normally open section reopens. This could cause the holding contacts to lock the circuit in the run position causing an accident. To prevent this possibility, a control relay is often employed (Figure 30-4). In the circuit shown in Figure 30-4, if the jog push button is pressed, M contactor energizes and connects the motor to the line. When the jog button is released, M coil de-energizes and disconnects the motor from the line.

When the run push button is pressed, CR relay energizes and closes both CR contacts. The CR contacts connected in parallel with the run button close to maintain the circuit to CR coil, and the CR contacts connected in parallel with the jog button close and complete a circuit to M coil.

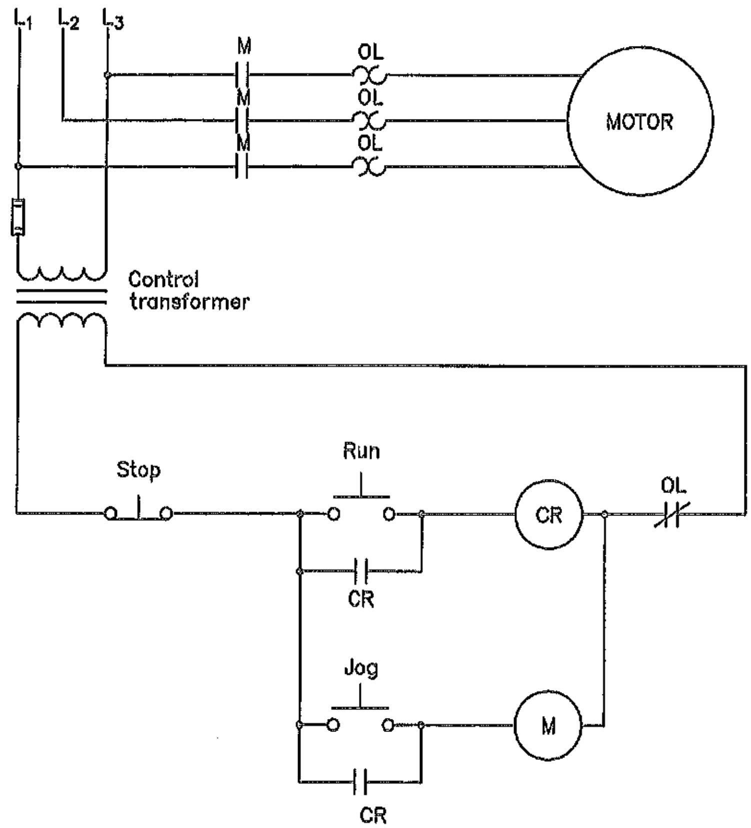



**Figure 30-4** Run-jog control using a control relay.

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

### Materials Required

Three-phase power supply

Three-phase motor starter

1 three-phase motor or equivalent motor load

3 double-acting push buttons (N.O./N.C. on each button)

1 8-pin tube socket

1 8-pin control relay

1 single-pole switch

Control transformer

### Connecting Jogging Circuits

In this experiment four different jog circuits will be connected in the laboratory. Three of these circuits are illustrated in Figures 30-2, 30-3, and 30-4. The fourth circuit will be designed by the student in accord with given circuit parameters.

## Connecting Circuit 1

1. Refer to the schematic diagram in Figure 30-2. Place wire numbers beside the components following the procedure discussed in previous experiments.
2. Using the components shown in Figure 30-5, place corresponding wire numbers beside the components.
3. Connect the circuit by following the wire numbers in the schematic diagram in Figure 30-2.
4. Turn on the power and test the circuit for proper operation. The motor should jog when the switch is open and run when the switch is closed.
5. **Turn off the power** and disconnect the circuit.

## Connecting the Second Run-Jog Circuit

1. Using the schematic shown in Figure 30-3, place wire numbers beside the components.
2. Place corresponding wire numbers beside the components shown in Figure 30-6.
3. Connect the circuit using the schematic diagram in Figure 30-3.
4. After checking with the instructor, turn on the power and test the circuit for proper operation.
5. **Turn off the power** and disconnect the circuit.

## Connecting the Third Run-Jog Circuit

The third run-jog circuit involves the use of a control relay. In this circuit, an 8-pin control relay will be used. Eight-pin relays are designed to fit into an 8-pin tube socket. Therefore, the socket is the device to which connection is made, not the relay itself. Eight-pin relays commonly have coils with different voltage ratings such as 12 VDC, 24 VDC, 24 VAC, and 120 VAC, so make certain that the coil of the relay you use is rated for the circuit control voltage. Most 8-pin relays contain two single-pole, double-throw contacts. A diagram showing the standard pin connection for 8-pin relays with two sets of contacts is shown in Figure 30-7.

## Connecting the Tube Socket

When making connections to tube sockets, it is generally helpful to place the proper relay pin numbers beside the component on the schematic diagram. To distinguish pin numbers from wire numbers, pin numbers will be circled. The schematic in Figure 30-4 is shown in Figure 30-8 with the addition of relay pin numbers. The connection diagram in Figure 30-7 shows that the relay coil is connected to pins 2 and 7. Note that CR relay coil in Figure 30-8 has a circled 2 and 7 placed beside it.

The connection diagram also indicates that the relay contains two sets of normally open contacts. One set is connected to pins 1 and 3, and the other set is connected to pins 8 and 6. Note in the schematic of Figure 30-8 that one of the normally open CR contacts has the circled numbers 1 and 3 beside it and the other normally open CR contact has the circled numbers 8 and 6 beside it.

1. Using the drawing in Figure 30-8, place wire numbers on the schematic.
2. Using the wire numbers placed on the schematic diagram in Figure 30-8, place corresponding wire numbers beside the proper components shown in Figure 30-9.

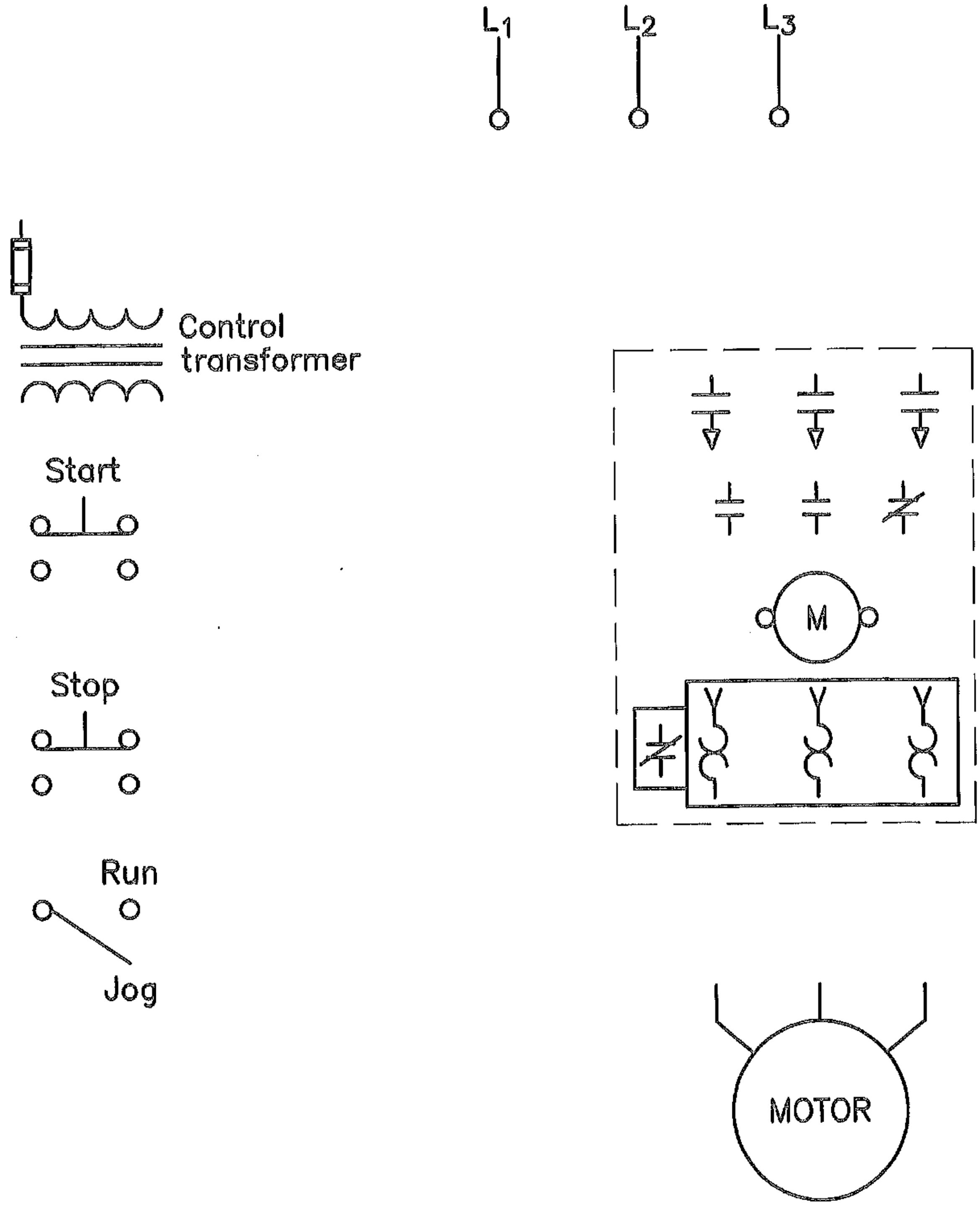



**Figure 30-5** Components needed to connect circuit 1.

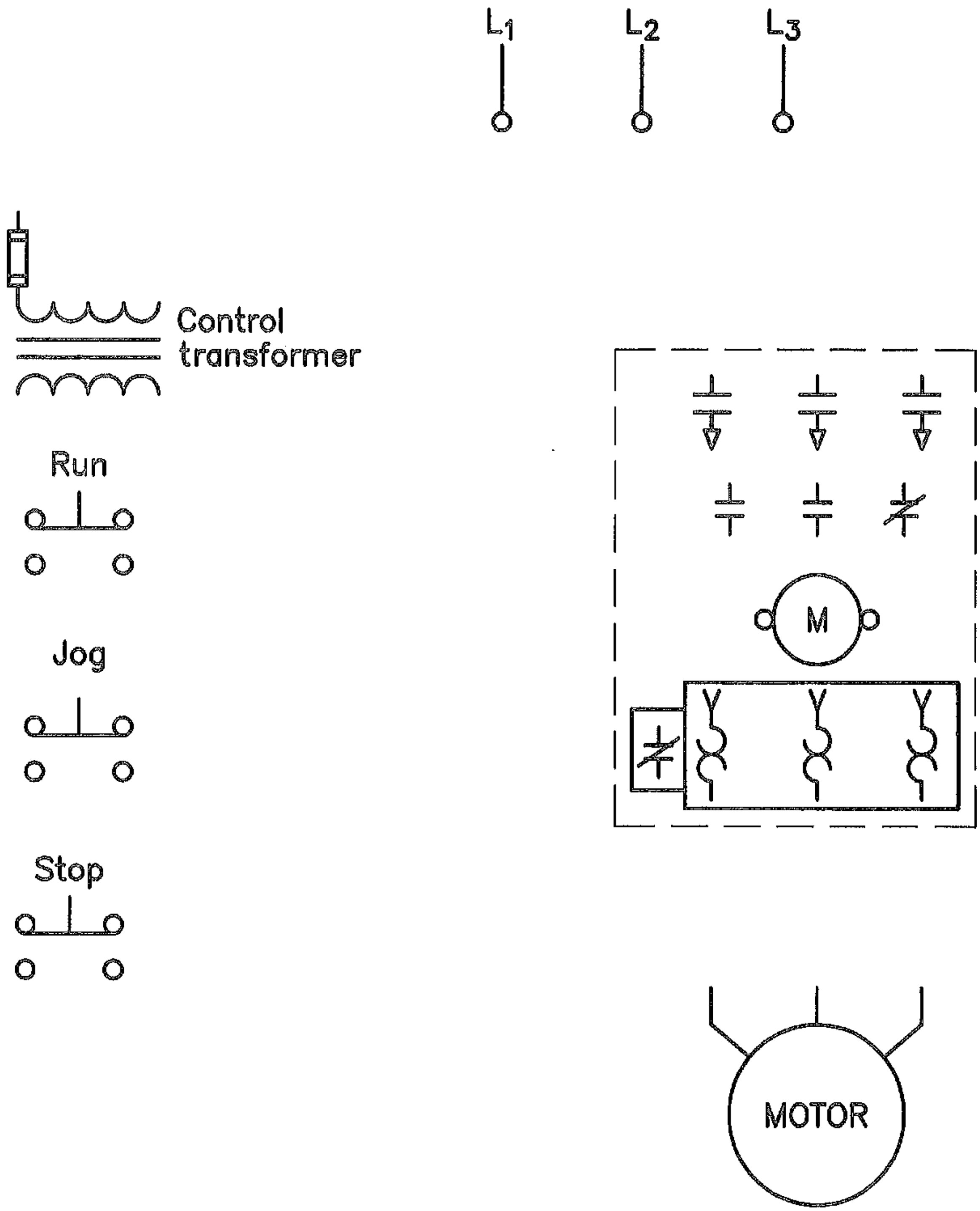
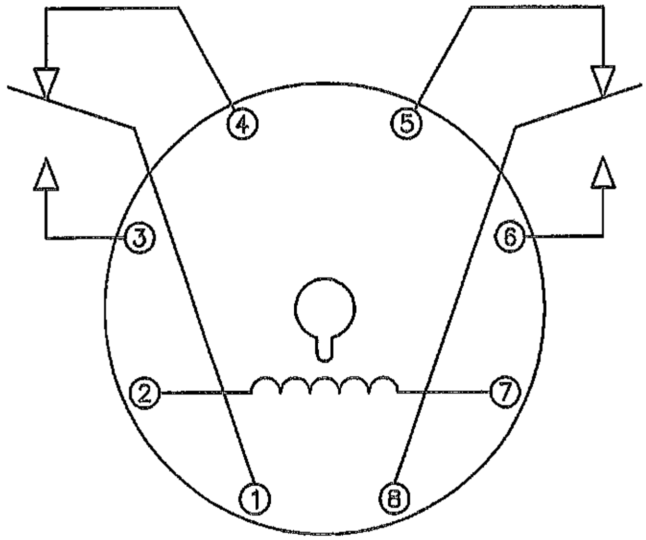
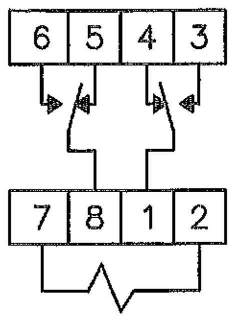



**Figure 30-6** Components needed to connect the second run-jog circuit.




Typical pin connection for an 8-pin relay




Typical 8-pin socket connection

**Figure 30-7** Standard diagram for an 8-pin control relay.

3. Connect the circuit shown in Figure 30-8.
4. After checking with the instructor, turn on the power and test the circuit for proper operation.
5. **Turn off the power** and disconnect the circuit.

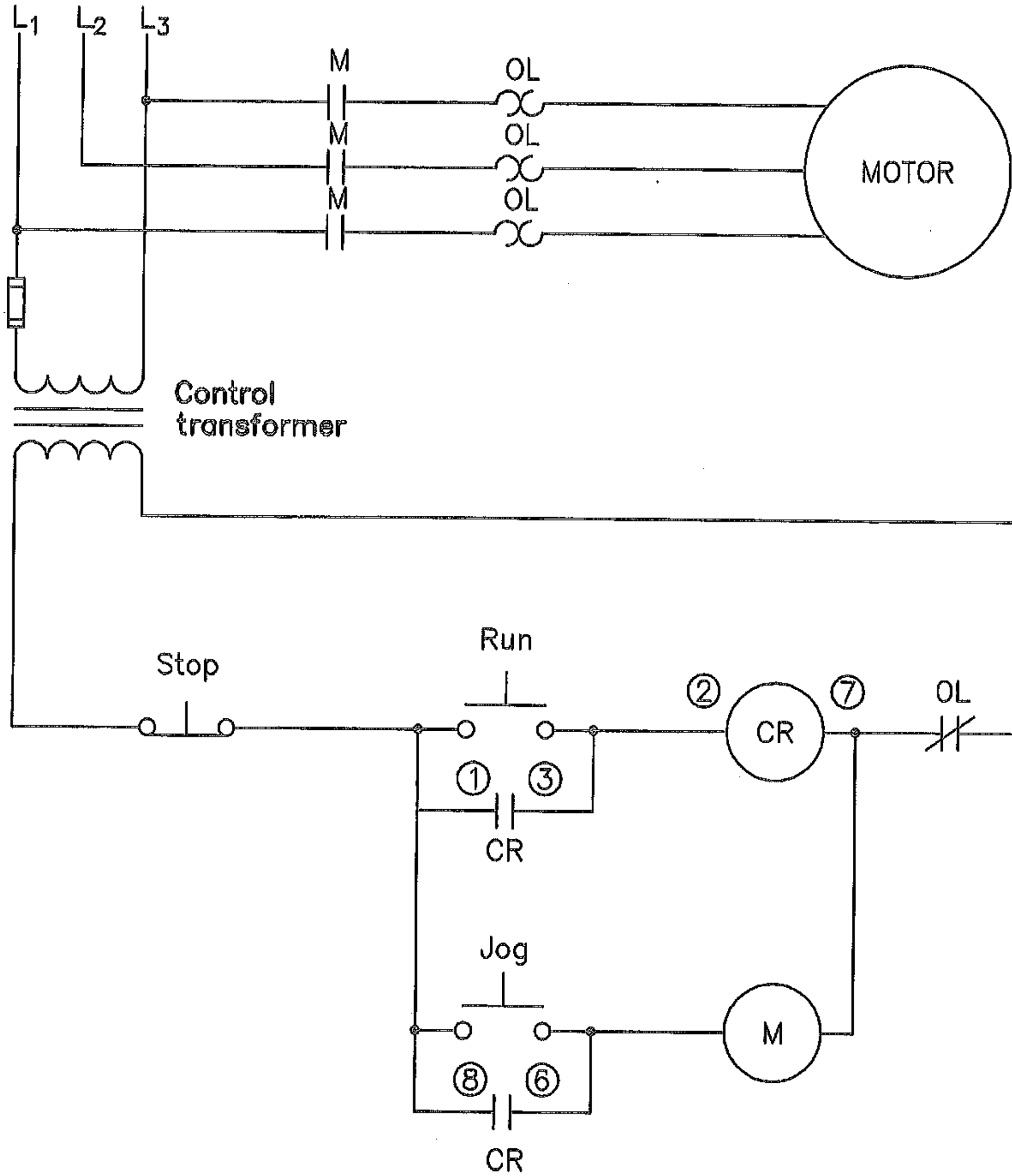



**Figure 30-8** Adding pin numbers aids in connecting the circuit.

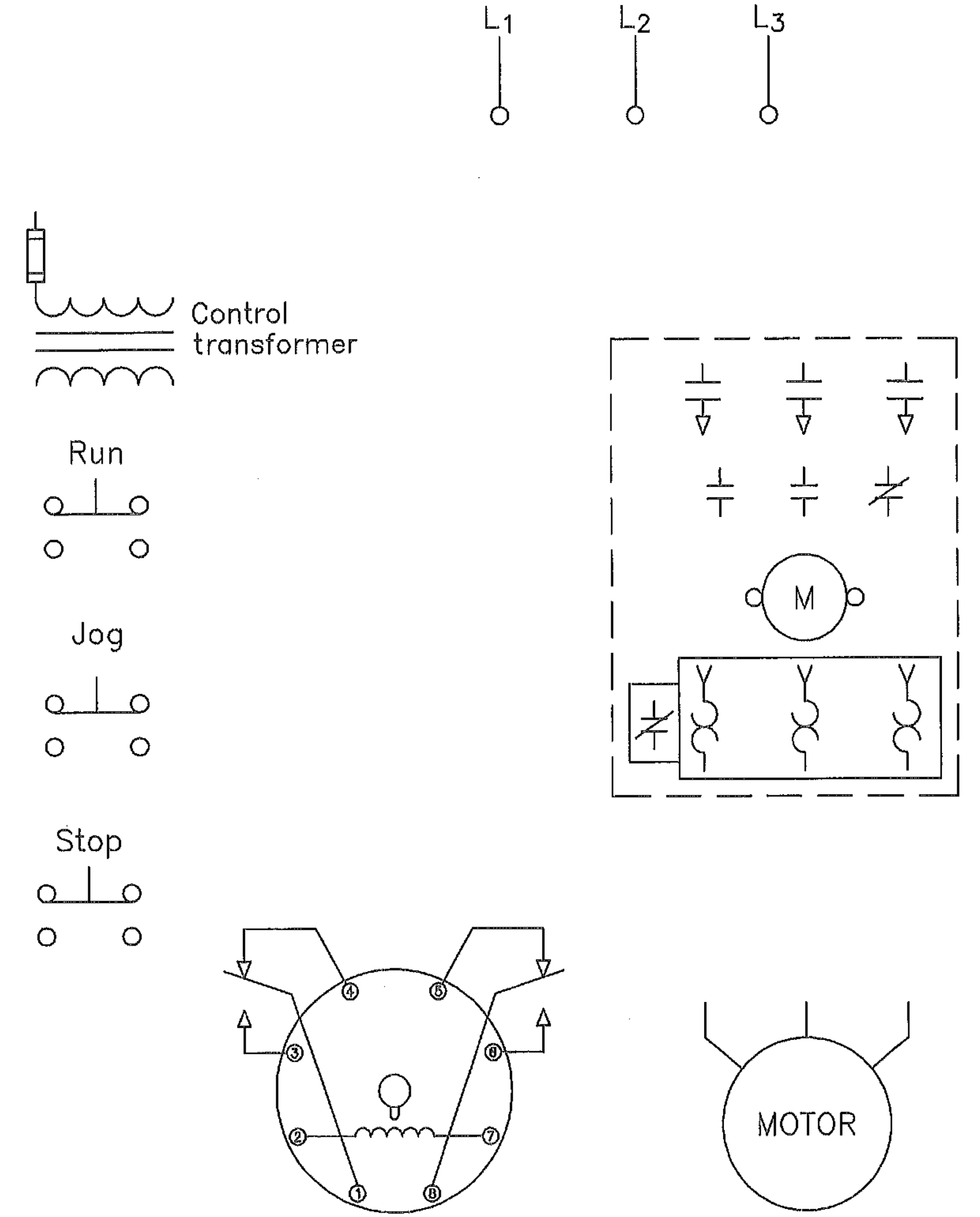



**Figure 30-9** Components for circuit.

## Review Questions

1. Explain the difference between inching and jogging.

2. What is the main purpose of jogging?

3. Refer to the circuit shown in Figure 30-10. In this circuit, the jog button has been connected incorrectly. The normally closed section has been connected in parallel with the run push button and the normally open section has been connected in series with the holding contacts. Explain how this circuit operates.

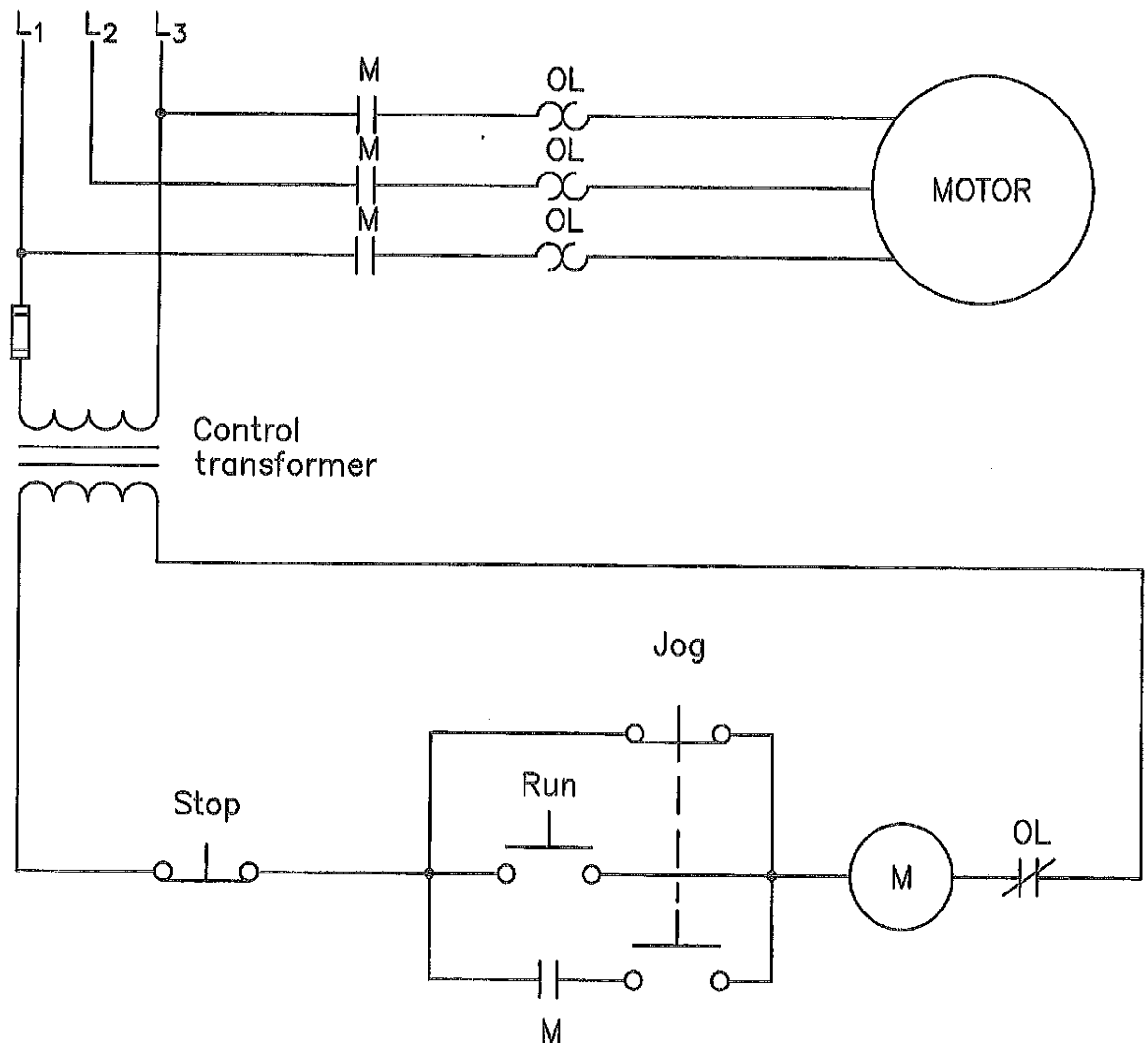



**Figure 30-10** Jog button has been connected incorrectly.

4. Refer to the circuit shown in Figure 30-11. In this circuit the jog push button has again been connected incorrectly. The normally closed section of the button has been connected in series with the normally open run push button and the normally open section of the jog button is connecting in parallel with the holding contacts. Explain how this circuit operates.

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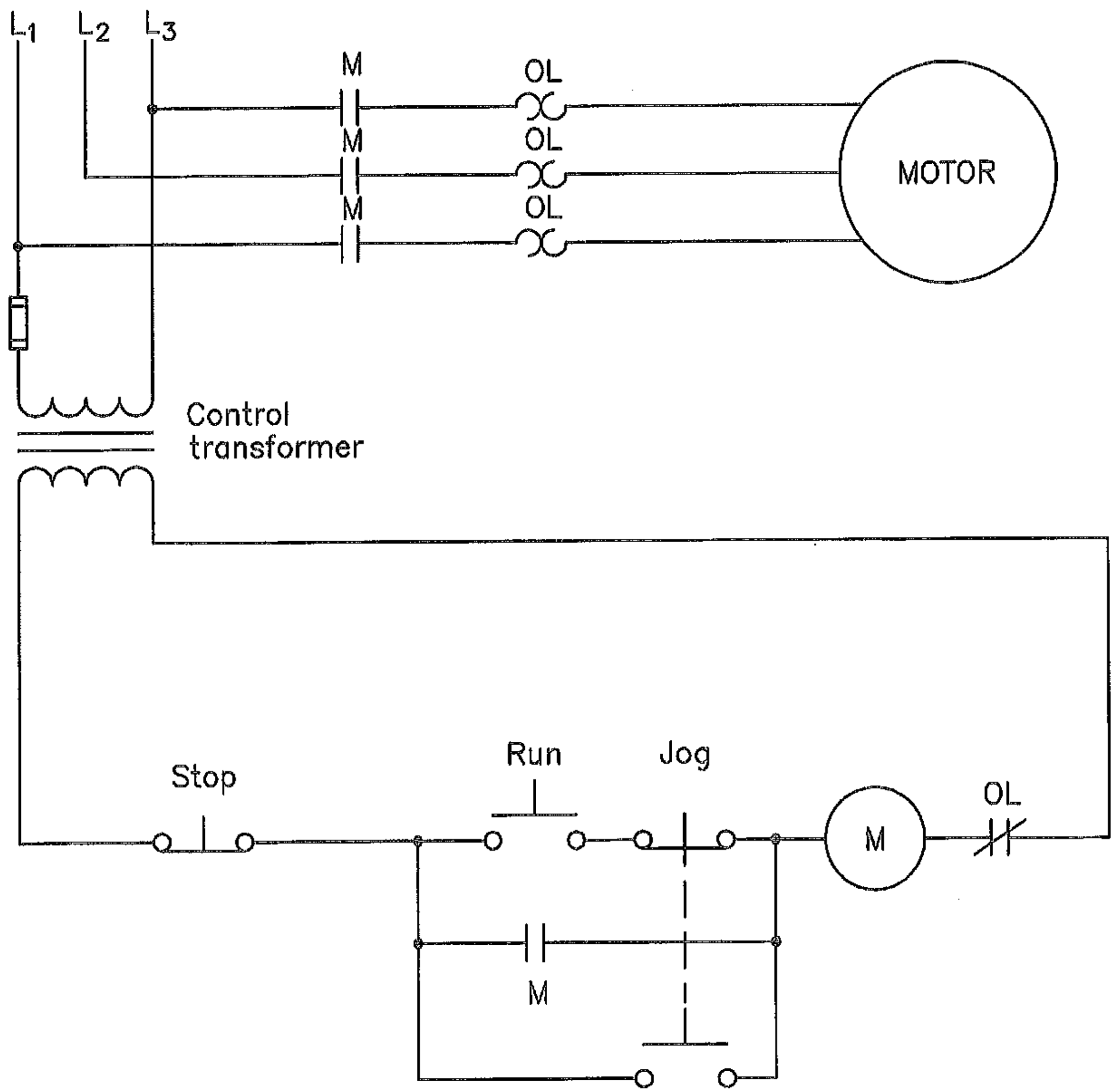


**Figure 30-11** Push button has been connected incorrectly.

5. In the space provided in Figure 30-12, design a run-jog circuit to the following specifications:
   a. The circuit contains two push buttons, a normally closed stop button and a normally open start button.
   b. When the start button is pressed, the motor will run normally. When the stop button is pressed, the motor will stop.
   c. If the stop button is manually held in, however, the motor can be jogged by pressing the start button.
   d. The circuit contains a control transformer, motor, and three-phase motor starter with at least one normally open auxiliary contact.
6. After your instructor has approved the new circuit design, connect the circuit in the laboratory.
7. Turn on the power and test the circuit for proper operation.
8. **Turn off the power** and disconnect the circuit. Return the components to their proper place.

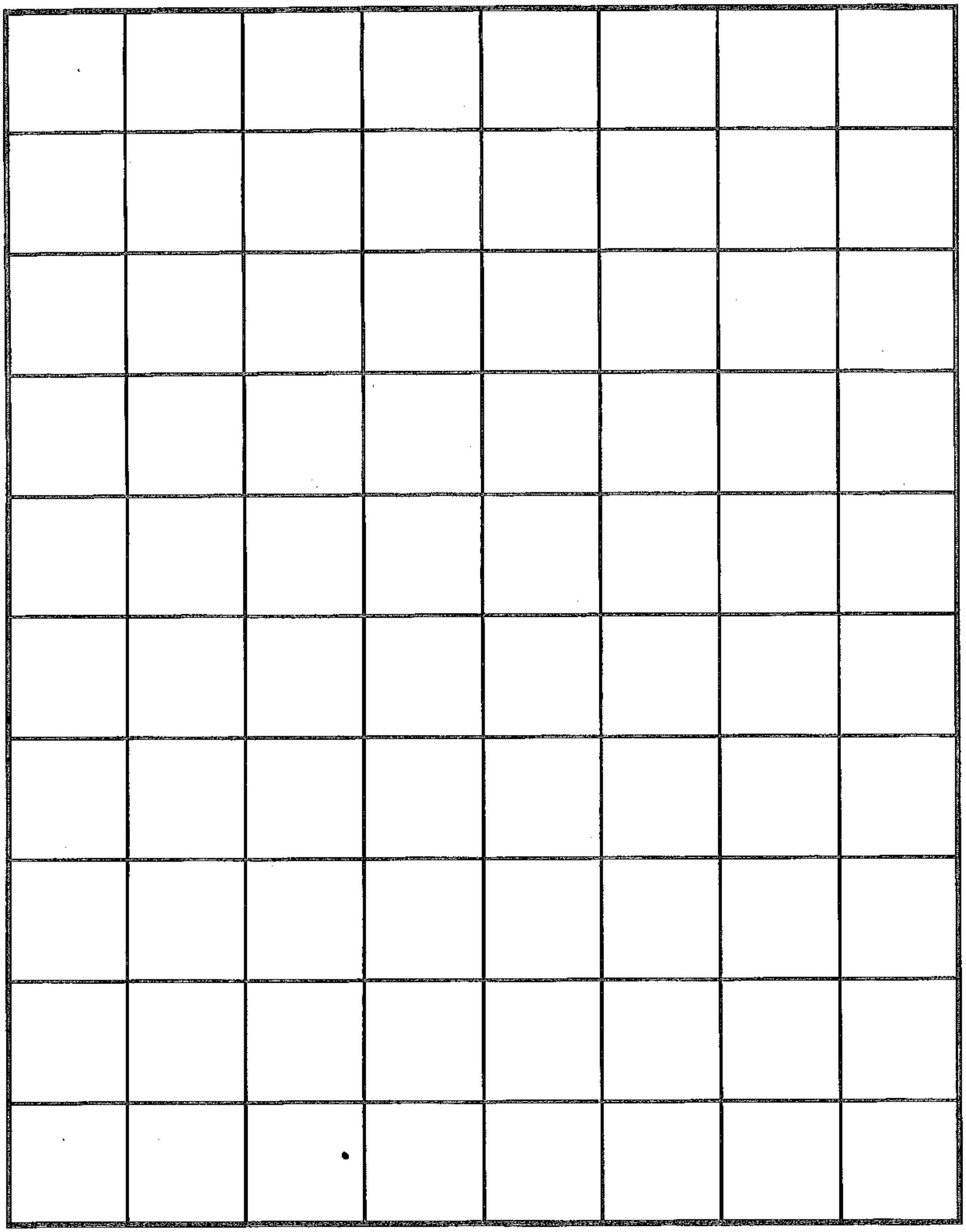

**Figure 30-12** Circuit design.

# Unit 27 Multiple Push-Button Stations

## Objectives

After studying this unit, you should be able to:

- Place wire numbers on a schematic diagram.
- Place corresponding numbers on control components.
- Draw a wiring diagram from a schematic diagram.
- Connect a control circuit using two stop and two start push buttons.

There may be times when it is desirable to have more than one start-stop push-button station to control a motor. In this experiment the basic start-stop push-button control circuit discussed previously will be modified to include a second stop and start push button.

When a component is used to perform the function of stop in a control circuit, it will generally be a normally closed component and be connected in series with the motor starter coil. In this example a second stop push button is to be added to an existing start-stop control circuit. The second push button will be added to the control circuit by connecting it in series with the existing stop push button (Figure 27-1).

When a component is used to perform the function of start, it is generally normally open and connected in parallel with the existing start button (Figure 27-2). If either start button is pressed, a circuit will be completed to M coil. When M coil energizes, all M contacts change position. The three load contacts connected between the three-phase power line and the motor close to connect the motor to the line. The normally open auxiliary contact connected in parallel with the two start buttons close to maintain the circuit to M coil when the start button is released.

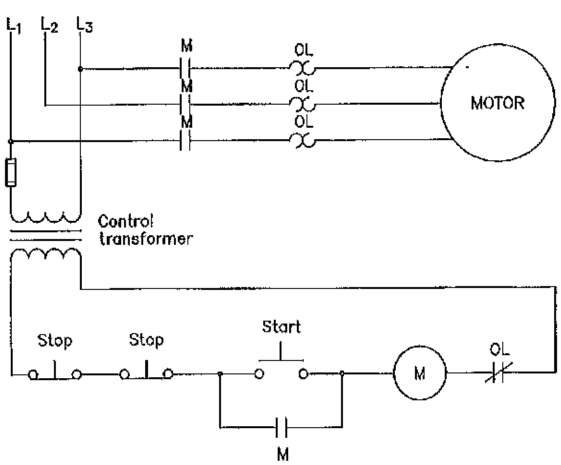


**Figure 27-1** Adding a stop button to the circuit.

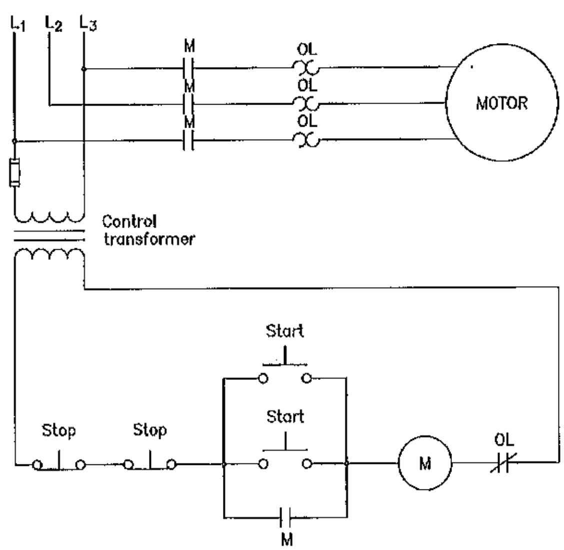


**Figure 27-2** A second start button is added to the circuit.

## Developing the Wiring Diagram

Now that the circuit logic has been developed in the form of a schematic diagram, a wiring diagram will be drawn from the schematic. The components needed to connect this circuit are shown in Figure 27-3. Following the same procedure discussed in Experiment 1, wire numbers will be placed on the schematic diagram (Figure 27-4). After wire numbers are placed on the schematic, corresponding numbers will be placed on the control components (Figure 27-5).

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

## Materials Required

Three-phase power supply

Three-phase squirrel cage induction motor or simulated load

4 double-acting push buttons (N.O./N.C. on same button)

Three-phase motor starter or contactor with overload relay containing three load contacts and at least one normally open auxiliary contact

Control transformer

## Connecting the Circuit

1. Using the schematic in Figure 27-4 or the diagram with numbered components in Figure 27-5, connect the circuit in the laboratory by connecting all like numbers together.

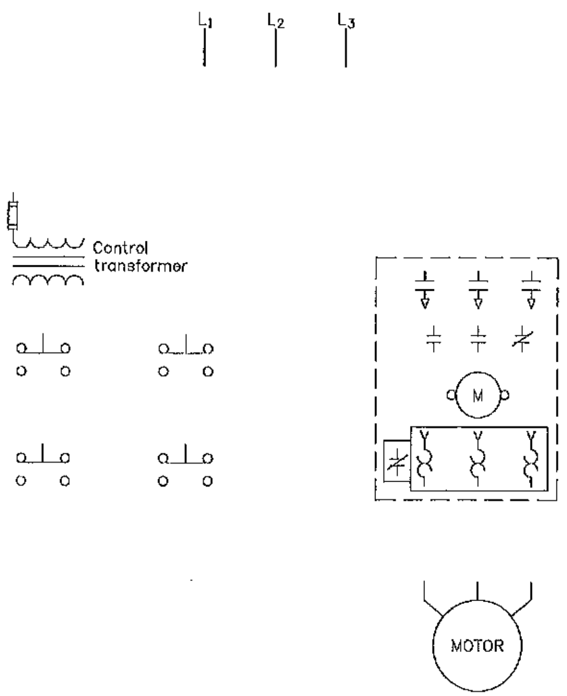


**Figure 27-3** Components needed to produce a wiring diagram.

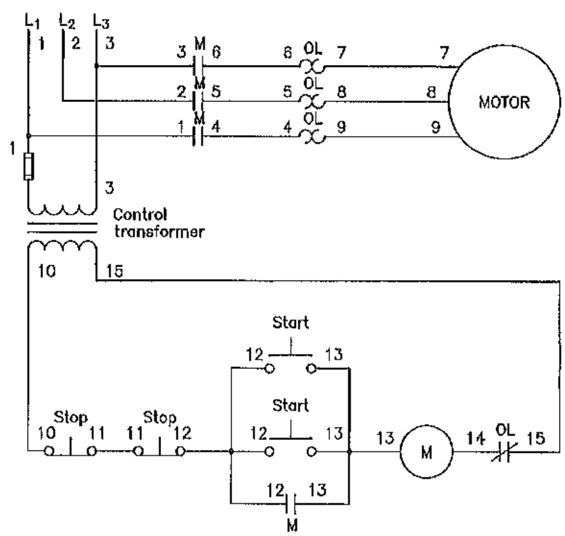


**Figure 27-4** Numbering the schematic diagram.

2. After the circuit has been connected, check with your instructor before turning on the power.
3. Turn on the power and test the circuit for proper operation.
4. **Turn off the power** and disconnect the circuit. Return all components to their proper place.

## Review Questions

1. When a component is to be used for the function of start, is the component generally normally open or normally closed?

___

2. When a component is to be used for the function of stop, is the component generally normally open or normally closed?

___

3. The two stop push buttons in Figure 27-2 are connected in series with each other. What would be the action of the circuit if they were to be connected in parallel as shown in Figure 27-6?

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4. What would be the action of the circuit if both start buttons were to be connected in series as shown in Figure 27-7?

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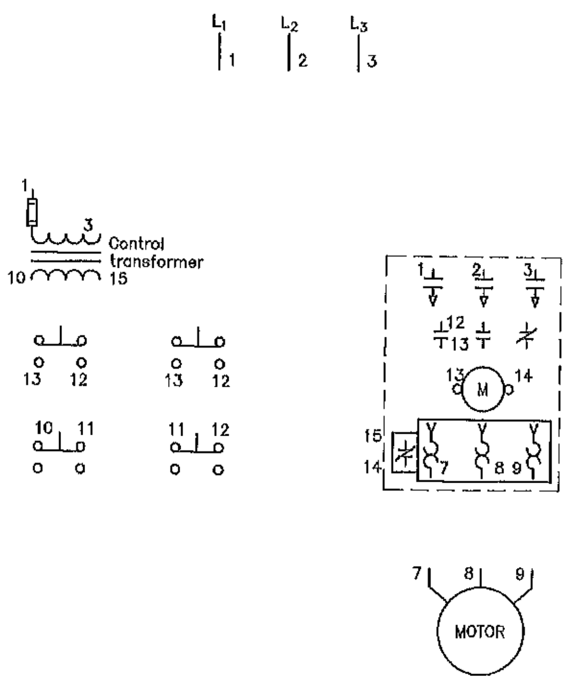


**Figure 27-5** Numbering the components.

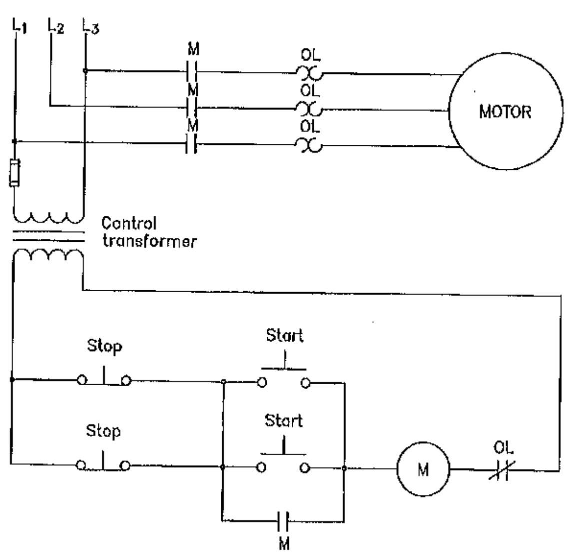


**Figure 27-6** The stop buttons are connected in parallel.

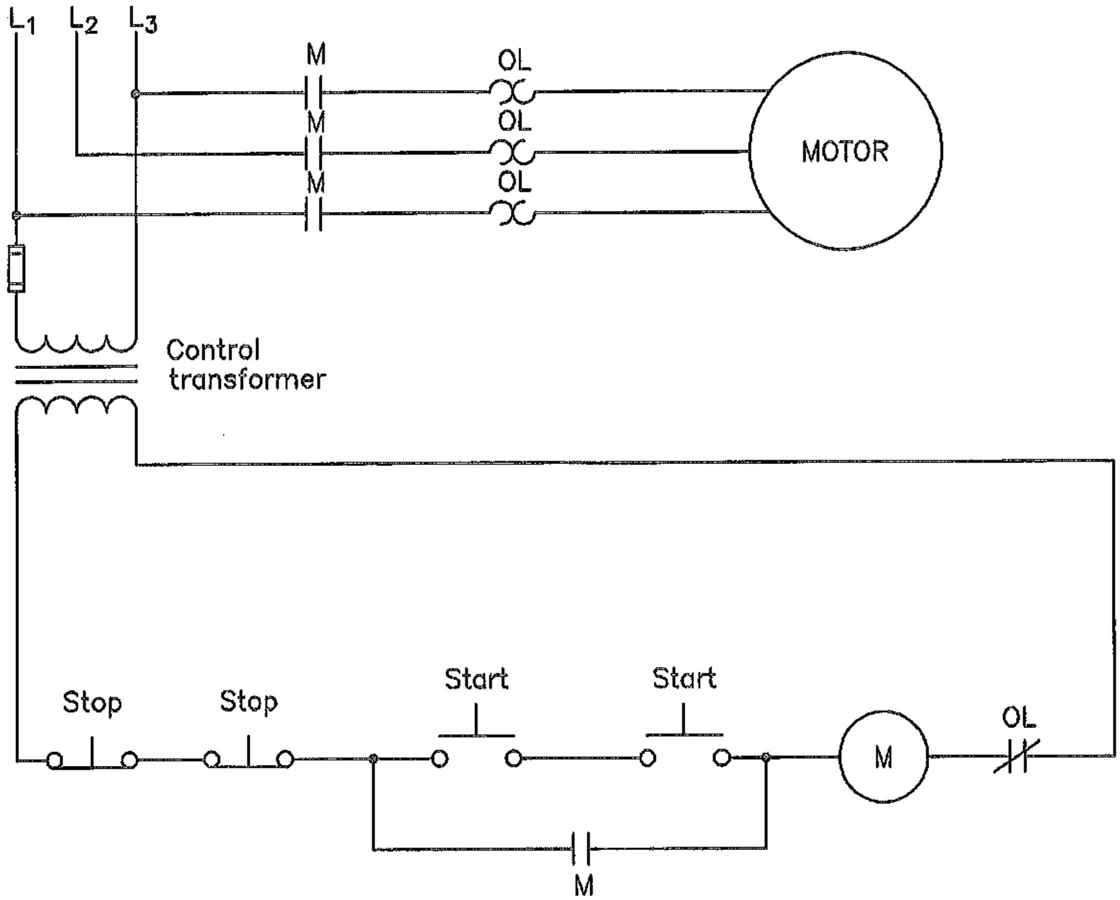


**Figure 27-7** The start buttons are connected in series.

5. Following the procedure discussed previously, place wire numbers on the schematic in Figure 27-7. Place corresponding wire numbers on the components shown in Figure 27-8.

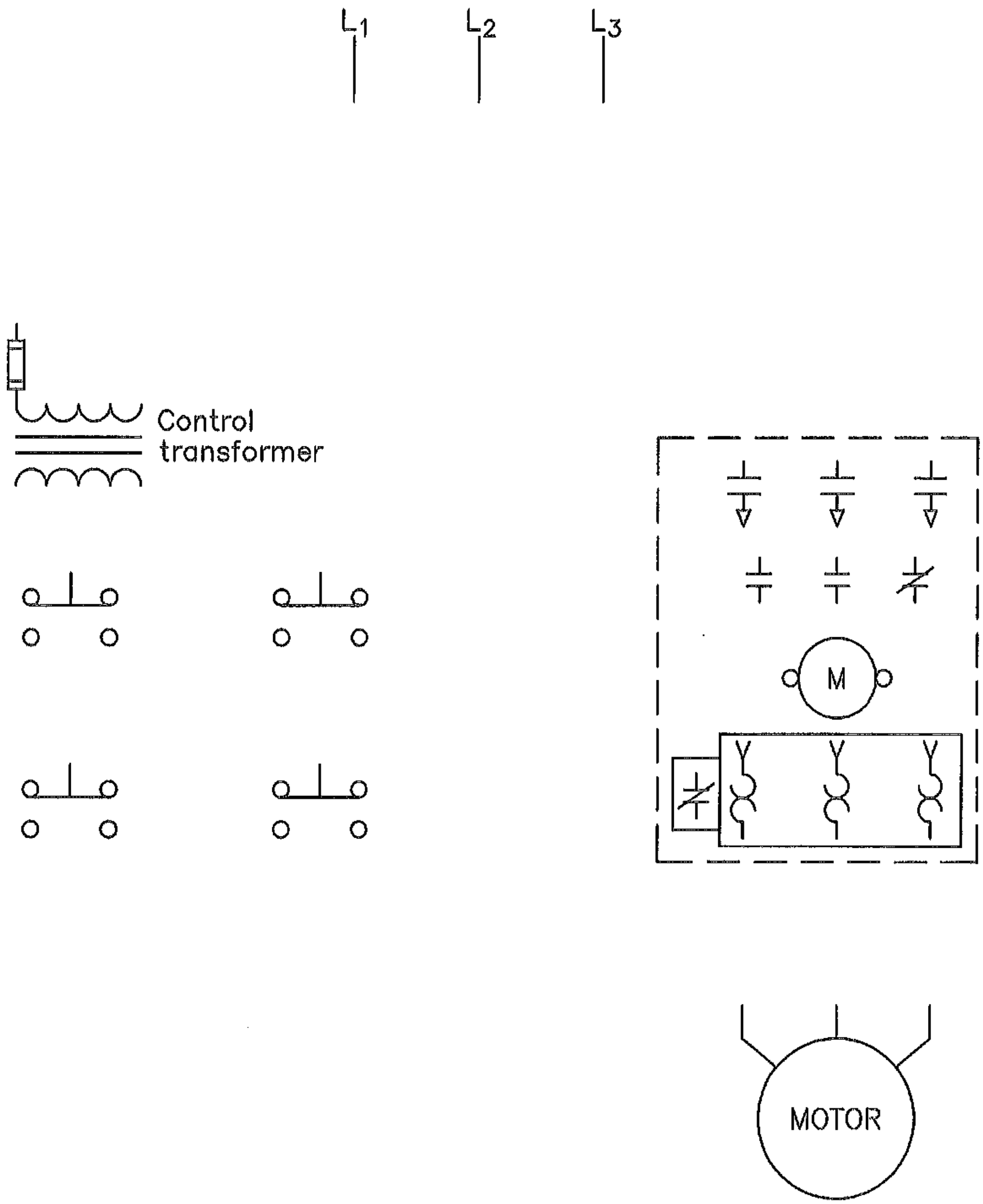


**Figure 27-8** Add wire numbers to these components.

# Unit 31 On-Delay Timers

## Objectives

After studying this unit, you should be able to:

- Discuss the operation of an on-delay timer.
- Draw the NEMA contact symbols used to represent both normally open and normally closed on-delay contacts.
- Discuss the difference in operation between pneumatic and electronic timers.
- Connect a circuit in the laboratory employing an on-delay timer.

Timers can be divided into two basic types: on-delay and off-delay. Although there are other types such as one shot and interval, they are basically an on- or off-delay timer. In this unit the operation of on-delay timers is discussed. The operating sequence of an on-delay timer is as follows:

When the coil is energized, the timed contacts will delay changing position for some period of time. When the coil is de-energized, the timed contacts will return to their normal position immediately. In this explanation, the word "timed contacts" is used. The reason is that some timers contain both timed and instantaneous contacts. When using a timer of this type, care must be taken to connect to the proper set of contacts.

**Helpful Hint**

When the coil is energized, the timed contacts will delay changing position for some period of time. When the coil is de-energized, the timed contacts will return to their normal position immediately.

## Timed Contacts

The timed contacts are controlled by the action of the timer, while the instantaneous contacts operate like any standard set of contacts on a control relay; when the coil energizes, the contacts change position immediately, and when the coil de-energizes they change back to their normal position immediately.

The standard NEMA symbols used to represent on-delay contacts are shown in Figure 31-1. The arrow points in the direction the contact will move after the delay period. The normally open contact, for example, will close after the time delay period, and the normally closed contact will open after the time delay period.

## Instantaneous Contacts

Instantaneous contacts are drawn in the same manner as standard relay contacts. Figure 31-2 illustrates a set of instantaneous contacts controlled by timer TR. The instantaneous contacts are often used as holding or sealing contacts in a control circuit. The control circuit shown in Figure 31-3 illustrates an on-delay timer used to delay the starting of a motor.

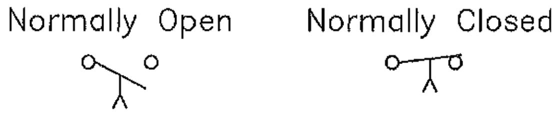


**Figure 31-1** NEMA standard symbols for on-delay contacts.

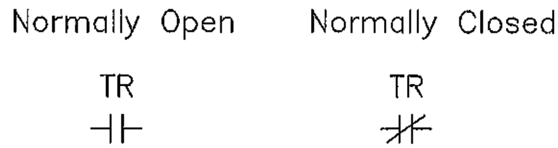


**Figure 31-2** Instantaneous contact symbols.

When the start push button is pressed, TR coil energizes and the normally open instantaneous TR contacts close immediately to hold the circuit. After the preset time period, the normally open TR timed contacts will close and energize the coil of M starter, which connects the motor to the line.

When the stop button is pressed and TR coil de-energizes, both TR contacts return to their normal position immediately. This de-energizes M coil and disconnects the motor from the line.

## Control Relays Used with Timers

Not all timers contain instantaneous contacts. Most electronic timers, for example, do not. When an instantaneous contact is needed and the timer does not have one available, it is common practice to connect the coil of a control relay in parallel with the coil of the timer (Figure 31-4). In this way the electronic timer will operate with the timer. In the circuit shown in Figure 31-4, both coils TR and CR will energize when the start button is pressed. This causes CR contact to close and seal the circuit.

## Time Delay Methods

Although there are two basic types of timers, there are different methods employed to obtain a time delay. One of the oldest methods still in general use is the pneumatic timer. Pneumatic timers use a bellows or diaphragm and operate on the principle of air displacement. Some type

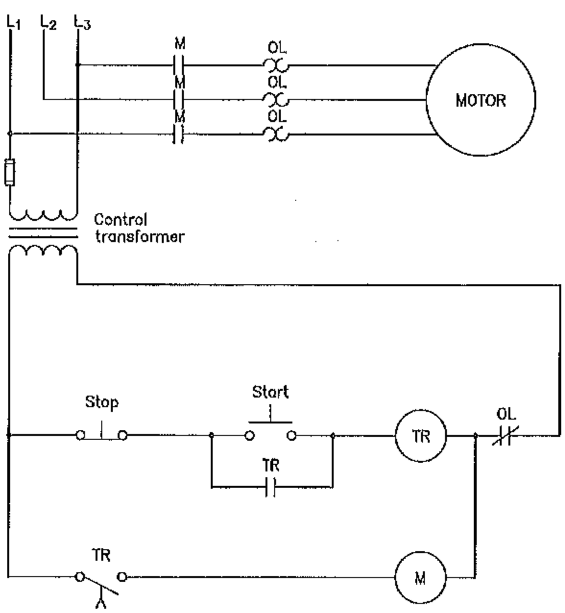


**Figure 31-3** The motor starts after the start button is pressed.

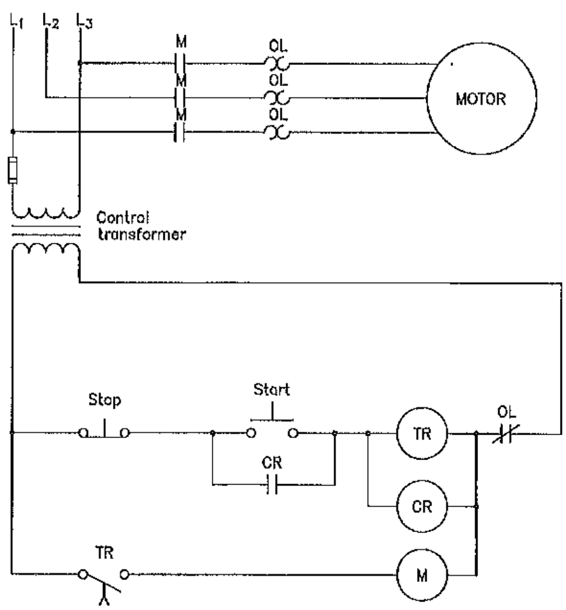


**Figure 31-4** A control relay furnishes the instantaneous contact.

of needle valve is generally used to regulate the airflow and thereby regulate the time delay. Pneumatic timers are simple in that they contain a coil, contacts, and some method of adjusting the amount of time delay. Because of their simplicity of operation, when control circuits are in the design stage, the circuit logic is generally developed with the assumption that pneumatic timers will be used. After the circuit logic has been developed, it may be necessary to make changes that will accommodate a particular type of timer.

Another very common method of providing a time delay is with an electric clock similar to a wall clock. These timers contain a small single-phase synchronous motor. As a general rule, most clock timers can be set for different full-scale values by changing the gear ratio.

Electronic timers are becoming very popular for several reasons:

1. They are much less expensive than pneumatic or clock timers.
2. They have better repeat accuracy than pneumatic or clock timers.
3. Most can be set for 0.1-second delays and many can be set to an accuracy of 0.01 second.
4. Many electronic timers are intended to be plugged into an 8- or 11-pin tube socket. This makes replacing the timer much simpler and takes less time.

## LABORATORY EXERCISE

Name ______________________________ Date __________

### Materials Required

Three-phase power supply

Control transformer

2 double-acting push buttons (N.O./N.C. on each button)

2 three-phase motor starters with at least one normally open auxiliary contact

Dayton Solid-State Timer—model 6A855 or equivalent and 11-pin socket

8-pin control relay and 8-pin socket

2 three-phase motors or equivalent motor loads

### The First Circuit

The first circuit to be connected is shown in Figure 31-4. In this circuit it will be assumed that an 11-pin timer is being used and that the coil is connected to pins 2 and 10, and a set of normally open timed contacts is connected to pins 1 and 3. The coil of the 8-pin control relay is connected to pins 2 and 7 and a normally open contact is connected to pins 1 and 3. When using control devices that are connected with 8- and 11-pin sockets, it is generally helpful to place pin numbers beside the component. To prevent pin numbers from being confused with wire numbers, a circle will be drawn around the pin numbers (Figure 31-5).

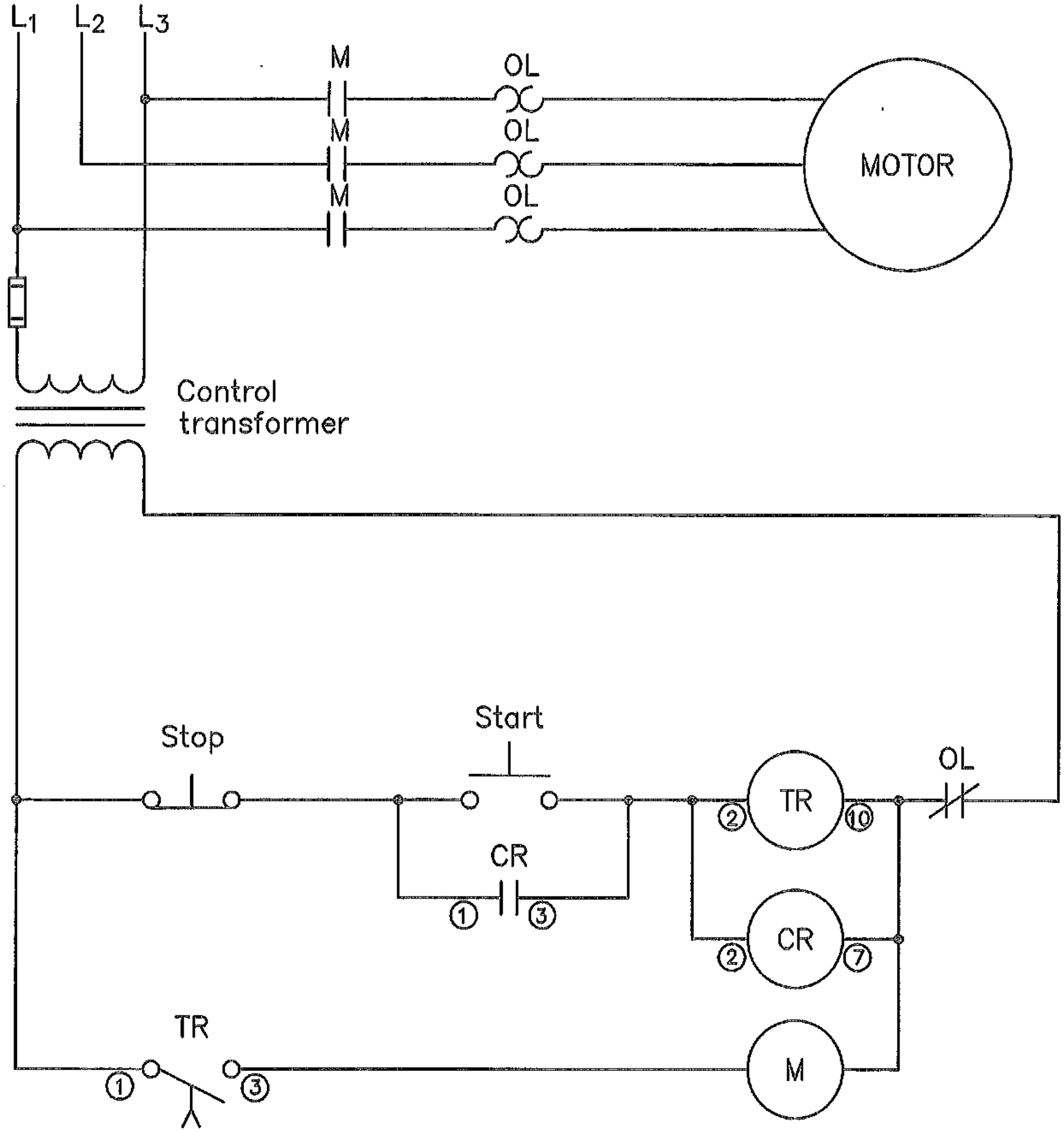


**Figure 31-5** Placing pin numbers beside the components.

## Connecting Circuit #1

1. Using the circuit shown in Figure 31-5, place wire numbers beside the components.
2. Connect the control part of the circuit by following the wire numbers placed beside the components. Note the pin numbers beside the coils and contacts of the timer and control relay.
3. Plug the timer and control relay into their appropriate sockets. Set the timer to operate as an on-delay timer and set the time period for 5 seconds.
4. After checking with the instructor, turn on the power and test the operation of the circuit.
5. **Turn off the power.**

6. If the control part of the circuit operated correctly, connect the motor or equivalent motor load.
7. Turn on the power and test the total circuit for proper operation.
8. **Turn off the power** and disconnect the circuit.

## Discussing Circuit #2

In the next circuit, two motors are to be started with a 5-second time delay between the starting of the first motor and the second motor. In this circuit a normally open auxiliary contact on starter 1M is used as the holding contact, making the use of the control relay unnecessary.

When the start button is pressed, coils 1M and TR energize immediately. This causes motor #1 to start operating and timer TR to begin timing. After 5 seconds, TR contacts close and connect motor #2 to the line. When the stop button is pressed, or if an overload on either motor should occur, all coils will be de-energized and both motors will stop.

## Connecting Circuit #2

1. Using the circuit shown in Figure 31-6, place pin numbers beside the timer coil and normally open contact.
2. Place wire numbers on the circuit in Figure 31-6.
3. Connect the control part of the circuit.
4. Turn on the power and test the circuit for proper operation.
5. **Turn off the power.**
6. If the control part of the circuit operated properly, connect the motors or equivalent motor loads.
7. Turn on the power and test the circuit for proper operation.
8. **Turn off the power** and disconnect the circuit.

## Review Questions

1. Explain the operation of an on-delay timer.

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2. Explain the difference between timed contacts and instantaneous contacts.

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3. Refer to the circuit shown in Figure 31-3. If the timer has been set for a delay of 10 seconds, explain the operation of the circuit when the start button is pressed.

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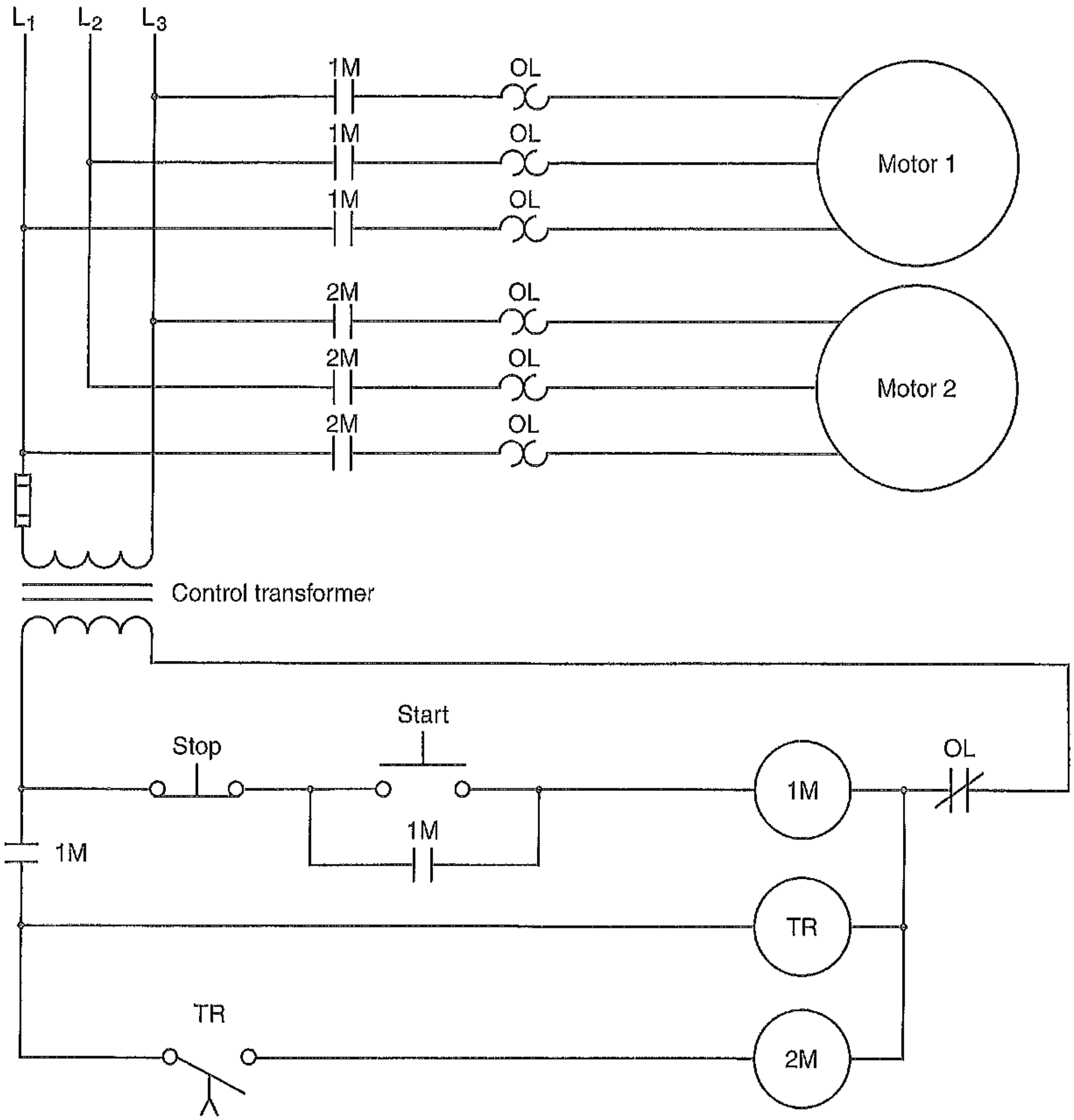


**Figure 31-6** Motor 2 starts after motor 1.

4. In the circuit shown in Figure 31-3, is it necessary to hold the start button closed for a period of at least 10 seconds to ensure that the circuit will remain energized? Explain your answer.

5. Assume that the timer in Figure 31-3 is set for a delay of 10 seconds. Now assume that the start button is pressed, and after a delay of 8 seconds the stop button is pressed. Will the motor start 2 seconds after the stop button is pressed?

6. What is generally done to compensate when a set of instantaneous timer contacts is needed and the timer does not contain them?

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7. Refer to the circuit shown in Figure 31-6. Assume that it is necessary to stop the operation of both motors after the second motor has been operating for a period of 10 seconds. Using the space provided in Figure 31-7, redraw the circuit to turn off both motors after the second motor has been in operation for 10 seconds. (Note: It will be necessary to use a second timer.)

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8. After your instructor has approved the design change, connect the new circuit in the laboratory and test it for proper operation.

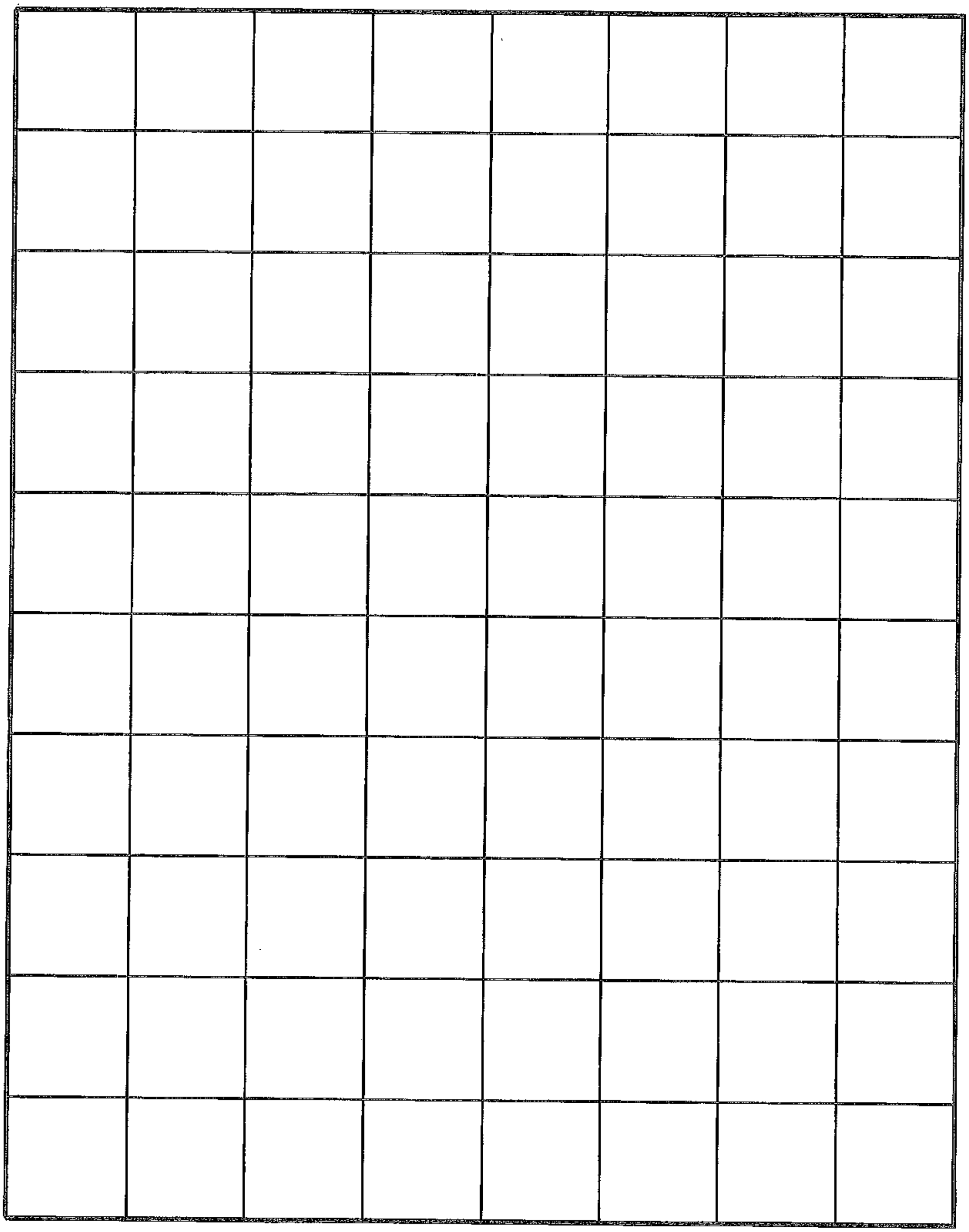

**Figure 31-7** Circuit redesign.

# Unit 32 Off-Delay Timers

## Objectives

After studying this unit, you should be able to:

- Discuss the operation of an off-delay timer.
- Draw the NEMA contact symbols used to represent both normally open and normally closed off-delay contacts.
- Discuss the difference in operation between pneumatic and electronic timers.
- Connect a circuit in the laboratory employing an off-delay timer.

The logic of an off-delay timer is as follows: When the coil is energized, the timed contacts change position immediately. When the coil is de-energized, the timed contacts remain in their energized position for some period of time before changing back to their normal position. Figure 32-1 shows the standard NEMA contact symbols used to represent an off-delay timer. Notice that the arrow points in the direction the contact will move after the time delay period. The arrow indicates that the normally open contact will delay reopening and that the normally closed contact will delay reclosing. Like on-delay timers, some off-delay timers will contain instantaneous contacts as well as timed contacts, and some will not.

**Helpful Hint**

When the coil is energized, the timed contacts change position immediately. When the coil is de-energized, the timed contacts remain in their energized position for some period of time before changing back to their normal position.

## Example Circuit #1

The circuit shown in Figure 32-2 illustrates the logic of an off-delay timer. It will be assumed that the timer has been set for a delay of 5 seconds. When switch $S_1$ closes, TR coil energizes. This causes the normally open TR contacts to close immediately and turn on the lamp. When switch $S_1$ opens, TR coil will de-energize, but the TR contacts will remain closed

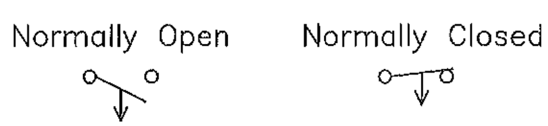


**Figure 32-1** NEMA standard symbols for off-delay contacts.

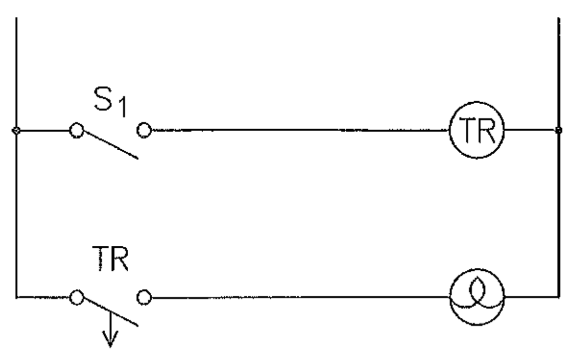


**Figure 32-2** Basic operation of an off-delay timer.

for 5 seconds before they reopen. Notice that the time delay period does not start until the coil is de-energized.

## Example Circuit #2

In the second example it is assumed that timer TR has been set for a delay of 10 seconds. Two motors start when the start button is pressed. When the stop button is pressed, motor #1 stops operating immediately, but motor #2 continues to run for 10 seconds (Figure 32-3). In this circuit the coil of the off-delay timer has been placed in parallel with motor starter 1M, permitting the action of the timer to be controlled by the first motor starter.

## Example Circuit #3

Now assume that the logic of the previous circuit is to be changed so that when the start button is pressed both motors still start at the same time, but when the stop button is pressed, motor #2 must stop operating immediately and motor #1 continues to run for 10 seconds. In this circuit the action of the timer must be controlled by the operation of starter 2M instead of starter 1M (Figure 32-4). In the circuit shown in Figure 32-4, a control relay is used to energize both motor starters at the same time. Notice that timer coil TR energizes at the same time as starter 2M, causing the normally open TR contacts to close around the CR contact connected in series with coil 1M.

When the stop button is pressed, coil CR de-energizes and all CR contacts open. Power is maintained to starter 1M, however, by the now closed TR contacts. When the CR contact connected in series with coils 2M and TR opens, these coils de-energize, causing motor #2 to stop operating and starting the time sequence for the off-delay timer. After a delay of 10 seconds, TR contacts reopen and de-energize coil 1M, stopping the operation of motor #1.

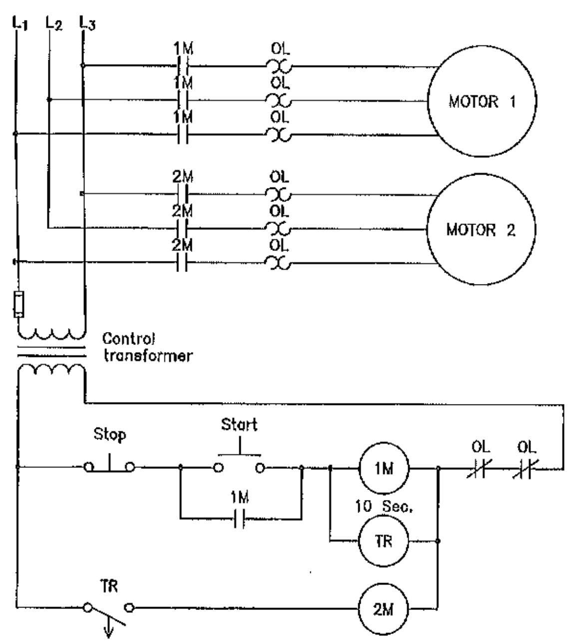


**Figure 32-3** Off-delay motor circuit using pneumatic timer.

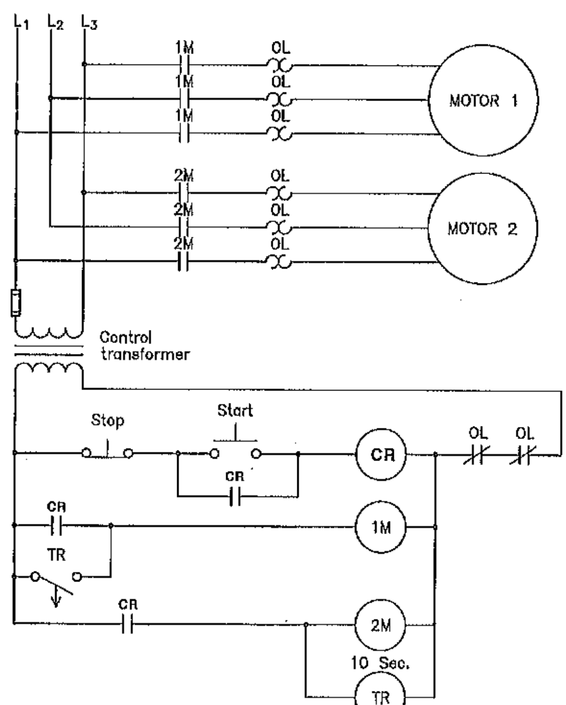


**Figure 32-4** Motor 1 stops after motor 2.

## Using Electronic Timers

In the circuits shown in Figure 32-3 and Figure 32-4, it was assumed that the off-delay timers were of the pneumatic type. It is common practice to develop circuit logic assuming that the timers are of the pneumatic type. The reason for this is that the action of a pneumatic timer is controlled by the coil being energized or de-energized. The action of the timer is dependent on air pressure, not an electric circuit. This, however, is generally not the case when using solid-state time delay relays. Solid-state timers that can be used as off-delay timers are generally designed to be plugged into an 11-pin tube socket. The pin connection for a Dayton model 6A855 timer is shown in Figure 32-5. Although this is by no means the only type of electronic timer available, it is typical of many.

Notice in Figure 32-5 that power is connected to pins 2 and 10. When this timer is used in the on-delay mode, there is no problem with the application of power because the time sequence starts when the timer is energized. When power is removed, the timer de-energizes and the contacts return to their normal state immediately.

An off-delay timer, however, does not start the timing sequence until the timer is de-energized. Since this timer depends on an electronic circuit to operate the timing mechanism, power must be connected to the timer at all times. Therefore, some means other than disconnecting the power must be used to start the timing circuit. This particular timer uses pins 5 and 6

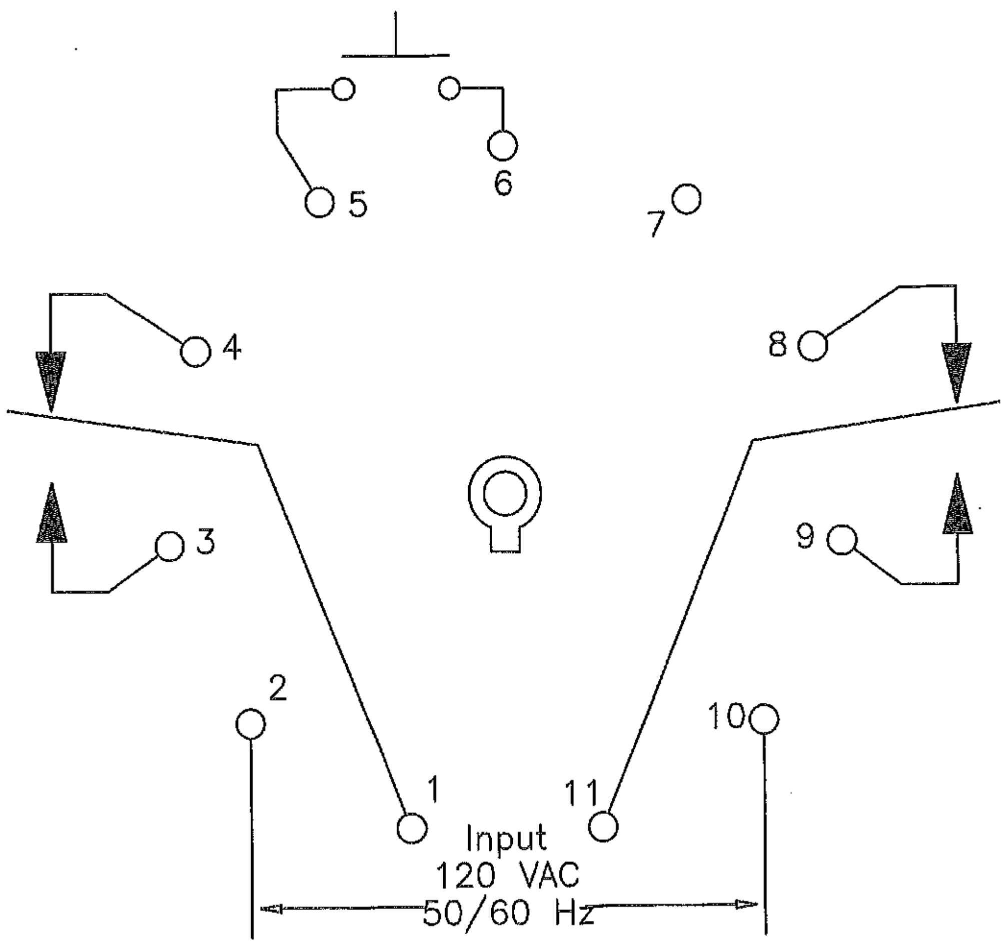


**Figure 32-5** Connection diagram for a Dayton model 6A855 timer.

to start the operation. The diagram in Figure 32-5 uses a start switch to illustrate this operation. When pins 5 and 6 are shorted together, it has the effect of energizing the coil of an off-delay timer and all contacts change position immediately. The timer will remain in this state as long as pins 5 and 6 are short circuited together. When the short circuit between pins 5 and 6 is removed, it has the effect of de-energizing the coil of a pneumatic off-delay timer and the timing sequence will start. At the end of the time period, the contacts will return to their normal position.

## LABORATORY EXERCISE

Name ______________________________ Date __________

### Materials Required:

Three-phase power supply

Control transformer

2 double-acting push buttons (N.O./N.C. on each button)

2 three-phase motor starters with at least one normally open auxiliary contact

Dayton Solid-State Timer—model 6A855 or equivalent

11-pin control relay and two 11-pin sockets

2 three-phase motors or equivalent motor loads

### Amending Circuit #1

The circuit in Figure 32-3 has been amended in Figure 32-6 to accommodate the use of an electronic timer. Notice in this circuit that power is connected to pins 2 and 10 of the timer at all times. Since the action of the timer in the original circuit is that the coil of the timer operates at the same time as starter coil 1M, an auxiliary contact on starter 1M will be used to control the action of timer TR. When the start button is pressed, coil 1M energizes and all 1M contacts close. This connects motor #1 to the line, the 1M contact in parallel with the start button seals the circuit, and the normally open 1M contact connected to pins 5 and 6 of the timer closes and starts the operation of the timer. When timer pins 5 and 6 become shorted, the timed contact connected in series with 2M coil closes and energizes starter 2M.

When the stop button is pressed, coil 1M de-energizes and all 1M contacts return to their normal position, stopping the operation of motor #1. When the 1M contacts connected to timer pins 5 and 6 reopen, the timing sequence of the timer begins. After a delay of 10 seconds, timed contact TR reopens and disconnects starter coil 2M from the circuit. This stops the operation of motor #2.

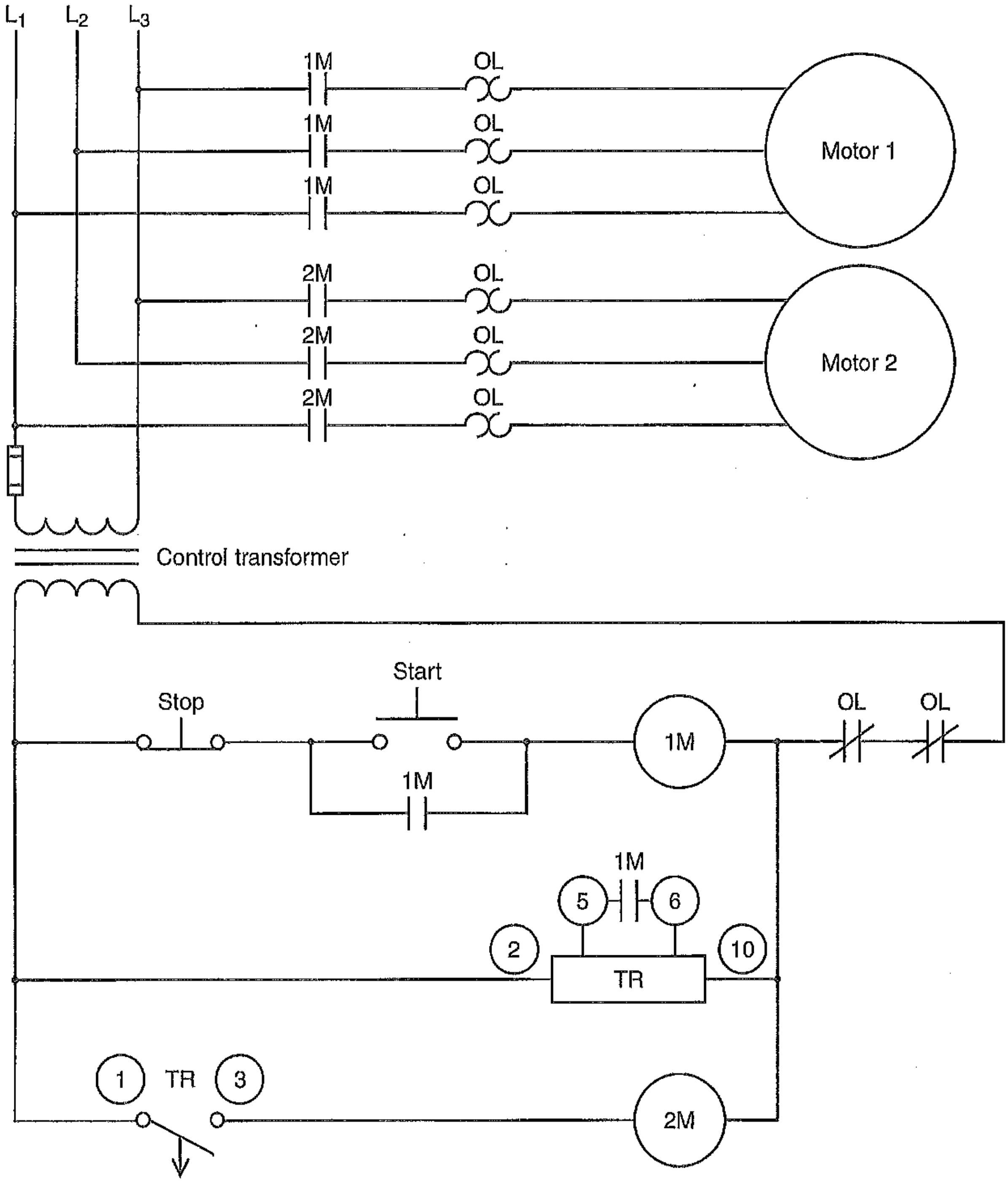


**Figure 32-6** Amending the first circuit for an electronic timer.

## Amending Circuit #2

Circuit #2 will be amended in much the same way as circuit #1. The timer must have power connected to it at all times (Figure 32-7). Notice in this circuit that the action of the timer is controlled by starter 2M instead of 1M. When coil 2M energizes, a set of normally open 2M contacts closes and shorts pins 5 and 6 of the timer. When coil 2M de-energizes, the 2M auxiliary contacts reopen and start the time sequence of timer TR.

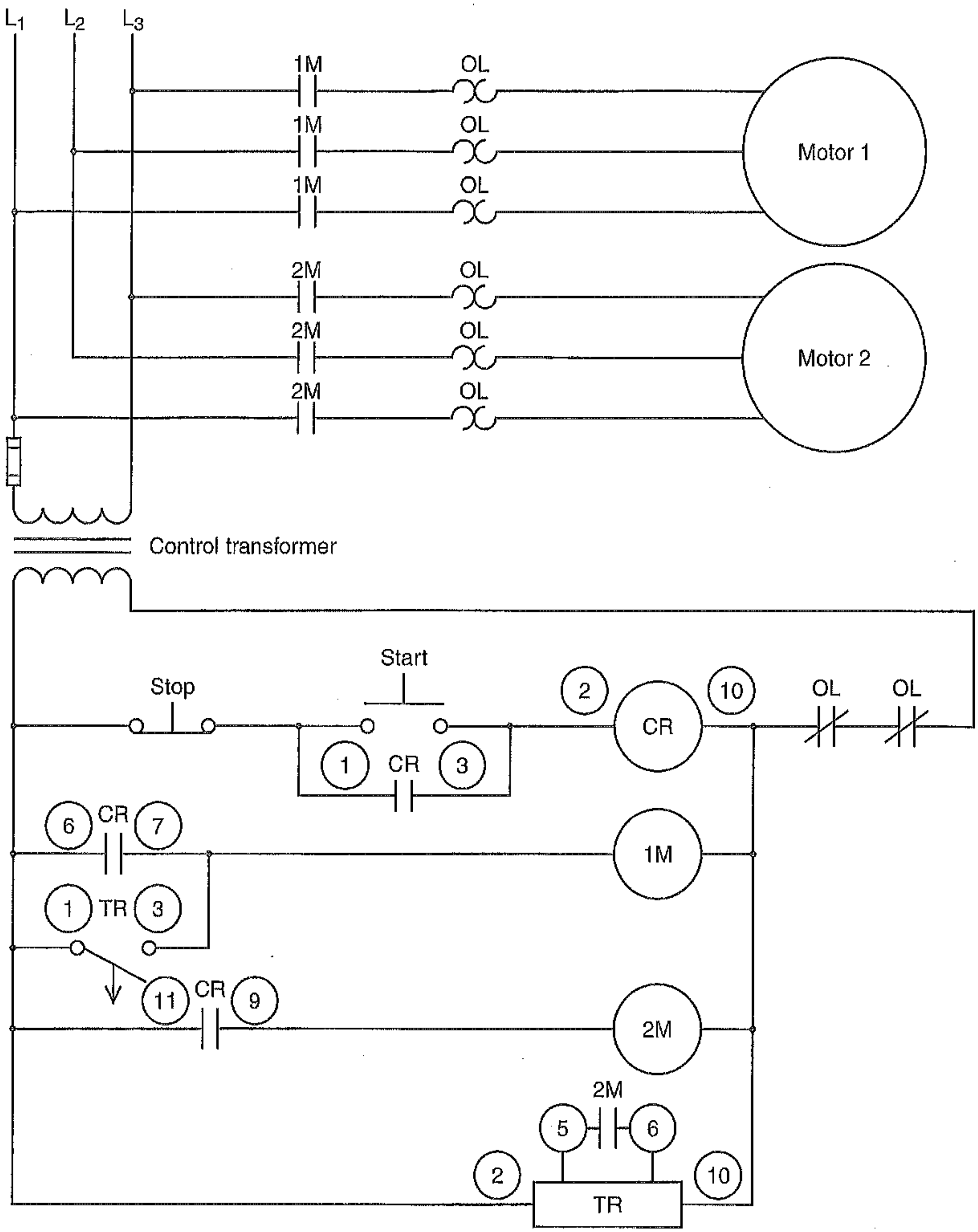


**Figure 32-7** Amending circuit 2 for an electronic timer.

Circuit #2 assumes the use of an 11-pin control relay instead of an 8 pin. An 11-pin control relay contains three sets of contacts instead of two. Figure 32-8 shows the connection diagram for most 11-pin control relays. Notice that normally open contacts are located on pins 1 and 3, 6 and 7, and 9 and 11. The coil pins are 2 and 10. Pin numbers have been placed beside the components in Figure 32-7.

## Connecting the First Circuit

1. Place wire numbers on the schematic shown in Figure 32-6.
2. Using an 11-pin tube socket, connect the control part of the circuit in Figure 32-6.
3. Set the electronic timer to operate as an off-delay timer and set the time delay for 10 seconds.
4. Plug the timer into the tube socket and turn on the power.
5. Test the control part of the circuit for proper operation.
6. If the control portion of the circuit operated properly, connect the motors or equivalent motor loads and test the entire circuit for proper operation.
7. **Turn off the power** and disconnect the circuit.

## Connecting the Second Circuit

1. Place wire numbers on the schematic diagram shown in Figure 32-7.
2. Using two 11-pin tube sockets, connect the control part of the circuit.
3. Set the electronic timer to operate as an off-delay timer and set the time delay for 10 seconds.
4. Plug the timer and control relay into the tube sockets and turn on the power.
5. Test the control part of the circuit for proper operation.

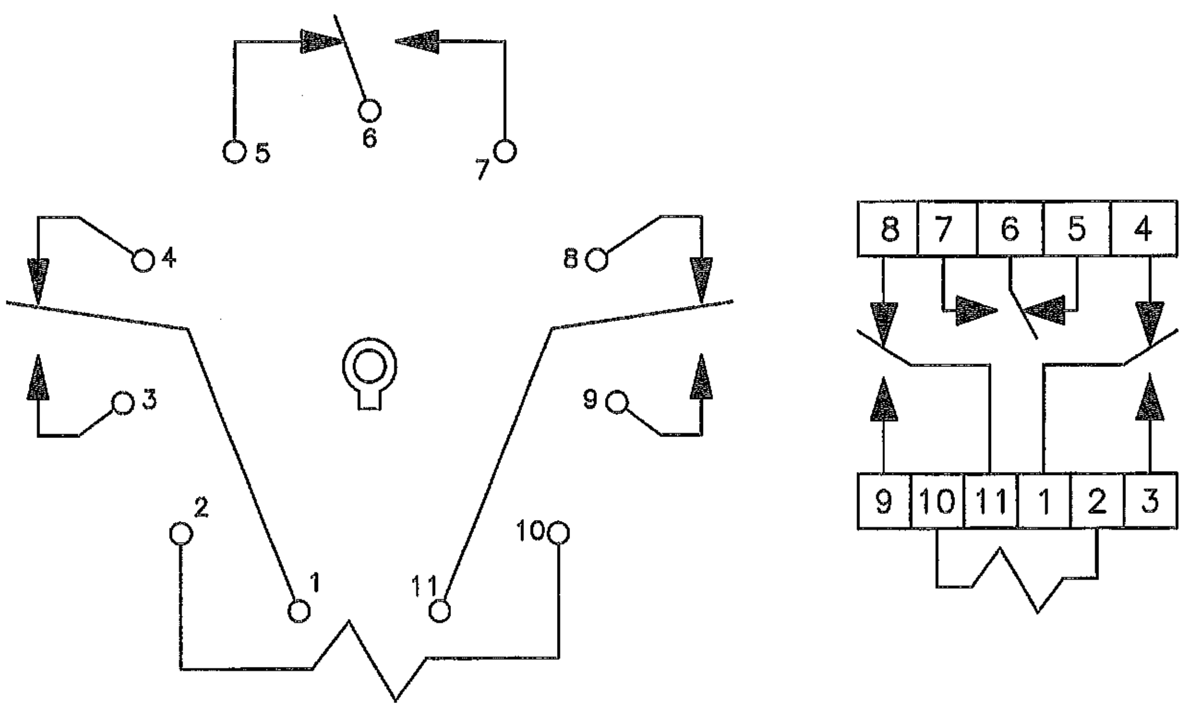


**Figure 32-8** Connection diagram for an 11-pin control relay.

6. If the control portion of the circuit operated properly, connect the motors or equivalent motor loads and test the entire circuit for proper operation.
7. **Turn off the power** and disconnect the circuit.
8. Return the components to their proper location.

## Review Questions

1. Describe the operation of an off-delay timer.

2. Why is it common practice to develop circuit logic assuming all timers are of the pneumatic type?

3. Refer to the schematic diagram shown in Figure 32-6. Assume that starter coil 2M is open. Describe the action of the circuit when the start button is pressed and when the stop button is pressed.

4. Refer to the circuit shown in Figure 32-7. Assume that when the start button is pressed, motor #1 starts operating immediately, but motor #2 does not start. When the stop button is pressed, motor #1 stops operating immediately. Which of the following could cause this condition?
   a. 1M coil is open.
   b. 2M coil is open.
   c. Timer TR is not operating.
   d. CR coil is open.
5. Refer to the circuit shown in Figure 32-7. When the start button is pressed, both motors #1 and #2 start operating immediately. When the stop button is pressed, motor #2 stops operating immediately, but motor #1 remains running and does not turn off after the time delay period has expired. Which of the following could cause this condition?
   a. CR contacts are shorted together.
   b. 2M auxiliary contacts connected to pins 5 and 6 of the timer did not close.
   c. 2M auxiliary contacts connected to pins 5 and 6 of the timer are shorted.
   d. The stop button is shorted.
6. Refer to the circuit shown in Figure 32-7. Assume that timer TR is set for a delay of 10 seconds. Now assume that timer TR is changed from an off-delay timer to an on-delay timer. Explain the operation of the circuit.

7. Using the space provided in Figure 32-9, modify the circuit in Figure 32-7 to operate as follows:
   a. When the start button is pressed, motor #1 starts running immediately. After a delay of 10 seconds, motor #2 begins running. Both motors remain operating until the stop button is pressed or an overload occurs.
   b. When the stop button is pressed, motor #2 stops operating immediately, but motor #1 continues to operate for a period of 10 seconds before stopping.
   c. An overload on either motor will stop both motors immediately.
   d. Assume the use of electronic timers in final design.
8. After your instructor has approved the modification, connect your circuit in the laboratory.
9. Turn on the power and test the circuit for proper operation.
10. **Turn off the power**, disconnect the circuit, and return the components to their proper location.

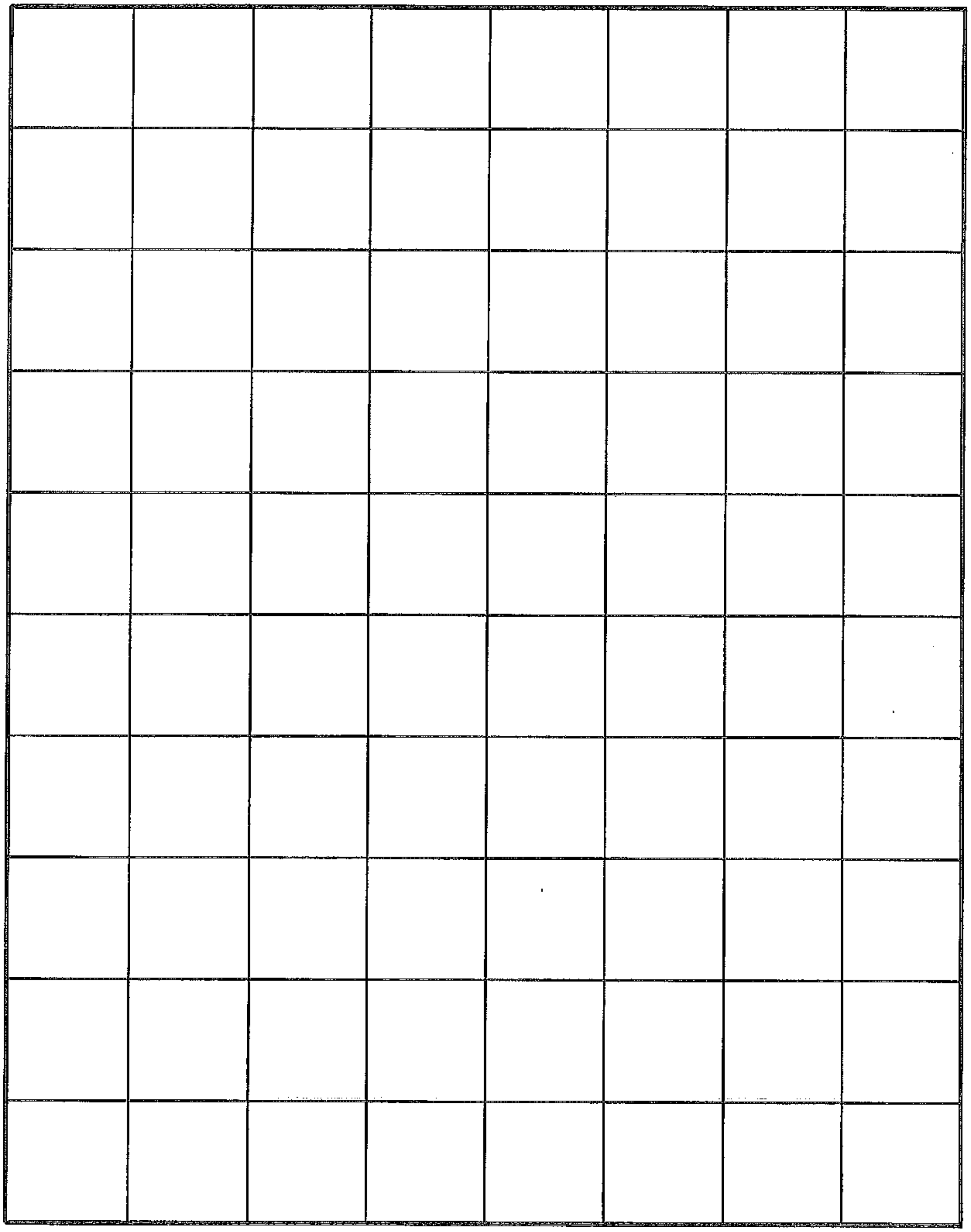

**Figure 32-9** Amending the circuit design.

# Unit 33 Changing the Logic of an On-Delay Timer to an Off-Delay Timer

## Objectives

After studying this unit, you should be able to:

- Discuss the difference in logic between on- and off-delay timers.
- Draw a schematic diagram of a circuit that will change the logic of an on-delay timer into the logic of an off-delay timer.
- Connect an on-delay timer circuit that will operate with the logic of an off-delay timer.

Some manufacturers purchase on-delay timers only. The reason for this is that most timing circuits require the logic of an on-delay timer. If it should become necessary to construct a circuit with the logic of an off-delay timer, it is a relatively simple matter to build a circuit using an on-delay timer that will operate with the same logic as an off-delay timer. A circuit of this type is shown in Figure 33-1. The basic idea is to cause the timer to start operating when a control component is turned off instead of on. Control relay CR is used to perform this function.

In the circuit shown in Figure 33-1, starter 1M is to energize immediately when switch S1 closes. When switch S1 opens, starter 1M should remain energized for some period of time before de-energizing. This is the logic of an off-delay timer. This logic can be accomplished by using an on-delay timer and the circuit shown in Figure 33-1. When switch S1 closes, CR coil energizes and all CR contacts change position (Figure 33-2). The normally closed CR contact connected in series with TR coil opens to prevent the timer energizing. The normally open CR contact connected in series with starter coil 1M closes and energizes the coil. This causes both 1M auxiliary contacts to close. Starter 1M is now energized, but the timer has not started its time sequence.

When switch S1 is reopened, CR coil de-energizes and all CR contacts return to their normal position (Figure 33-3). When the CR contact connected in series with starter coil 1M reopens, a current path is maintained though the now closed 1M auxiliary contact connected

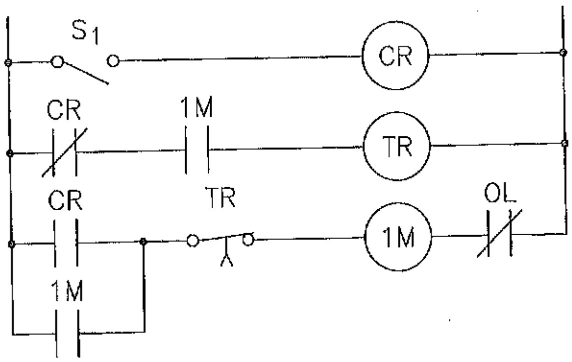


**Figure 33-1** Basic circuit to change the logic of an on-delay timer into an off-delay timer.

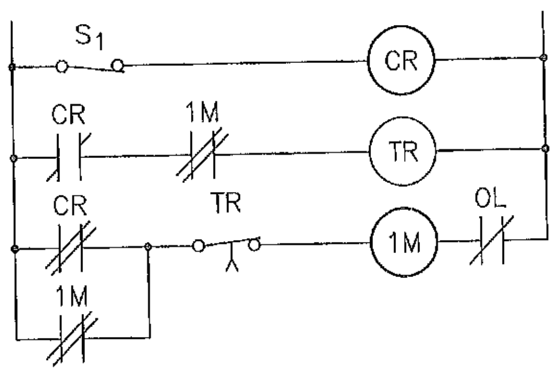


**Figure 33-2** Starter 1M energizes immediately, but the timer does not start timing.

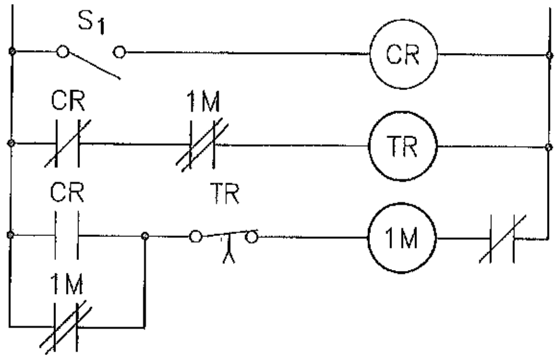


**Figure 33-3** Switch $S_1$ opens and starts the timer.

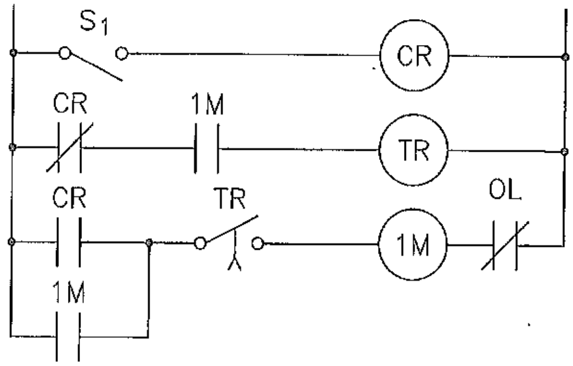


**Figure 33-4** Starter 1M de-energizes when timer contact TR opens.

in parallel with the open CR contact. When the CR contact connected in series with timer coil TR closed, it provided a path to coil TR and the timer began its time sequence.

At the end of the timing sequence, timed contact TR opens and de-energizes coil 1M, causing all 1M contacts to return to their normal position (Figure 33-4). The auxiliary 1M contact connected in series with timer coil TR opens and de-energizes coil TR. This causes contact TR to reclose and the circuit is back to the beginning state shown in Figure 33-1.

## Changing an Existing Schematic

The circuit shown in Figure 33-5 is an off-delay timer circuit for the control of two motors. It is assumed that the timer used in this circuit is a pneumatic timer. This circuit was discussed in the previous unit. Both motors start when the start button is pressed. When the stop button is pressed, motor #2 stops operating immediately, but motor #1 continues to operate for a period of 10 seconds. Now assume that it is necessary to change the circuit logic to permit an on-delay timer to be used.

Notice in the circuit in Figure 33-5 that timer coil TR is energized or de-energized at the same time as starter coil 2M. In the amended circuit, starter 2M will control the starting of on-delay timer TR (Figure 33-6). A set of 1M auxiliary contacts prevents coil TR from being energized until starter 1M has been energized. To understand the operation of the circuit, trace the logic through each step of operation. Assume that the start button is pushed and coil CR energizes. This causes all CR contacts to close and connect starters 1M and 2M to the line (Figure 33-7). Both 1M auxiliary contacts close, but the normally closed 2M auxiliary contact connected in series with TR coil opens and prevents it from starting its time sequence.

When the stop button is pressed, CR coil de-energizes and all CR contacts return to their normal position (Figure 33-8). Motor starter 1M remains energized because of the closed 1M auxiliary contact connected in parallel with the CR contact. When starter 2M de-energizes, the normally closed auxiliary contact connected in series with timer coil TR recloses and on-delay timer TR begins its timing sequence.

After a delay of 10 seconds, timed contact TR opens and disconnects starter coil 1M from the line (Figure 33-9). This stops the operation of motor #1 and returns all 1M auxiliary contacts to their normal position. When timer TR de-energizes, timed contact TR returns to its normally closed position and the circuit is back to its original state as shown in Figure 33-6.

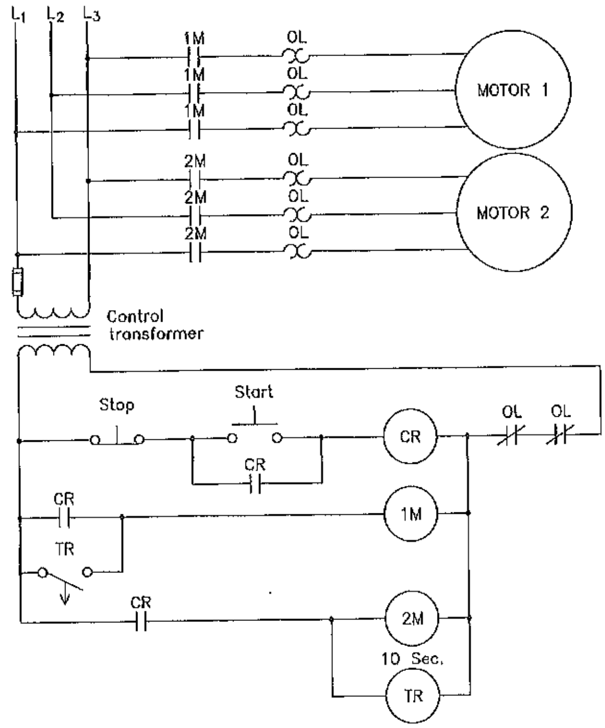


**Figure 33-5** Off-delay timer circuit using a pneumatic timer.

## LABORATORY EXERCISE

Name ______________________________ Date __________

### Materials Required

Three-phase power source

Control transformer

2 three-phase motors or equivalent motor load

2 three-phase motor starters with at least two normally open and one normally closed auxiliary contacts

8-pin or 11-pin on-delay timer with appropriate socket

11-pin control relay with 11-pin socket

### Connecting the Circuit

1. Using the circuit shown in Figure 33-6, place pin numbers beside the control components that mount into tube sockets. These components will probably be the control relay and the timer. Be sure to place pin numbers beside contacts as well as coils. Circle the pin numbers to distinguish them from wire numbers.
2. Place wire numbers on the schematic diagram.
3. Connect the control part of the circuit.

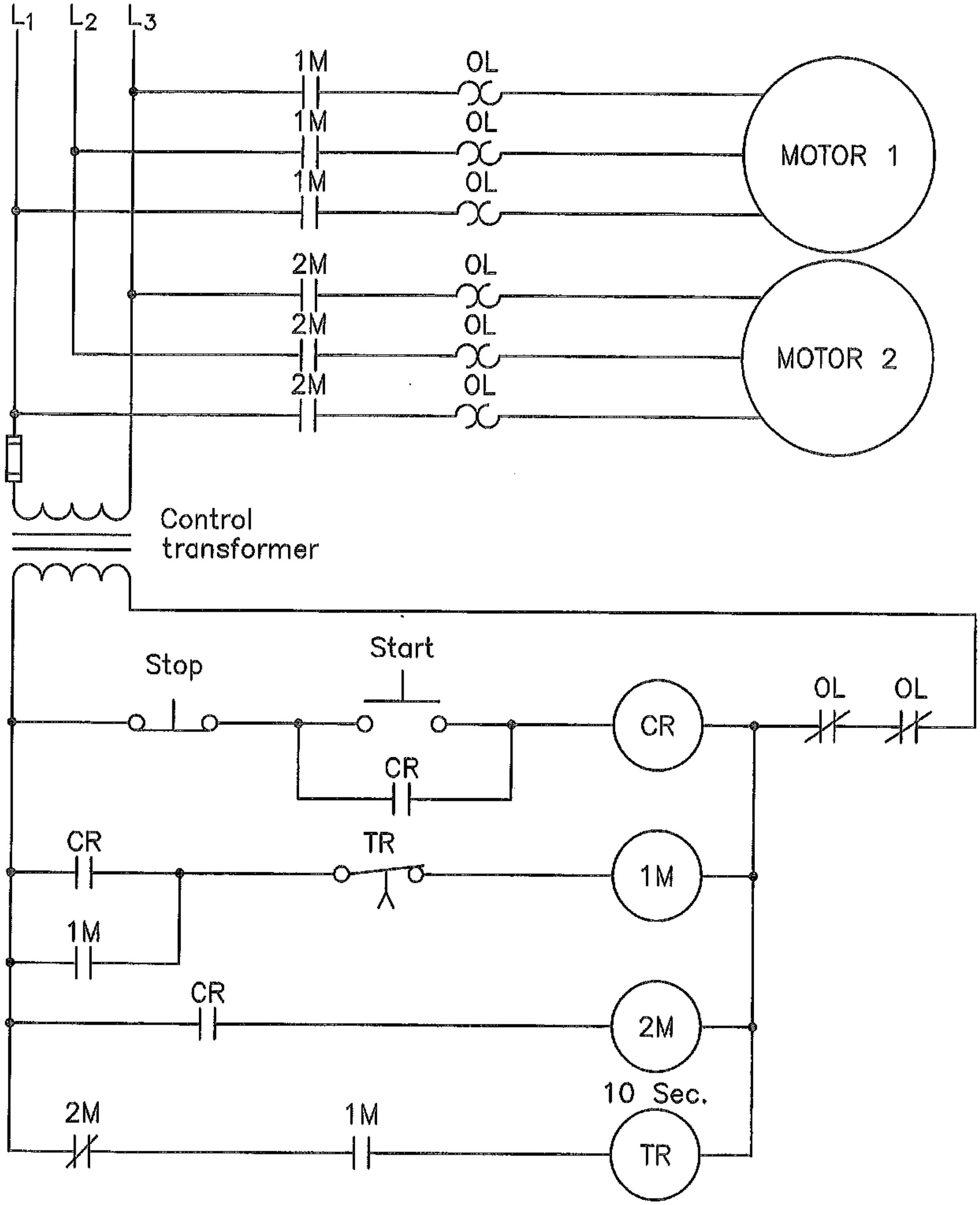


**Figure 33-6** Modifying the circuit for an on-delay timer.

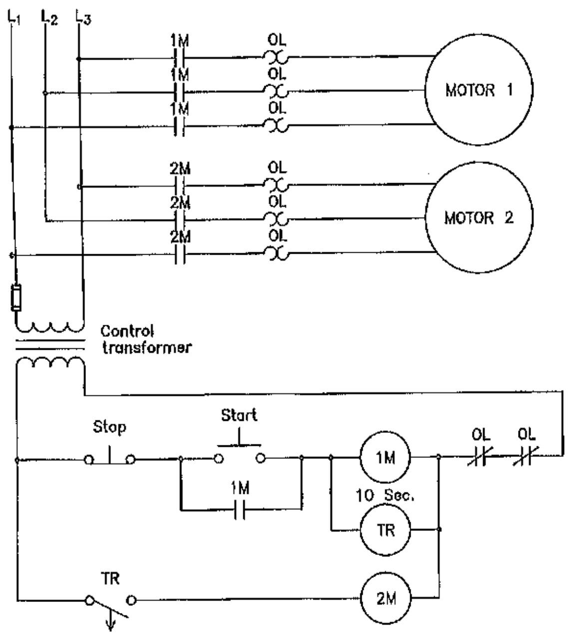


Figure 33-7 Both motors start at the same time.

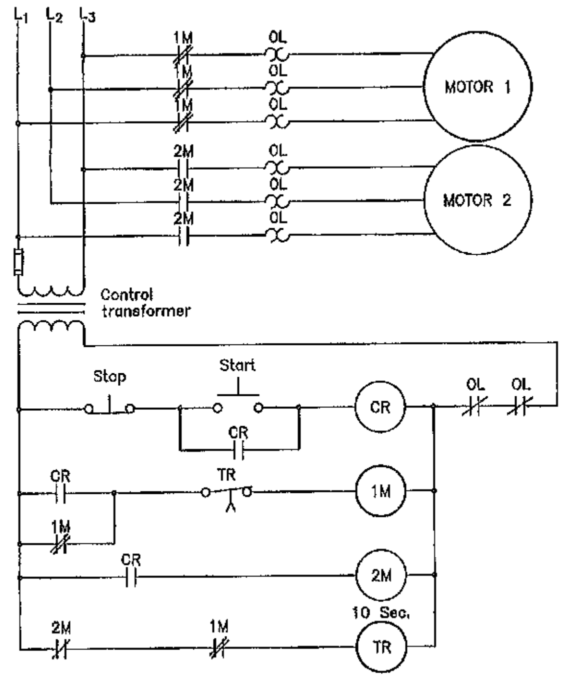


Figure 33-8 Starter 2M de-energizes; timer TR starts its time sequence.

4. Turn on the power and test the circuit for proper operation.
5. If the control part of the circuit operates properly, **turn off the power** and connect the motors or equivalent motor loads.
6. Turn on the power and test the entire circuit for proper operation.
7. **Turn off the power** and disconnect the circuit.

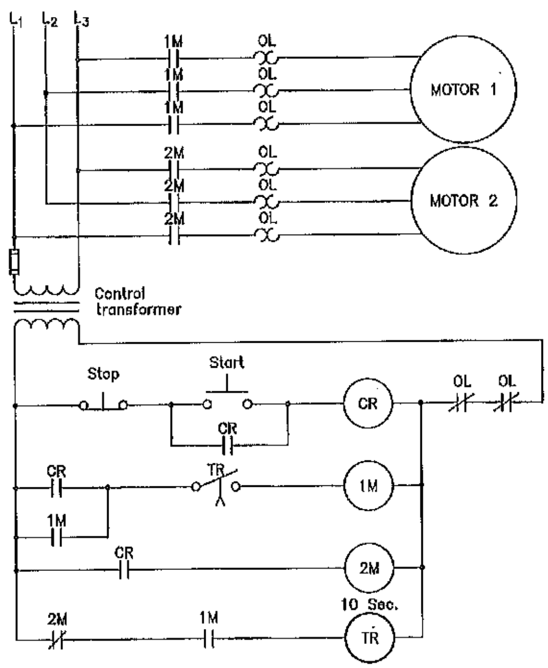


Figure 33-9 Timed contact de-energizes starter 1M.

## Review Questions

1. Why do some companies purchase only on-delay timers?

2. Refer to the circuit shown in Figure 33-10. This circuit assumes the use of a pneumatic off-delay timer. It is also assumed that the timer is set for a delay of 10 seconds. Describe the operation of this circuit when the start push button is pressed.

3. Assume that the circuit in Figure 33-10 is in operation. Describe the action of the circuit when the stop button is pressed.

4. The circuit shown in Figure 33-10 employs a pneumatic off-delay timer. Redraw the circuit in the space provided in Figure 33-11 to use an electronic on-delay timer. Make certain that the logic of the circuit is the same.
5. After your instructor has approved the redrawn circuit, connect the circuit in the laboratory.
6. Turn on the power and test the circuit for proper operation.
7. **Turn off the power** and return the components to their proper place.

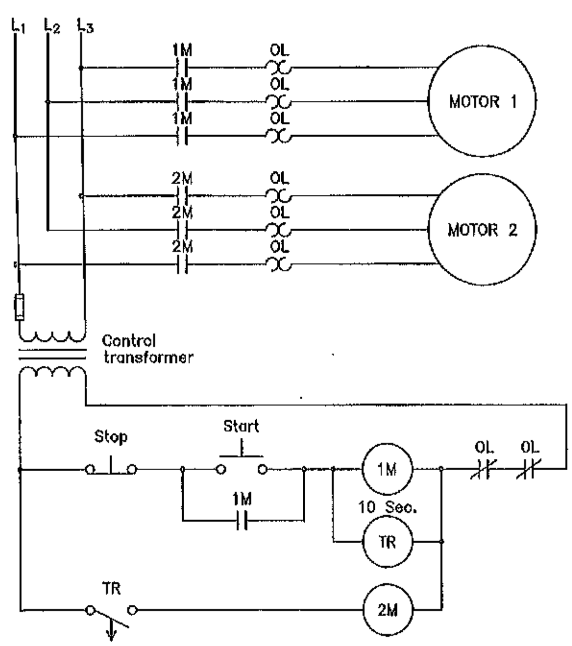


**Figure 33-10** Motor 1 stops operating before motor 2.

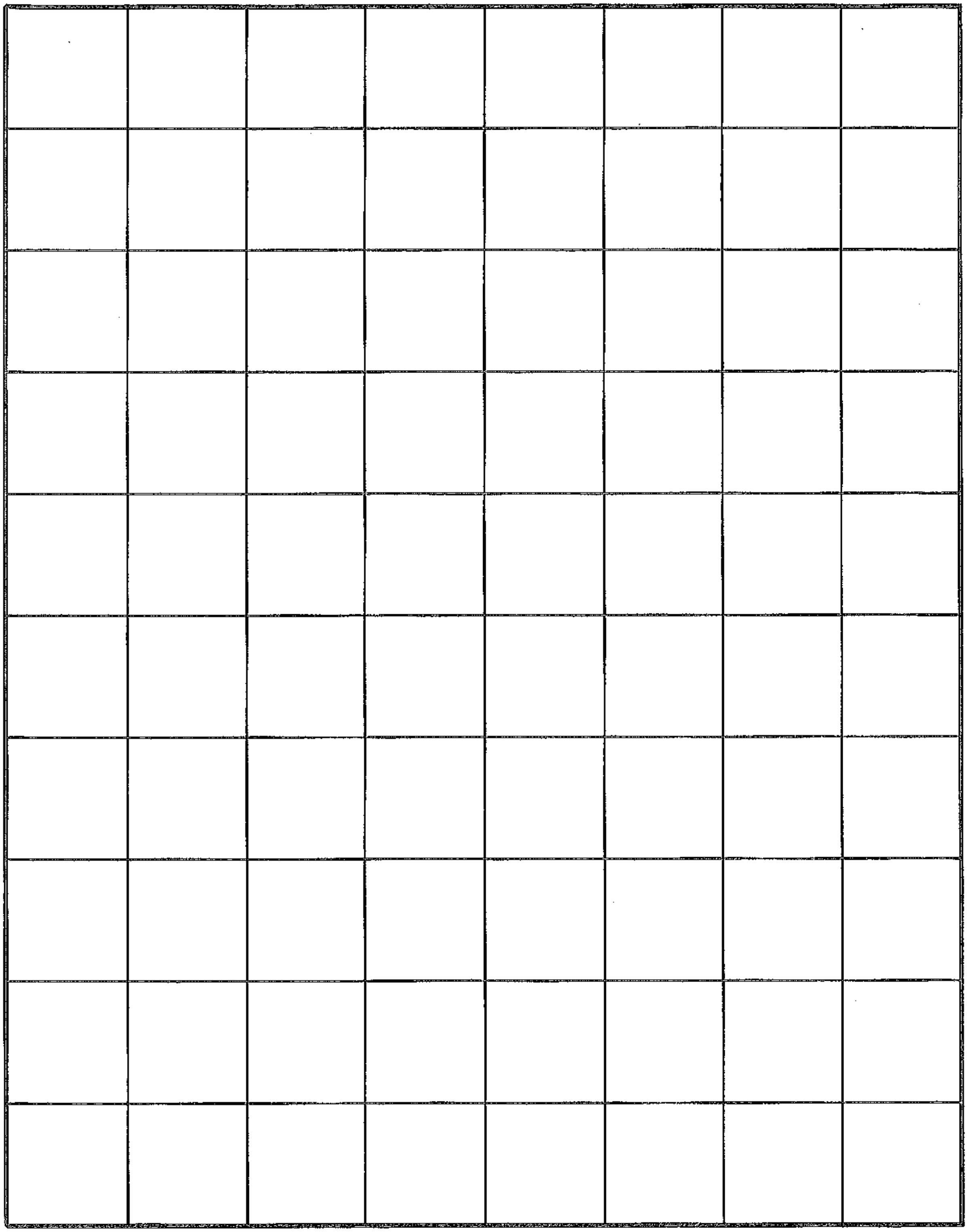

**Figure 33-11** Circuit redesign.

# Unit 34 Designing a Printing Press Circuit

## Objectives

After studying this unit, you should be able to:

- Describe a step-by-step procedure for designing a motor control circuit.
- Design a basic control circuit.
- Connect the completed circuit in the laboratory.

## LABORATORY EXERCISE

Name ______________________________________________ Date ________

## Materials Required

Three-phase power supply

Three-phase motor starter

8- or 11-pin on-delay relay with appropriate socket

Three-phase motor or equivalent motor load

Pilot light

Buzzer or simulated load

Control transformer

8-pin control relay and 8-pin socket

In this experiment a circuit for a large printing press will be designed in a step-by-step procedure. The owner of a printing company has the following concern when starting a large printing press:

The printing press is very large and the surrounding noise level is high. There is a danger that when the press starts, a person unseen by the operator may have his or her hands in the press. To prevent an accident, I would like to install a circuit that sounds an alarm and flashes a light for 10 seconds before the press actually starts. This would give the person time to get clear of the machine before it starts.

To begin the design procedure, list the requirements of the circuit. List not only the concerns of the owner but also any electrical or safety requirements that the owner may not be aware of. Understand that the owner is probably not an electrical technician and does not know all the electrical requirements of a motor control circuit.

1. There must be a start and stop push-button control.
2. When the start button is pressed, a warning light and buzzer turn on.

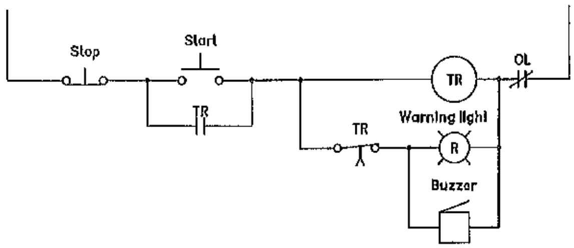


**Figure 34-1** First step in the circuit design.

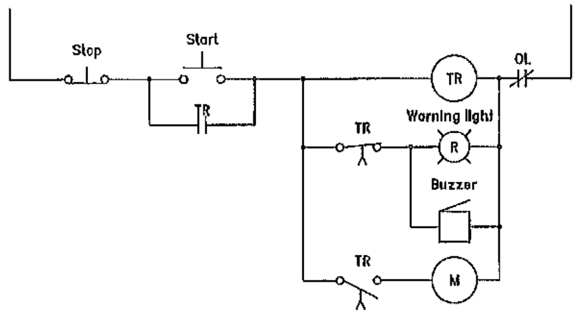


**Figure 34-2** Completing the circuit logic.

3. After a delay of 10 seconds, the warning light and buzzer turn off and the press motor starts.
4. The press motor should be overload protected.
5. When the stop push button is pressed, the circuit will de-energize even if the motor has not started.

To begin design of the circuit, fulfill the first requirement of the logic: "When the start button is pressed, a warning light and buzzer turn on for a period of 10 seconds." This first part of the circuit can be satisfied with the circuit shown in Figure 34-1. In this example a timer is used because the warning light and buzzer are to remain on for only 10 seconds. Since the warning light and buzzer are to turn on immediately when the start button is pressed, a normally closed timed contact is used. This circuit also assumes that the timer contains an instantaneous contact that is used to hold the circuit in after the start button is released.

The next part of the logic states that after a delay of 10 seconds the warning light and buzzer are to turn off and the press motor is to start. As the present circuit is shown in Figure 34-1, when the start button is pressed, TR coil will energize. This causes the normally open instantaneous TR contacts to close and hold TR coil in the circuit when the start button is released. At the same time, timer TR starts its timing sequence. After a delay of 10 seconds, the normally closed TR timed contact connected in series with the warning light and buzzer will open and disconnect them from the circuit.

The only remaining circuit logic is to start the motor after the warning light and buzzer have turned off. This can be accomplished with a normally open timed contact controlled by timer TR (Figure 34-2). At the end of the timing sequence, the normally closed TR contact will open and disconnect the warning light and buzzer. At the same time, the normally open TR timed contact will close and energize the coil of M starter. The normally closed overload contact connected in series with the rest of the circuit will de-energize the entire circuit in the event of motor overload.

Now that the logic of the control circuit has been completed, the motor load can be added as shown in Figure 34-3.

## Addressing a Potential Problem

The completed circuit shown in Figure 34-3 assumes the use of a timer that contains both timed and instantaneous contacts. This contact arrangement is common for certain types of timers such as pneumatic and some clock timers, but most electronic timers do not

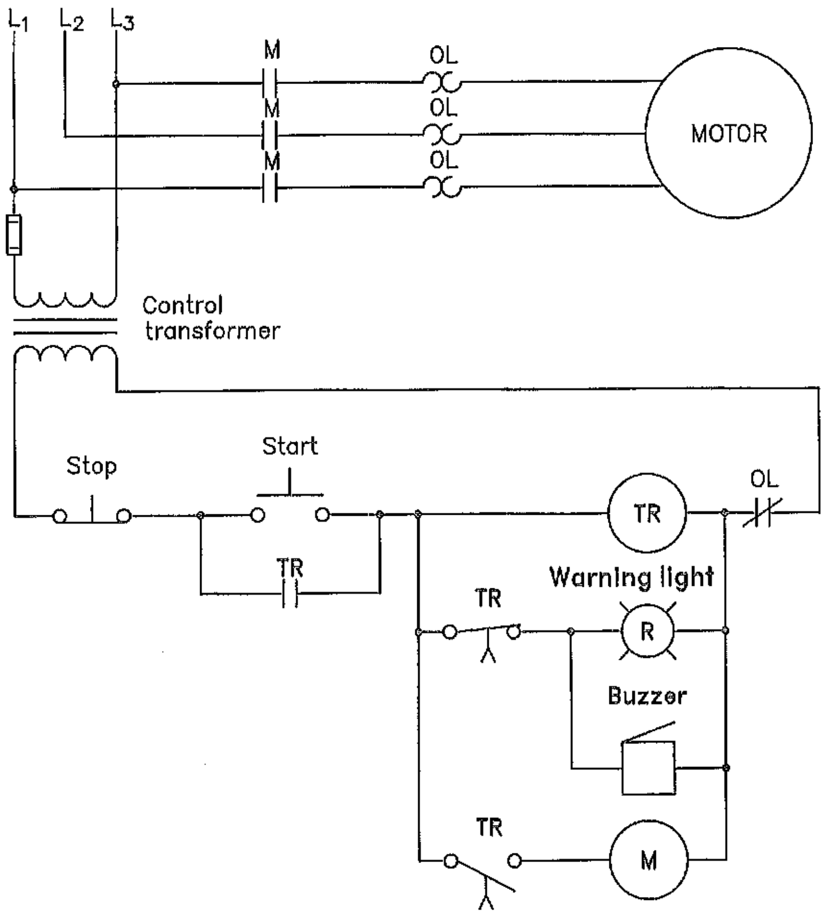


**Figure 34-3** The complete circuit.

contain instantaneous contacts. If this is the case, a control relay can be added to supply the needed instantaneous contact by connecting the coil of the control relay in parallel with the coil of TR timer (Figure 34-4).

## Connecting the Circuit

1. It will be assumed that the timer in this circuit is the electronic type. Therefore, it will be assumed that a control relay will be used to provide the normally open holding contacts. Assuming the use of an electronic on-delay timer and an 8-pin control relay, place pin numbers beside the components of the timer and control relay shown in Figure 34-4. Circle the numbers to distinguish them from wire numbers.
2. Place wire numbers beside the components in Figure 34-4.
3. Connect the control portion of the circuit. (Note: It may be necessary to use a pilot light for the buzzer if one is not available.)
4. Turn on the power and test the control part of the circuit for proper operation.
5. **Turn the power off.**
6. If the control part of the circuit operated properly, connect the motor or simulated motor load to the circuit.
7. Turn on the power and test the entire circuit for proper operation.
8. **Turn off the power** and return the components to their proper location.

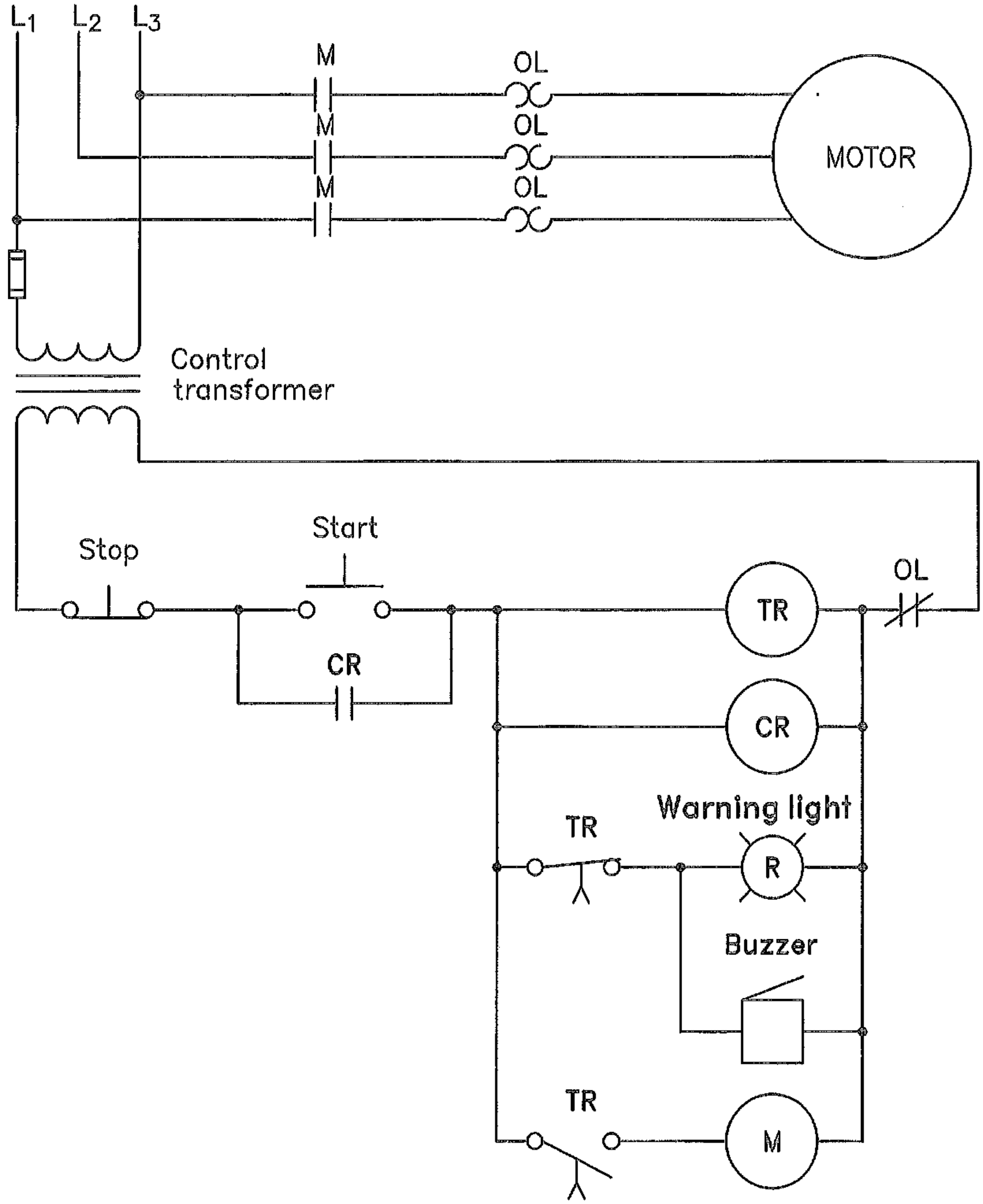


**Figure 34-4** Adding a control relay.

## Review Questions

1. What should be the first step when beginning the design of a control circuit?

2. Why is it sometimes necessary to connect the coil of a control relay in parallel with the coil of a timer?

3. Refer to the circuit shown in Figure 34-3. Assume that the on-delay timer is replaced with an off-delay timer. Describe the action of the circuit when the start button is pressed.

4. Describe the operation of the circuit when the stop button is pressed. Assume the circuit is running with an off-delay timer as described in question 3.

5. Refer to the circuit shown in Figure 34-4. Assume the owner decides to change the logic of the circuit as follows:

   *When the operator presses the start button, a warning light and buzzer turn on for a period of 10 seconds. During this 10 seconds, the operator must continue to hold down the start button. If the start button should be released, the timing sequence will stop and the motor will not start. At the end of 10 seconds, provided the operator continues to hold the start button down, the warning light and buzzer will turn off and the motor will start. When the motor starts, the operator can release the start button and the press will continue to run.*

Amend the circuit in Figure 34-4 to meet the requirement.

# Unit 35 Sequence Starting and Stopping for Three Motors

## Objectives

After studying this unit, you should be able to:

- Discuss the step-by-step procedure for designing a circuit.
- Change a circuit designed with pneumatic timers into a circuit to use electronic timers.
- Connect the circuit in the laboratory.
- Troubleshoot the circuit.

## LABORATORY EXERCISE

Name ______________________________ Date __________

## Materials Required

Three-phase power supply

Control transformer

2 8-pin control relays and 8-pin sockets

3 three-phase motor starters

4 electronic timers (Dayton model 6A855 or equivalent) and 11-pin sockets

3 three-phase motors or equivalent motor loads

In this experiment a circuit will be designed and connected. The requirements of the circuit are as follows:

1. Three motors are to start in sequence from motor #1 to motor #3.
2. There is to be a time delay of 3 seconds between the starting of each motor.
3. When the stop button is pressed, the motors are to stop in sequence from motor #3 to motor #1.
4. There is to be a time delay of 3 seconds between the stopping of each motor.
5. An overload on any motor will stop all motors.

When designing a control circuit, satisfy one requirement at a time. This may at times lead to an unforeseen dead end, but don't let these dead ends concern you. When they happen, back up and redesign around them. In this example the first part of the circuit is to start three motors in sequence from motor #1 to motor #3 with a 3-second delay between the starting of each motor. This is also the time to satisfy the requirement that an overload on any motor will stop all motors. The first part of the circuit can be satisfied by the circuit shown in Figure 35-1. (Note: In this experiment the motor connections will not be shown because of space limitations. It is to be assumed that the motor starters are controlling three-phase motors. It is also assumed that all timers are set for a delay of 3 seconds.)

When the start button is pressed, coils 1M and $TR_1$ energize. Starter 1M starts motor #1 immediately, and timer $TR_1$ starts its time sequence of 3 seconds. After a delay of 3 seconds, timed contact $TR_1$ closes and energizes coils 2M and $TR_2$. Starter 2M starts motor #2 and timer $TR_2$ begins its 3-second timing sequence. After a delay of 3 seconds, timed contact $TR_2$ closes and energizes motor #3. The motors have been started in sequence from #1 to #3 with a delay of 3 seconds between the starting of each motor. This satisfies the first part of the circuit logic.

The next requirement is that the circuit stop in sequence from motor #3 to motor #1. To fulfill this requirement, power must be maintained to starters 2M and 1M after the stop button has been pushed. In the circuit shown in Figure 35-1, this is not possible. Since all coils are connected after the M auxiliary holding contact, power will be disconnected from all coils when the stop button is pressed and the holding contact opens. This circuit has proven to be a dead end. There is no way to fulfill the second requirement with the circuit connected in this manner. Therefore, the circuit must be amended in such a manner that it will not only start in sequence from motor #1 to motor #3 with a 3-second time delay between the starting of each motor but also be able to maintain power after the start button is pressed. This amendment is shown in Figure 35-2.

To modify the circuit so that power can be maintained to coils 2M and 1M, a control relay has been added to the circuit. Contact $1CR_2$ prevents power from being applied to coils 1M and $TR_1$ until the start button is pressed.

## Designing the Second Part of the Circuit

The second part of the circuit states that the motors must stop in sequence from motor #3 to motor #1. Do not try to solve all the logic at once. Solve each problem as it arises. The first problem is to stop motor #3. In the circuit shown in Figure 35-2, when the stop button is

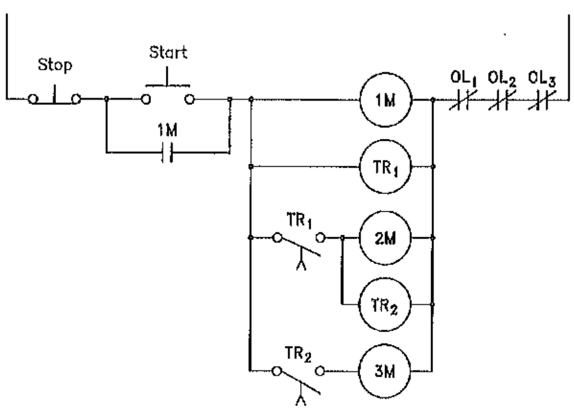


**Figure 35-1** The motors start in sequence from 1 to 3.

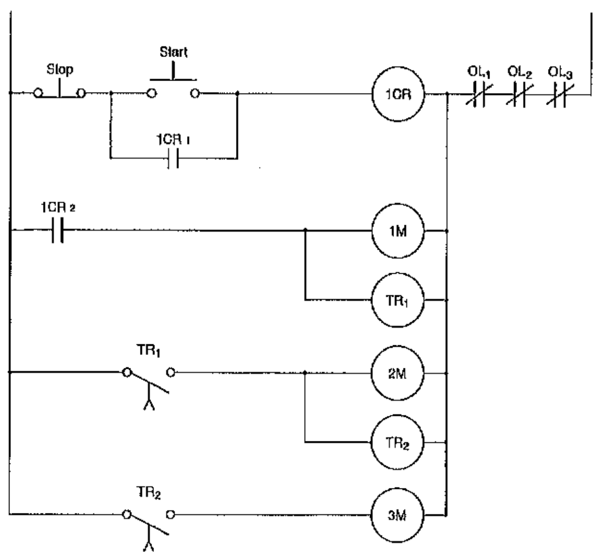


**Figure 35-2** A control relay is added to the circuit.

pressed, coil 1CR will de-energize. This will cause contact $1CR_2$ to open and de-energize coils 1M and $TR_1$. Contact $TR_1$ will open immediately and de-energize coils 2M and $TR_2$, causing contact $TR_2$ to open immediately and de-energize coil 3M. Notice that coil 3M does de-energize when the stop button is pressed, but so does everything else. The circuit requirement states that there is to be a 3-second time delay between the stopping of motor #3 and motor #2. Therefore, an off-delay timer will be added to maintain connection to coil 2M after coil 3M has de-energized (Figure 35-3).

The same basic problem exists with motor #1. In the present circuit, motor #1 will turn off immediately when the stop button is pressed. To help satisfy the second part of the problem, another off-delay relay must be added to maintain a circuit to motor #1 for a period of 3 seconds after motor #2 has turned off. This addition is shown in Figure 35-4.

Motors #2 and #1 will now continue to operate after the stop button is pressed, but so will motor #3. In the present design, none of the motors will turn off when the stop button is pressed. To understand this condition, trace the logic step-by-step. When the start button is pressed, coil 1CR energizes and closes all 1CR contacts. When contact $1CR_2$ closes, coils 1M and $TR_1$ energize. After a period of 3 seconds, timed contact $TR_1$ closes and energizes coils 2M, $TR_2$, and $TR_4$. Timed contact $TR_4$ closes immediately to bypass contact $1CR_2$. After a delay of 3 seconds, timed contact $TR_2$ closes and energizes coils 3M and $TR_3$. Timed contact $TR_3$ closes immediately and bypasses contact $TR_1$. When the stop button is pressed, coil 1CR de-energizes and all 1CR contacts open, but a circuit is maintained to coils 1M and $TR_1$ by contact $TR_4$. This prevents timed contact $TR_1$ from opening to de-energize coils 2M, $TR_2$, and $TR_4$, which in turn prevents timed contact $TR_2$ from opening to de-energize coils 3M and $TR_3$. To overcome this problem, two more contacts controlled by relay 1CR will be added to the circuit (Figure 35-5). The circuit will now operate in accord with all the stated requirements.

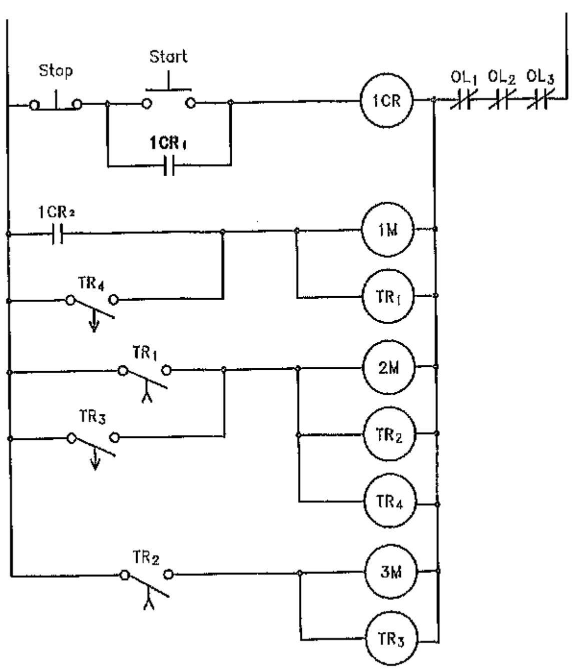


**Figure 35-3** Timer $TR_3$ prevents motor 2 from stopping.

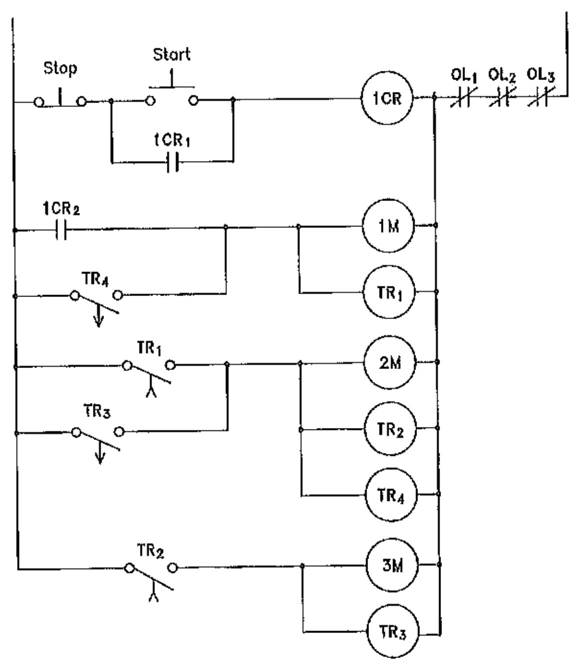


**Figure 35-4** Off-delay timer $TR_4$ prevents motor 1 from stopping.

## Modifying the Circuit

The circuit in Figure 35-5 was designed with the assumption that all the timers are of the pneumatic type. When this circuit is connected in the laboratory, 8-pin control relays and electronic timers will be used. The circuit will be amended to accommodate these components. The first change to be made concerns the control relays. Notice that the circuit requires the use of four normally open contacts controlled by coil 1CR. Since 8-pin control relays have only two normally open contacts, it will be necessary to add a second control relay, 2CR. The coil of relay 2CR will be connected in parallel with 1CR, which will permit both to operate at the same time (Figure 35-6).

Timers $TR_1$ and $TR_2$ are on-delay timers and do not require an adjustment in the circuit logic to operate. Timers $TR_3$ and $TR_4$, however, are off-delay timers and do require changing the circuit. The coils must be connected to power at all times. Assuming the use of a Dayton timer model 6A855, power would connect to pins 2 and 10. Starter 3M will be used to control the action of timer $TR_3$ by connecting a 3M normally open auxiliary contact to pins 5 and 6 of timer $TR_3$ (Figure 35-7). Starter 2M will control the action of timer $TR_4$ by connecting a 2M normally open auxiliary contact to pins 5 and 6 of that timer. The circuit is now complete and ready for connection in the laboratory.

## Connecting the Circuit

1. Using the circuit shown in Figure 35-7, place pin numbers beside the proper components. Circle the pin numbers to distinguish them from wire numbers.
2. Place wire numbers on the schematic.
3. Connect the control circuit in the laboratory.
4. Turn on the power and test the circuit for proper operation.

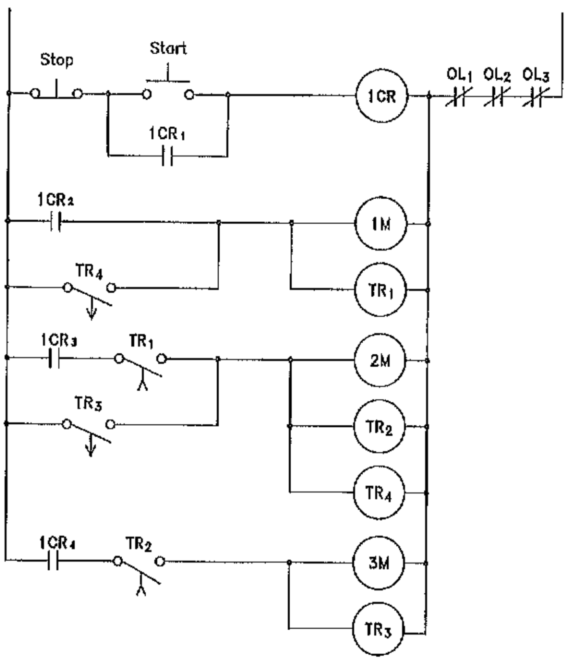


**Figure 35-5** Control relay contacts are added to permit the circuit to turn off.

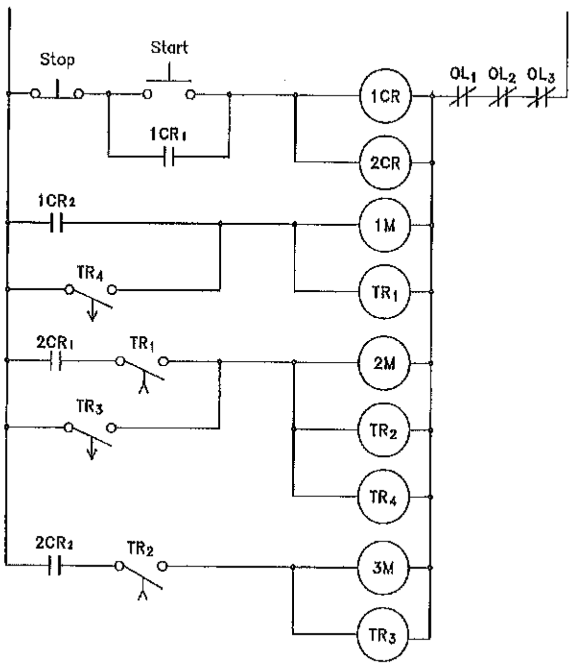


**Figure 35-6** Adding a control relay to the circuit.

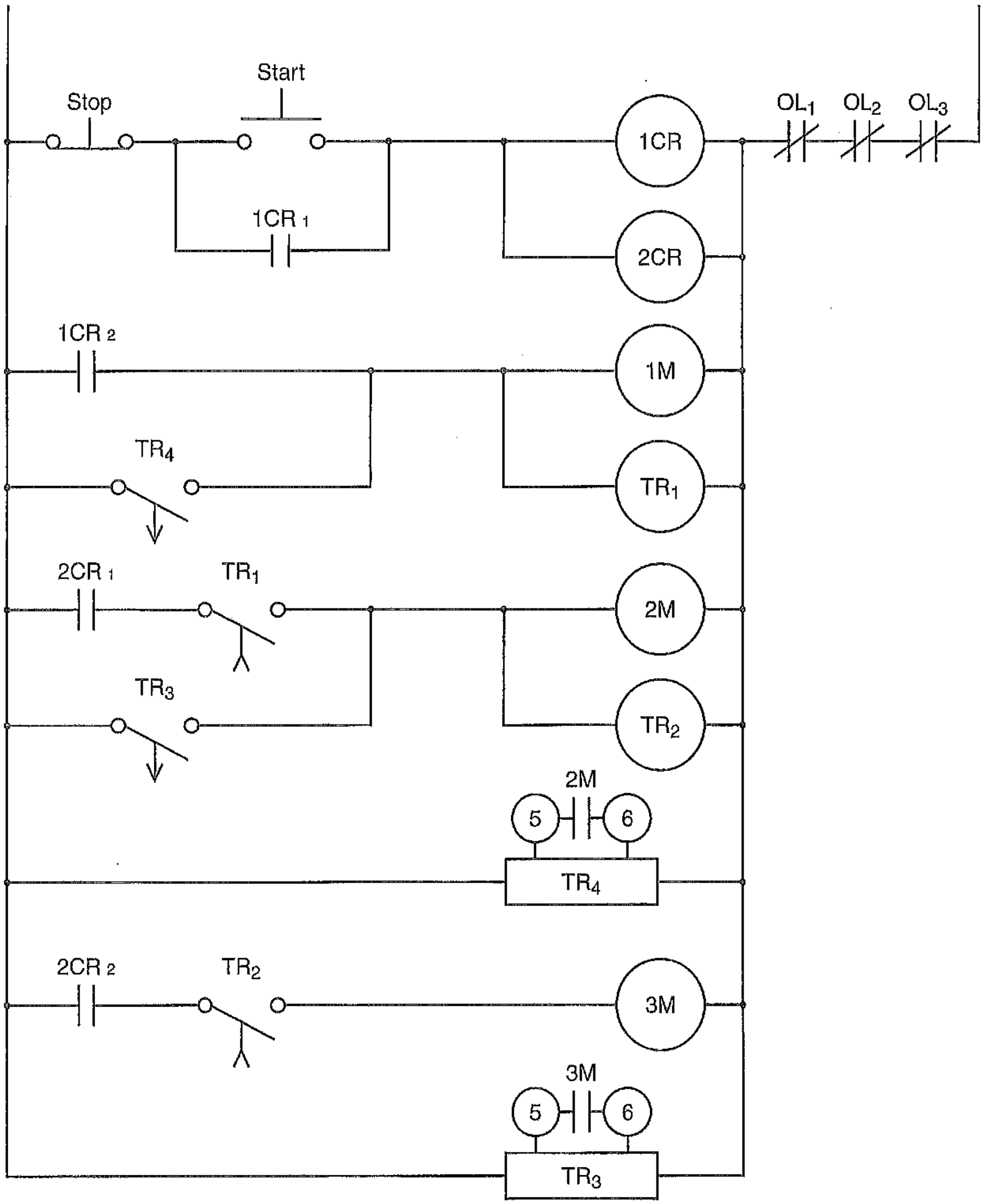


**Figure 35-7** Changing pneumatic timers for electronic timers.

5. **Turn off the power** and connect the motor loads to starters 1M, 2M, and 3M.
6. Turn on the power and test the complete circuit.
7. **Turn off the power.**
8. Disconnect the circuit and return the components to their proper places.

## Review Questions

Refer to the circuit in Figure 35-7 to answer the following questions. It is assumed that all timers are set for a delay of 3 seconds.

1. When the start button is pressed, motor #1 starts operating immediately. Three seconds later motor #2 starts, but motor #3 never starts. When the stop button is pressed, motor #2 stops operating immediately. After a delay of 3 seconds, motor #1 stops running. Which of the following could not cause this condition?
   a. $TR_3$ coil is open.
   b. 3M coil is open.
   c. $TR_2$ coil is open.
   d. 2CR coil is open.
2. When the start button is pressed, motor #1 starts operating immediately. Motor #2 does not start operating after 3 seconds, but after a delay of 6 seconds motor #3 starts operating. When the stop button is pushed, motors #3 and #1 stop operating immediately. Which of the following could cause this condition?
   a. 2CR coil is open.
   b. $TR_1$ coil is open.
   c. $TR_3$ coil is open.
   d. 2M coil is open.
3. When the start button is pressed, all three motors start normally with a 3-second delay between the starting of each motor. When the stop button is pressed, motor #3 stops operating immediately. After a delay of 3 seconds, both motors #2 and #1 stop operating at the same time. Which of the following could cause this problem?
   a. Timer $TR_1$ is defective.
   b. Timer $TR_2$ is defective.
   c. Timer $TR_3$ is defective.
   d. Timer $TR_4$ is defective.
4. When the start button is pressed, nothing happens. None of the motors start. Which of the following could *not* cause this problem?
   a. Overload contact $OL_1$ is open.
   b. 1CR relay coil is open.
   c. 2CR relay coil is open.
   d. The stop button is open.
5. When the start button is pressed, motor #1 does not start, but after a delay of 3 seconds motor #2 starts, and 3 seconds later motor #3 starts. When the stop button is pressed, motor #3 stops running immediately and after a delay of 3 seconds motor #2 stops running. Which of the following could cause this problem?
   a. Starter coil 1M is open.
   b. $TR_1$ timer coil is open.
   c. Timer $TR_4$ is defective.
   d. 1CR coil is open.

# Unit 36 Hydraulic Press Control Circuit

## Objectives

After studying this unit, you should be able to:

- Discuss the operation of this hydraulic press control circuit.
- Connect the circuit in the laboratory.
- Operate the circuit using toggle switches to simulate limit and pressure switches.

## LABORATORY EXERCISE

Name ______________________________ Date ________

## Materials Required

Three-phase power supply

Control transformer

Three-phase motor starter with at least two normally open auxiliary contacts

5 double-acting push buttons (N.O./N.C. on each button)

Pilot light

3 toggle switches that can be used to simulate two limit switches and one pressure switch

1 three-phase motor or equivalent motor load

2 solenoid coils or lamps to simulate solenoid coils

3 control relays with three sets of contacts (11-pin) and 11-pin sockets

3 control relays with two sets of contacts (8-pin) and 8-pin sockets

The next circuit to be discussed is a control for a large hydraulic press (Figure 36-1). In this circuit, a hydraulic pump must be started before the press can operate. Pressure switch PS closes when there is sufficient hydraulic pressure to operate the press. If switch PS should open, it will stop the operation of the circuit. A green pilot light is used to tell the operator that there is enough pressure to operate the press.

Two run push buttons are located far enough apart so that both of the operator's hands must be used to cause the press to cycle. This is to prevent the operator from getting his hands in the press when it is operating. Limit switches UPLS and DNLS are used to determine when the press is at the bottom of its downstroke and when it is at the top of its upstroke. In the event one or both of the run push buttons are released during the cycle, a reset button can be used to reset the press to its top position. The up solenoid causes the press to travel upward when it is energized, and the down solenoid causes the press to travel downward when it is energized.

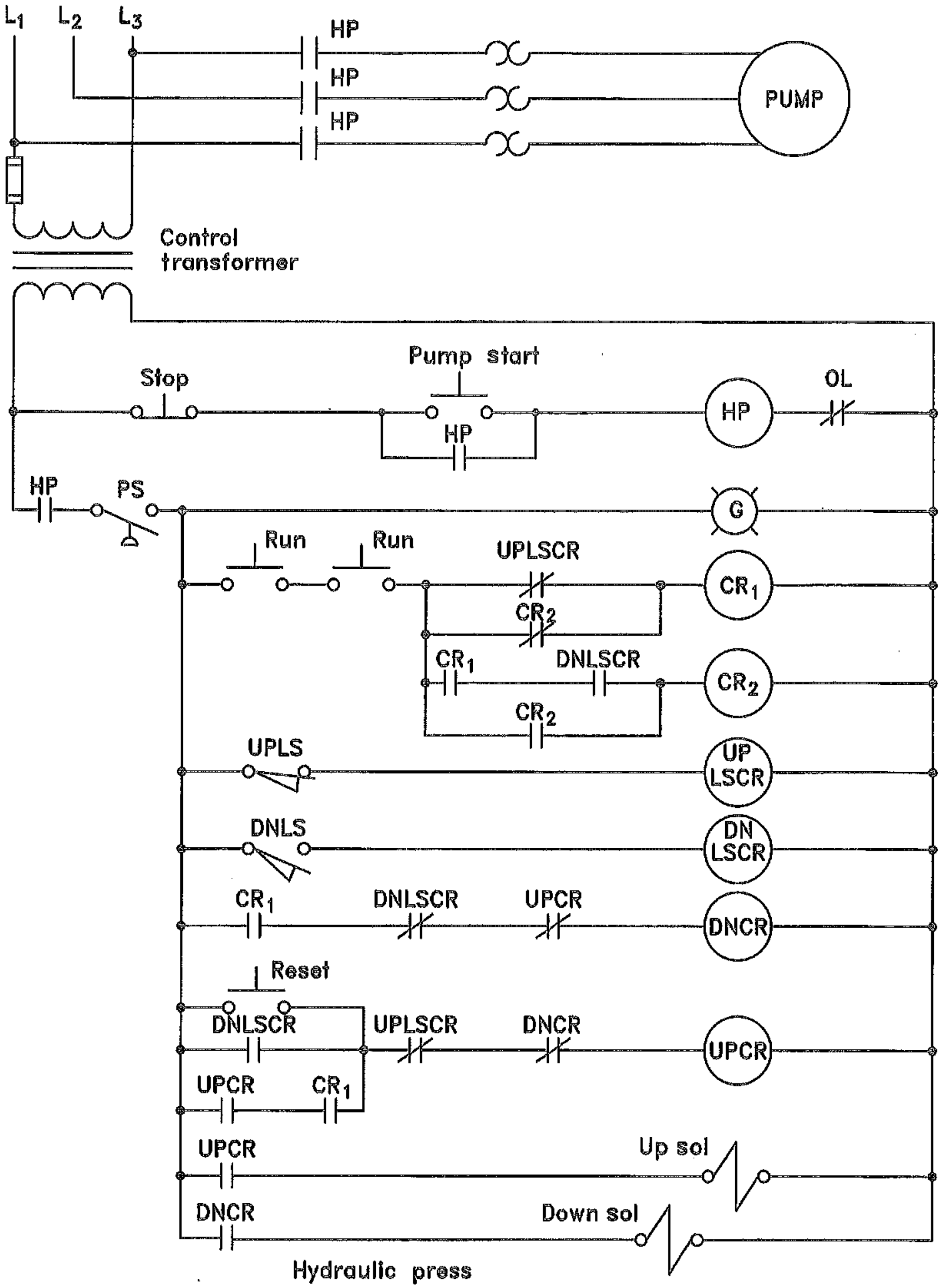


**Figure 36-1** Hydraulic press.

To understand the operation of this circuit, assume that the press is in the up position. Notice that limit switch UPLS is shown normally open held closed. This limit switch is connected normally open, but when the press is in the up position it is being held closed. Now assume that the hydraulic pump is started and that the pressure switch closes. When pressure switch PS closes, the green pilot light turns on and UPLSCR (Up Limit Switch Control Relay) energizes, changing all UPLSCR contacts (Figure 36-2).

When both run push buttons are held down, a circuit is completed to $CR_1$ relay, causing all $CR_1$ contacts to change position (Figure 36-3). The $CR_1$ contact connected in series with the coil of DNCR closes and energizes the relay, causing all DNCR contacts to change position. The DNCR contact connected in series with the down solenoid coil closes and energizes the down solenoid.

As the press begins to move downward, limit switch UPLS opens and de-energizes coil UPLSCR, returning all UPLSCR contacts to their normal position (Figure 36-4).

When the press reaches the bottom of its stroke, it closes down limit switch DNLS. This energizes the coil of the down limit switch control relay, DNLSCR, causing all DNLSCR contacts to change position (Figure 36-5). The normally open DNLSCR contact connected in series with

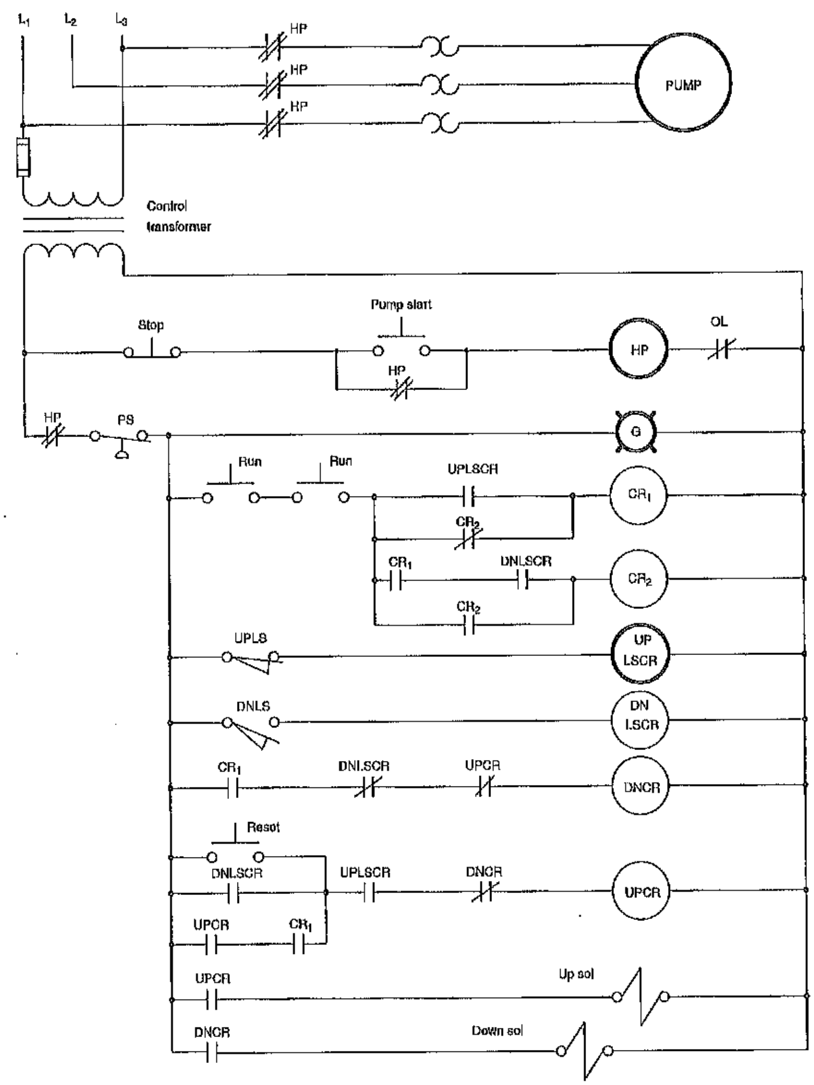


**Figure 36-2** The circuit with pump operating.

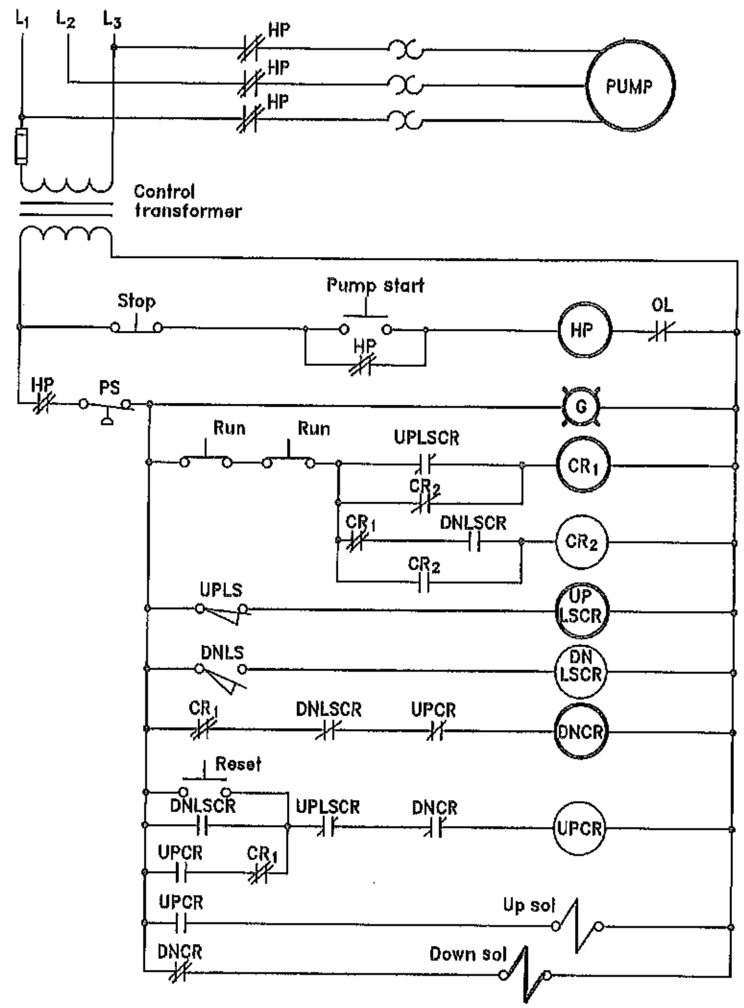


**Figure 36-3** Circuit is started.

the coil of $CR_2$ closes and energizes that relay, causing all $CR_2$ contacts to change position. The normally closed DNLSCR contact connected in series with DNCR coil opens and de-energizes that relay. All DNCR contacts return to their normal positions. The normally open contact connected in series with the down solenoid coil opens and de-energizes the solenoid. The normally closed DNCR contact connected in series with UPCR coil recloses and provides a current path to that relay.

The UPCR contact connected in series with coil DNCR opens and prevents coil DNCR from re-energizing when coil DNLSCR de-energizes. The normally open UPCR contact connected in series with the up solenoid closes and provides a current path to the up solenoid. When the press starts upward, limit switch DNLS reopens and de-energizes coil DNLSCR. A circuit is maintained to UPCR coil by the now closed UPCR contact connected in series with the $CR_1$ contact (Figure 36-6).

The press will continue to travel upward until it reaches its upper limit and closes limit switch UPLS, energizing coil UPLSCR (Figure 36-7). This causes both UPLSCR contacts to change position. The UPLSCR contact connected in series with coil UPCR opens and de-energizes the up solenoid. Notice that control relays $CR_1$ and $CR_2$ are still energized. Before the press can be re-cycled, one or both of the run buttons must be released to break

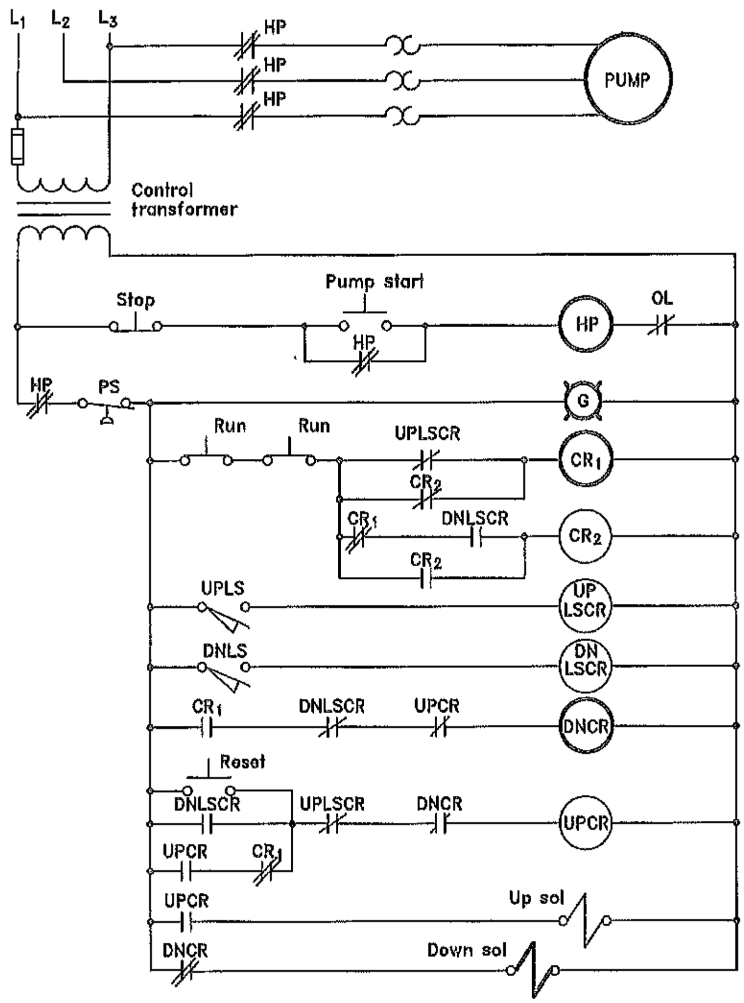


**Figure 36-4** The up limit switch opens.

the circuit to the control relays. This will permit the circuit to reset to the state shown in Figure 36-2. If for some reason the press should be stopped during a cycle, the reset button can be used to return the press to the starting position.

## Connecting the Circuit

In this exercise toggle switches will be used to simulate the action of the pressure switch and the two limit switches. Lights may also be substituted for the up and down solenoid coils.

1. Refer to the circuit shown in Figure 36-1. Count the number of contacts controlled by each of the control relays to determine which should be 11-pin and which should be 8-pin. Relays that need three contacts will have to be 11-pin, and relays that need two contacts may be 8-pin.
2. After determining whether a relay is to be 11-pin or 8-pin, identify the relay with some type of marker that can be removed later. Identifying the relays as $CR_1$, $CR_2$, and so on can make connection much simpler.
3. Place the pin numbers on the schematic in Figure 36-1 to correspond with the contacts and coils of the control relays. Circle the numbers to distinguish them from wire numbers.

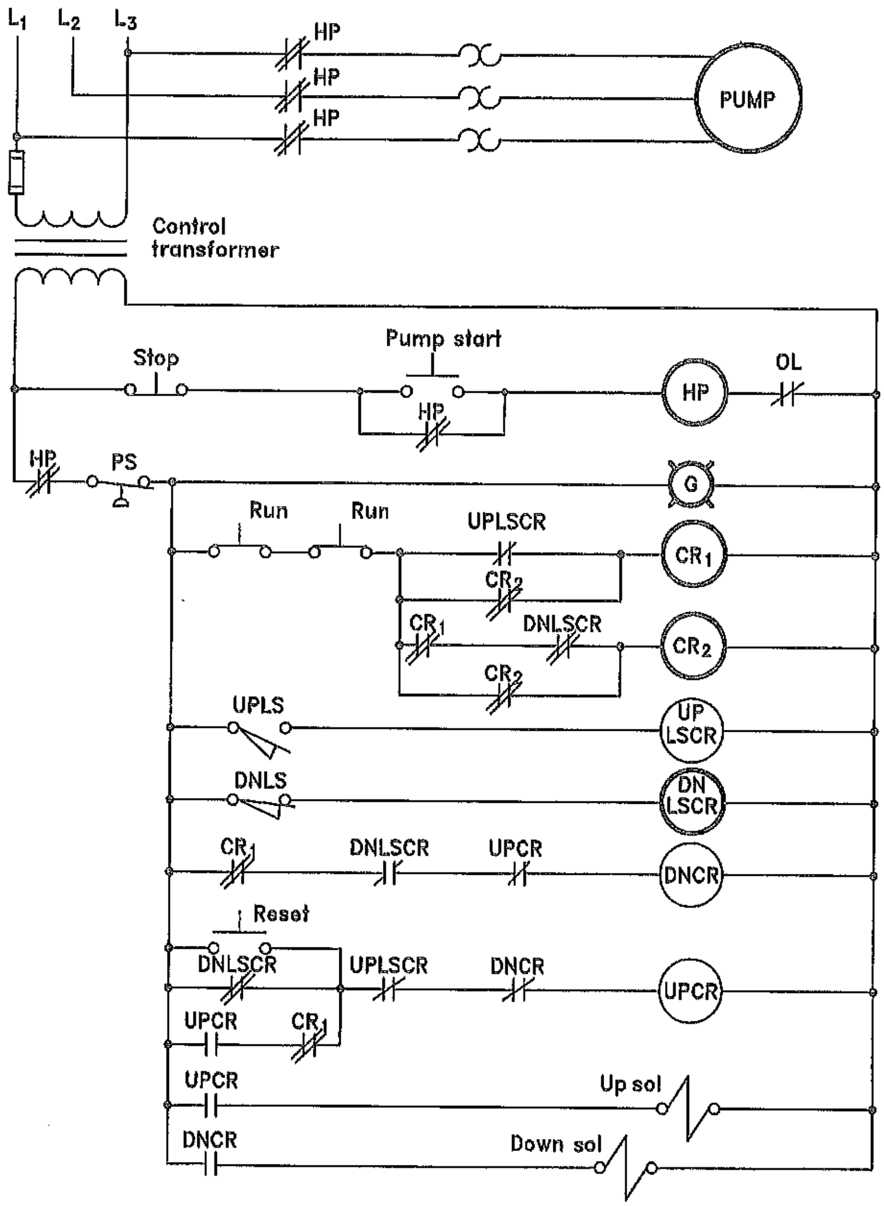


**Figure 36-5** DNLSCR and $CR_2$ relays energize.

4. Place wire numbers beside each component on the schematic.
5. Connect the circuit. (Note: When connecting the two run push buttons, connect them close enough together to permit both to be held closed with one hand.)

## Testing the Circuit

To test the circuit for proper operation:

1. Set the toggle switches used to simulate the pressure and down limit switch in the open (off) position. Set the toggle used to simulate the up limit switch in the closed (on) position.
2. Press the "pump start" button and the motor or simulated motor load should start operating.
3. Close the pressure switch. The pilot light and UPLSCR relay should energize.

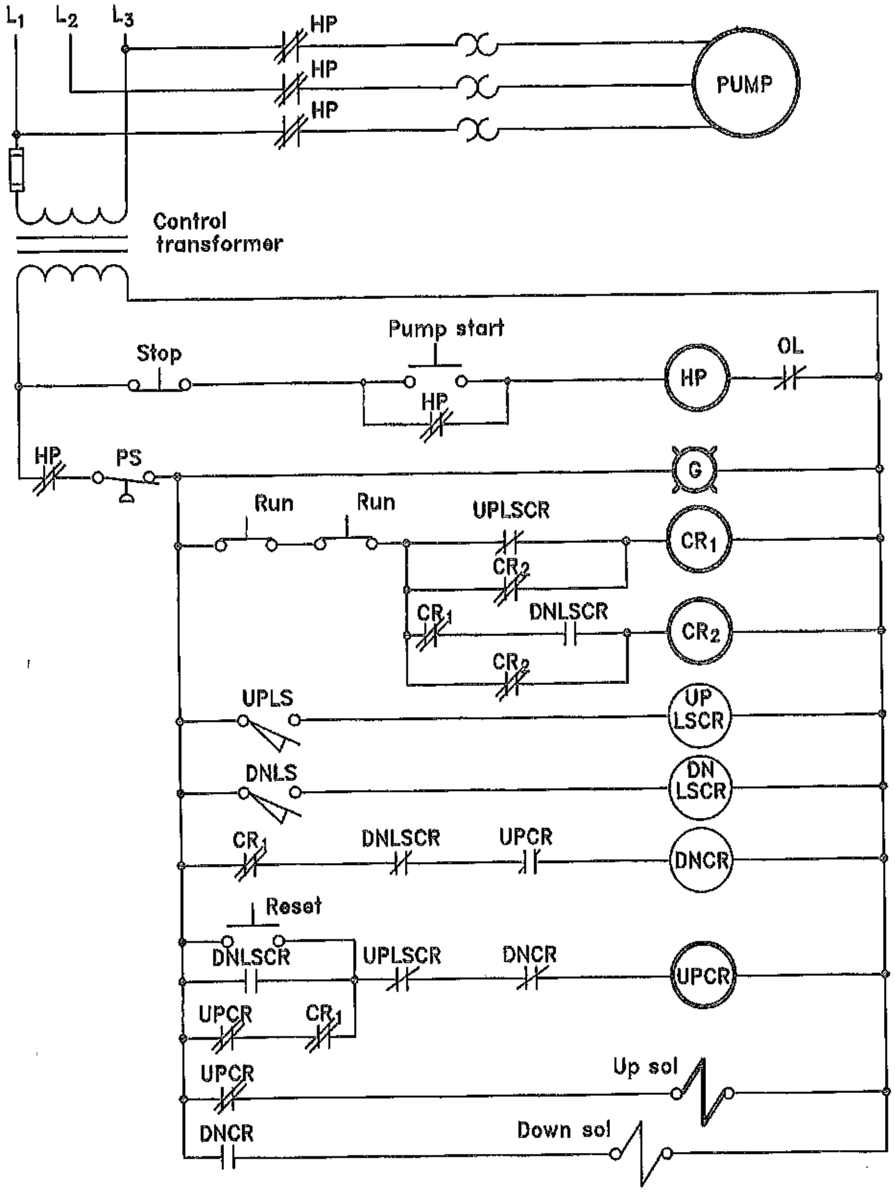


**Figure 36-6** Limit switch DNLS reopens.

4. Press and hold down both of the run push buttons. Relays $CR_1$ and DNCR should energize. The down solenoid should also turn on.
5. The press is now traveling in the down direction. Open the up limit switch. This should cause UPLSCR to de-energize. The down solenoid should remain turned on.
6. Close the down limit switch to simulate the press reaching the bottom of its stroke. DNLSCR, $CR_2$, and UPCR should energize. The press is now starting to travel upward.
7. Open the down limit switch. DNLSCR should de-energize, but the UPCR should remain energized.
8. Close the up limit switch to simulate the press reaching the top of its stroke. The up solenoid should turn off. Control relays $CR_1$ and $CR_2$ should both remain on as long as the two run buttons are held closed.
9. To restart the cycle, release the run buttons and reclose them.

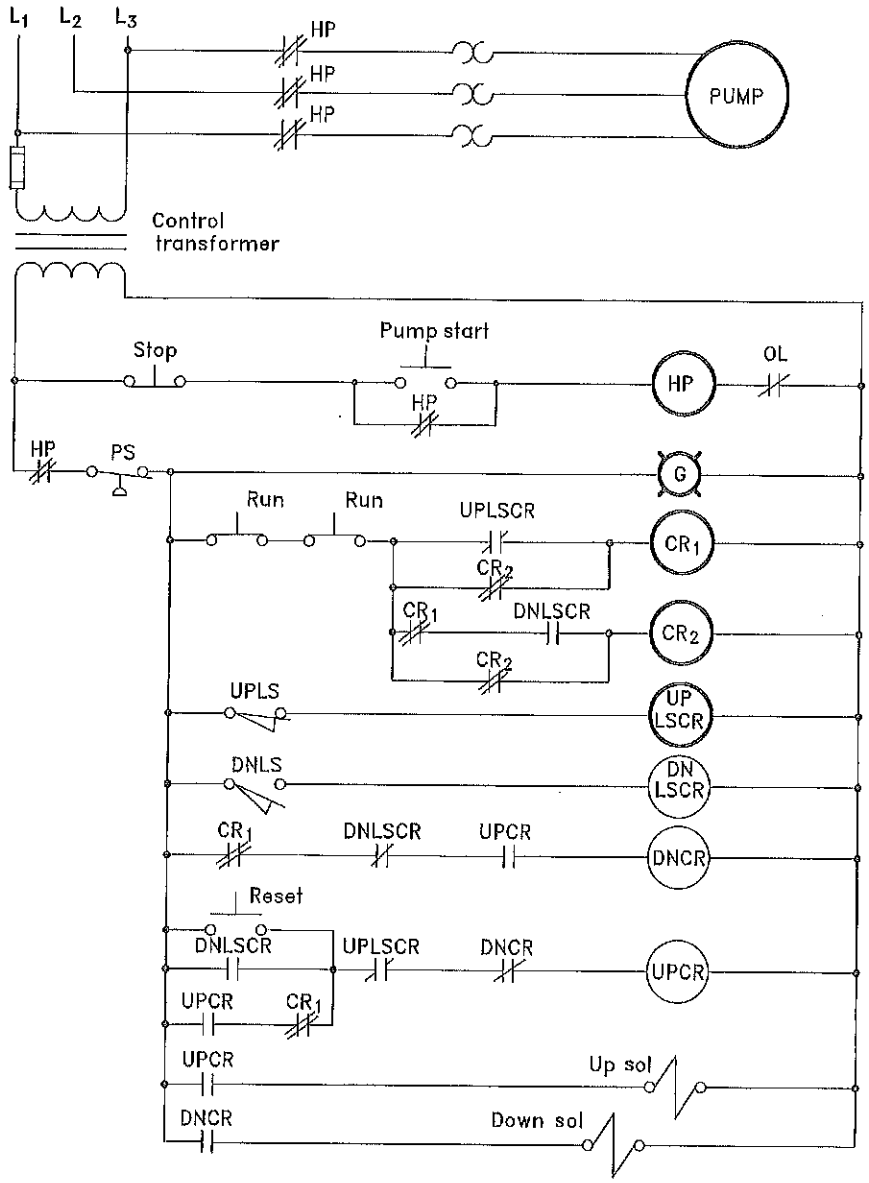


**Figure 36-7** The press completes the cycle.

## Review Questions

1. Assume that the hydraulic pump is running and the pilot light is turned on indicating that there is sufficient pressure to operate the press. Now assume that the up limit switch is not closed. What will be action of the circuit if both run buttons are pressed?

______________________________________________

______________________________________________

______________________________________________

2. Assume that the press is in the middle of its downstroke when the operator releases the two run push buttons. Explain the action of the circuit.

______________________________________________

______________________________________________

______________________________________________

3. Referring to the condition of the circuit as stated in question 2, what would happen if the two run push buttons are pressed and held closed? Explain your answer.

4. Referring to the condition of the circuit as stated in question 2, what would happen if the reset button is pressed and held closed? Explain your answer.

5. Assume that the press traveled to the bottom of its stroke and then started back up. When it reached the middle of its stroke, the power was interrupted. After the power has been restored, if the two run buttons are pressed, will the press continue to travel upward to complete its stroke, or will it start moving downward?

# Unit 37 Design of Two Flashing Lights

## Objectives

After studying this unit, you should be able to:

- Design a circuit from a written statement of requirements.
- Connect the circuit in the laboratory after the design has been approved.

## LABORATORY EXERCISE

Name ______________________________ Date __________

## Materials Required

Materials depend on the circuit design

In the space provided in Figure 37-1, draw a schematic diagram of a circuit that will fulfill the following requirements. Use two separate timers. Do not use an electronic timer set in the repeat mode. Remember that there is generally more than one way to design any circuit. Try to keep the design as simple as possible. The fewer components a circuit has, the less it is likely to fail.

1. An on-off toggle switch is used to connect power to the circuit.
2. When the switch is turned on, two lights will alternately flash on and off. Light #1 will be turned on when light #2 is turned off. When light #1 turns off, light #2 will turn on.
3. The lights are to flash at a rate of on for 1 second and off for 1 second.

When completed, have your instructor approve the design. After the design has been approved, connect it in the laboratory.

## Review Questions

1. When designing a control circuit that requires the use of a timing relay, what type of timer is generally used during the design?

______________________________

______________________________

______________________________

2. Should schematic diagrams be drawn to assume that the circuit is energized or de-energized?

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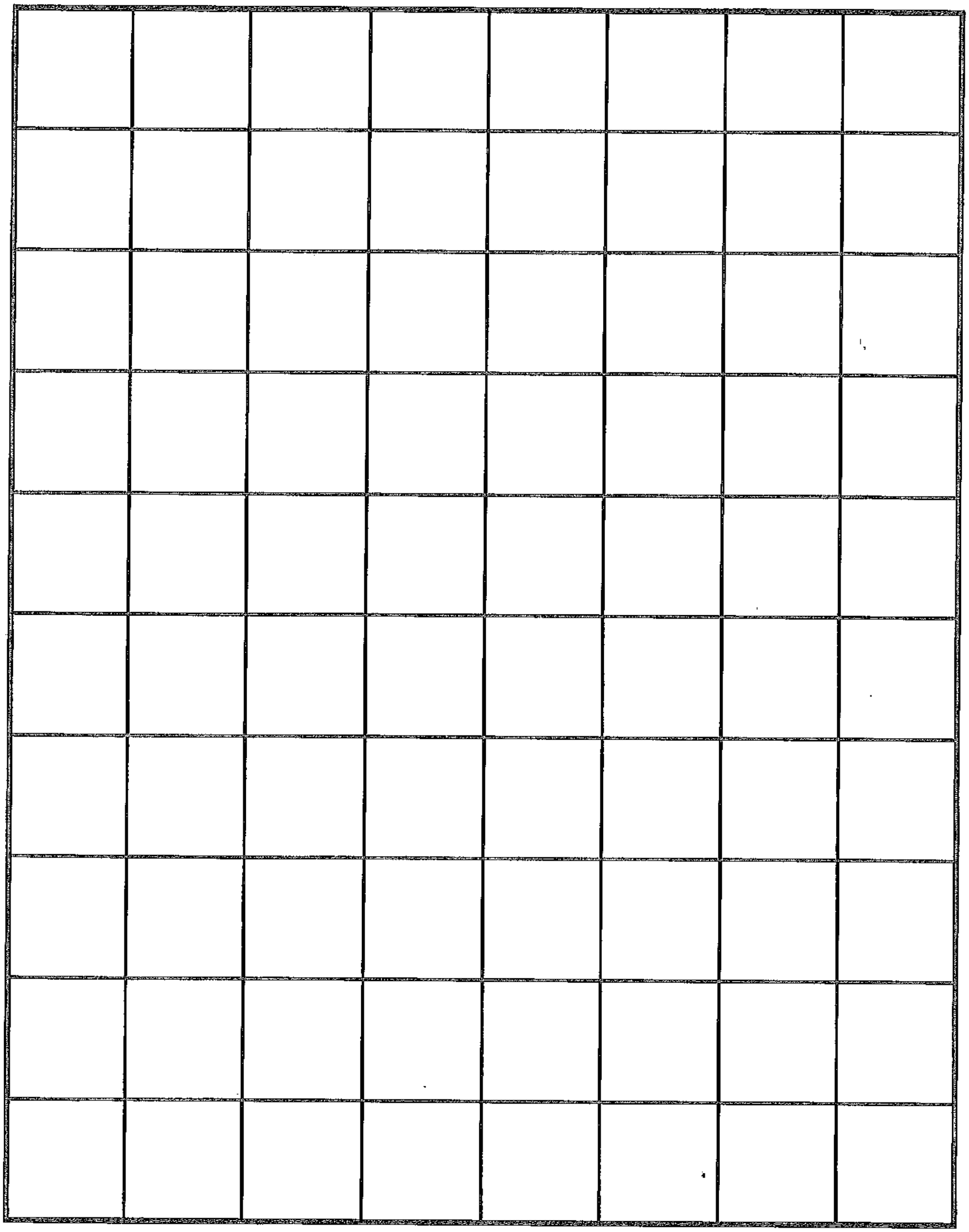

**Figure 37-1** Design of two flashing lights.

3. Explain the difference between a schematic and a wiring diagram.

4. In a forward-reverse control circuit, a normally closed F contact is connected in series with the R starter coil, and a normally closed R contact is connected in series with the F starter coil. What is the purpose of doing this and what is this contact arrangement called?

5. What type of overload relay is not sensitive to changes in ambient temperature?

# Unit 38 Design of Three Flashing Lights

## Objectives

After studying this unit, you should be able to:

- Design a motor control circuit using timers.
- Discuss the operation of this circuit.
- Connect this circuit in the laboratory.

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

## Materials Required

Materials depend on the design of the circuit

The design of this circuit will be somewhat similar to the circuit in Unit 37. This circuit, however, contains three lights that turn on and off in sequence. Use the space provided in Figure 38-1 to design this circuit. The requirements of the circuit are as follows:

1. A toggle switch is used to connect power to the circuit. When the power is turned on, light #1 will turn on.
2. After a delay of 1 second, light #1 will turn off and light #2 will turn on.
3. After a delay of 1 second, light #2 will turn off and light #3 will turn on.
4. After a delay of 1 second, light #3 will turn off and light #1 will turn back on.
5. The lights will repeat this action until the toggle switch is opened.

## Procedure

1. After the design of your circuit has been approved by your instructor, connect the circuit in the laboratory.
2. Test the circuit for proper operation.
3. Disconnect the circuit and return the components to their proper location.

## Review Questions

1. A 60 hp, three-phase squirrel cage induction motor is to be connected to a 480 volt line. What size NEMA starter should be used to make this connection?

______________________________________________

______________________________________________

______________________________________________

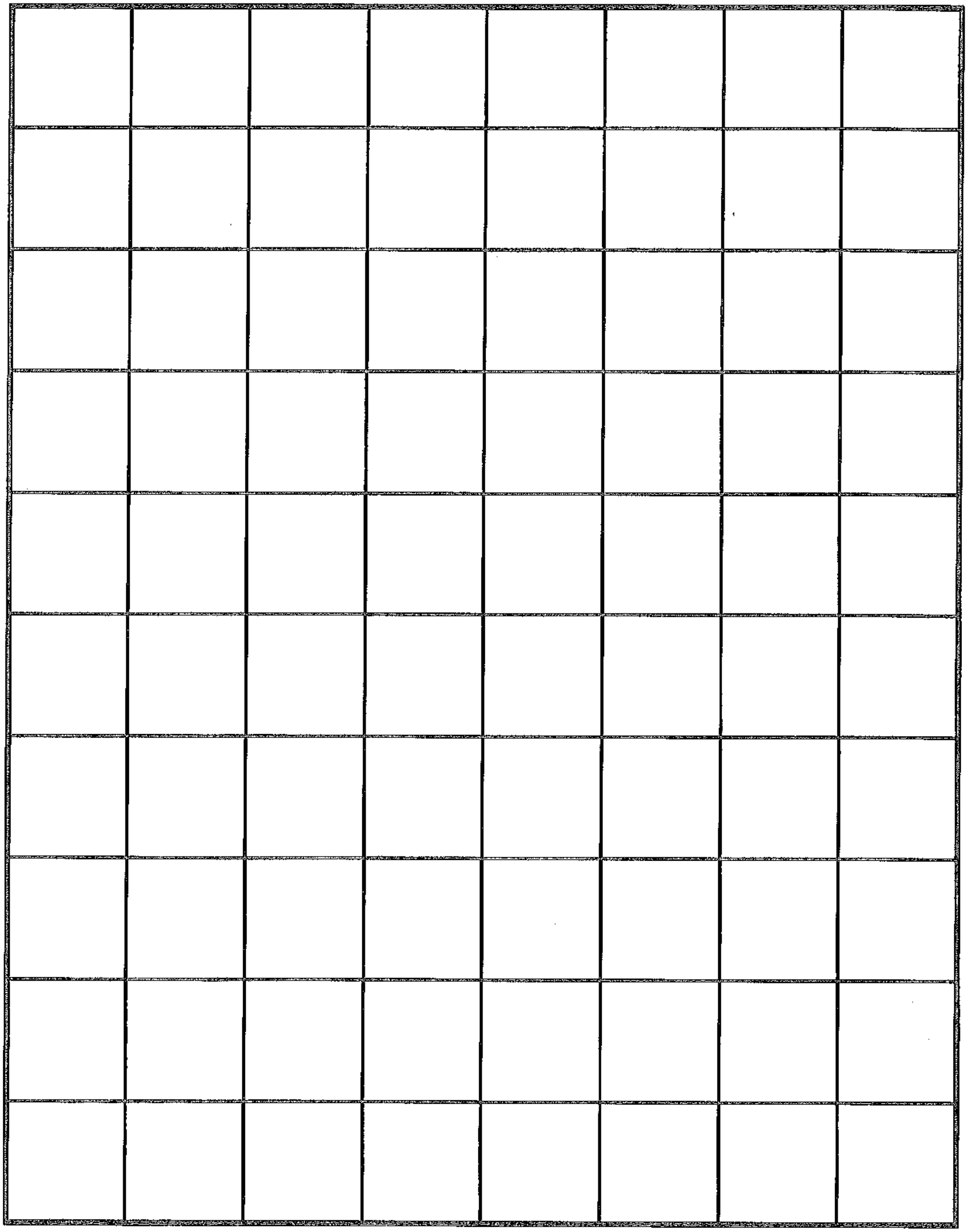

**Figure 38-1** Design of three lights that turn on and off in sequence.

2. An electrician is given a NEMA size 2 starter to connect a 30 hp, three-phase squirrel cage motor to a 575 volt line. Should this starter be used to operate this motor?

3. Assume that the motor in question 2 has a design code B. What standard size inverse time circuit breaker should be used to connect the motor?

4. The motor described in questions 2 and 3 is to be connected with copper conductors with type THHN insulation. What size conductors should be used? The termination temperature rating is not known.

5. Assume that the motor in question 2 has a nameplate current rating of 28 amperes and a marked service factor of 1. What size overload heater should be used for this motor?

# Unit 39 Control for Three Pumps

## Objectives

After studying this unit, you should be able to:

- Analyze a motor control circuit.
- List the steps of operation in a control circuit.
- Connect this circuit in the laboratory.

## LABORATORY EXERCISE

Name ______________________________________________ Date __________

## Materials Required

Three-phase power supply

Control transformer

3 motor starters with normally open auxiliary contacts

6 toggle switches to simulate auto-man switches and float switches

8-pin control relay and 8-pin socket

3 three-phase motors or equivalent motor loads

1 normally open and 1 normally closed push button

One of the primary duties of an industrial electrician is to troubleshoot existing control circuits. To troubleshoot a circuit, the electrician must understand what the circuit is designed to do and how it accomplishes it. To analyze a control circuit, start by listing the major components. Next, determine the basic function of each component. Finally, determine what occurs during the circuit operation.

To illustrate this procedure, the circuit previously discussed in Unit 36 will be analyzed. The hydraulic press circuit is shown in Figure 39-1. In order to facilitate circuit analysis, wire numbers have been placed beside the components. The first step will be to list the major components in the circuit.

1. Normally closed stop push button
2. Normally open push button used to start the hydraulic pump
3. Two normally open push buttons used as run buttons
4. Normally open push button used for the reset button
5. Normally open pressure switch
6. Two normally open limit switches

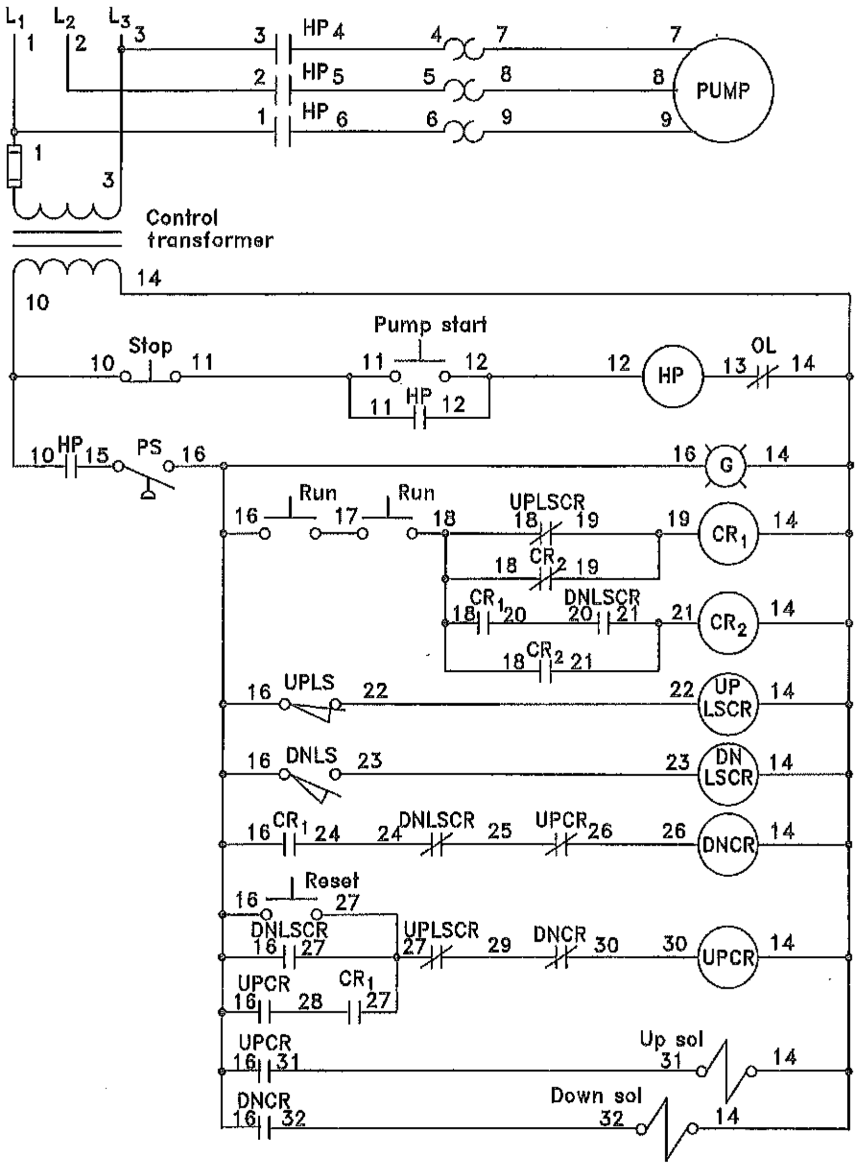


**Figure 39-1** Analyzing the circuit.

7. Two solenoid valves
8. Three 8-pin control relays ($CR_2$, UPLSCR, and DNCR)
9. Three 11-pin control relays ($CR_1$, DNLSCR, and UPCR)
10. Control transformer
11. Green pilot light

The next step in the process is to give a brief description of the function of each listed component:

1. (Normally closed stop push button)—Used to stop the operation of the hydraulic pump motor.
2. (Normally open push button used to start the hydraulic pump)—Starts the hydraulic pump.
3. (Two normally open push buttons used as run buttons)—Both push buttons must be held down to start the action of the press.

4. (Normally open push button used for the reset button)—Resets the press to the topmost position.
5. (Normally open pressure switch)—Determines whether or not there is enough hydraulic pressure to operate the press.
6. (Two normally open limit switches)—Determine when the press is at the top of its stroke and when it is at the bottom of its stroke.
7. (Two solenoid valves)—The up solenoid valve opens on energize to permit hydraulic fluid to move the press upward. The down solenoid valve opens on energize to permit hydraulic fluid to move the press downward.
8. (Three 8-pin control relays [$CR_2$, UPLSCR, and DNCR])—Part of the control circuit.
9. (Three 11-pin control relays [$CR_1$, DNLSCR, and UPCR])—Part of the control circuit.
10. (Control transformer)—Reduces the value of the line voltage to the voltage needed to operate the control circuit.
11. (Green pilot light)—Indicates there is enough hydraulic pressure to operate the pump.

The final step is to analyze the operation of the circuit. To analyze circuit operation, trace the current paths each time a change is made in the circuit. Start by pressing the pump start button.

1. When the pump start button is pressed, a circuit is completed to the coil of starter HP.
2. When coil HP energizes, all HP contacts change position. The three load contacts close to connect the pump motor to the line. The HP auxiliary contact located between wire points 11 and 12 closes to maintain the circuit after the pump start button is released, and the HP auxiliary contact located between wire numbers 10 and 15 closes to provide power to the rest of the circuit.
3. After the hydraulic pump starts, the hydraulic pressure in the system increases and closes the pressure switch.
4. When the pressure switch closes, a current path is provided to the green pilot light to indicate that there is sufficient hydraulic pressure to operate the press. A current path also exists through the normally open held closed up limit switch to control relay coil UPLSCR.
5. When UPLSCR relay energizes, both UPLSCR contacts open. The UPLSCR contact located between wire numbers 18 and 19 opens to break a current path to $CR_1$ coil. UPLSCR contact located between wire numbers 27 and 29 opens to break the current path to coil UPCR.
6. Both run push buttons must be held down to provide a current path through the normally closed $CR_2$ contact located between wire numbers 18 and 19 to the coil of $CR_1$ relay.
7. When $CR_1$ relay coil energizes, the $CR_1$ contact located between wire numbers 18 and 20 closes to provide a path to $CR_2$ coil in the event that the DNLSCR contact should close. The $CR_1$ contact located between wire numbers 16 and 24 closes to provide a current path to the down control relay (DNCR). The $CR_1$ contact located between wire numbers 28 and 27 closes to provide an eventual current path to the up control relay (UPCR).
8. When DNCR coil energizes, the DNCR contact located between wire numbers 29 and 30 opens to provide interlock with the up control relay. The DNCR contact between wire numbers 16 and 32 closes and provides a current path to the down solenoid valve.

9. When the down solenoid valve energizes, the press begins its downward stroke. This causes the normally open held closed up limit switch to open and de-energize the coil of the up limit switch control relay (UPLSCR).
10. Both UPLSCR contacts reclose.
11. When the press reaches the bottom of its stroke, the down limit switch located between wire numbers 16 and 23 closes to provide a current path to the coil of the down limit switch control relay (DNLSCR).
12. All DNLSCR contacts change position. The DNLSCR contact located between wire numbers 20 and 21 closes to provide a current path through the now closed $CR_1$ contact to the coil of $CR_2$ relay. The DNLSCR contact located between wire numbers 24 and 25 opens and breaks the current path to DNCR relay. The DNLSCR contact located between wire numbers 16 and 27 closes to provide a current path to UPCR relay when the DNCR contact located between 29 and 30 recloses.
13. When $CR_2$ coil energizes, the normally closed $CR_2$ contact located between wires 18 and 19 opens to prevent a maintained current path to $CR_1$ when the UPLSCR contact reopens. The normally open $CR_2$ contact located between 18 and 21 closes to maintain a current path to the coil of $CR_2$ in the event that $CR_1$ or DNLSCR contacts should open.
14. When the DNCR relay coil de-energizes, the DNCR contact located between wires 29 and 30 recloses to permit coil UPCR to be energized. The DNCR contact located between 16 and 32 reopens to break the current path to the down solenoid valve.
15. When the UPCR coil energizes, the normally closed UPCR contact located between wires 25 and 26 opens to provide interlock with the DNCR relay coil. The UPCR contact located between 16 and 28 closes to maintain a circuit through the now closed $CR_1$ contact to the coil of UPCR. The UPCR contact located between 16 and 31 closes and provides a current path to the up solenoid valve.
16. When the up solenoid valve opens, hydraulic fluid causes the press to begin its upward stroke.
17. When the press starts upward, the down limit switch reopens and de-energizes the coil of DNLSCR relay.
18. When coil DNLSCR de-energizes, the DNLSCR contact located between wires 20 and 21 reopens, but a current path is maintained by the now closed $CR_2$ contact. The DNLSCR contact located between 24 and 25 recloses, but the current path to DNCR coil remains broken by the UPCR contact located between 25 and 26. The DNLSCR contact located between wires 16 and 27 reopens, but a current path is maintained by the now closed UPCR and $CR_1$ contacts.
19. When the press reaches the top of its stroke, the up limit switch again closes and provides a current path to the coil of UPLSCR relay.
20. The UPLSCR contact located between wires 18 and 19 opens to break the current path to $CR_1$ coil. The UPLSCR contact located between wires 27 and 29 opens to break the current path to the coil of UPCR.
21. When $CR_1$ coil de-energizes, all $CR_1$ contacts return to their normal position. The $CR_1$ contact between wires 18 and 20 reopens, $CR_1$ contact between wires 16 and 24 reopens to prevent a current path from being established to the DNCR relay coil, and $CR_1$ contact between wires 27 and 28 reopens.

22. When coil UPCR de-energizes, its contacts return to their normal position. The UPCR contacts located between wires 16 and 28 reopen, and the UPCR contact located between wires 16 and 31 reopens to break the circuit to the up solenoid.
23. Before the circuit can be restarted, the current path to relay $CR_2$ must be broken by releasing one or both of the run push buttons. This will return all contacts back to their original state.
24. In the event the press should be stopped in the middle of its stroke, the up limit switch will be open and coil UPLSCR will be de-energized. The DNCR coil will also be de-energized. If the reset button is pressed and held, a circuit will be completed through the normally closed DNLSCR and DNCR contacts to the coil of UPCR. This will cause the up solenoid valve to energize and return the press to its up position.

## Determining What the Circuit Does

The circuit in this experiment is intended to operate three pumps. The pumps are used to pump water from a sump to a roof storage tank. The water in the storage tank is used for cooling throughout the plant. After the water has been used for cooling, it returns to the sump to be recooled. Three float switches are used to detect the water level in the storage tank. As the water is drained out of the tank, the level drops and the float switches turn on the pumps to pump water from the sump back to the storage tank (Figure 39-2).

## List the Components

In the space provided, list the major components in the control circuit shown in Figure 39-3.

1. ______
2. ______
3. ______
4. ______
5. ______
6. ______
7. ______
8. ______
9. ______
10. ______

## Describe the Components

In the space provided, give a brief description of the function of the components in this circuit.

1. ______
______
______

2. ______
______
______

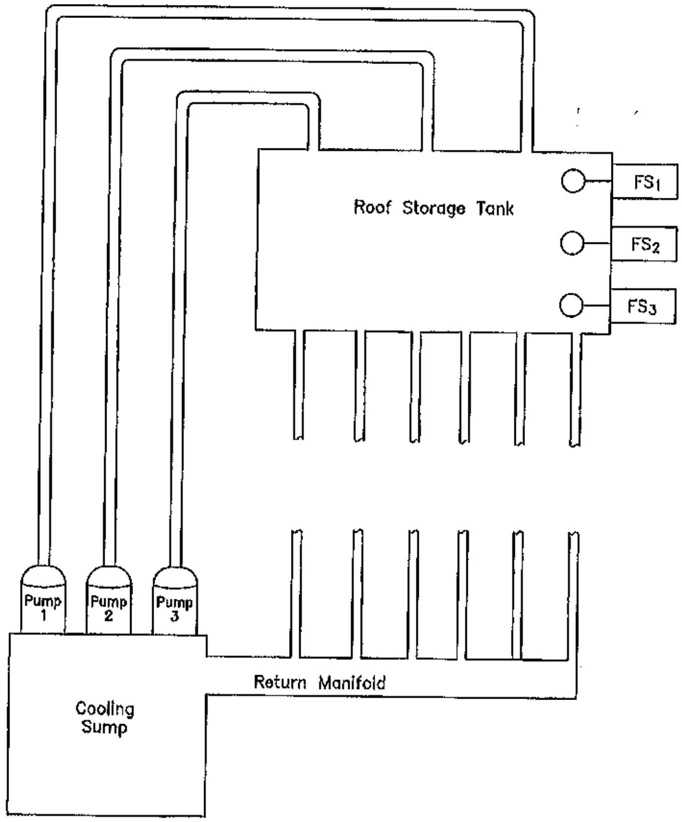


**Figure 39-2** Roof-mounted tank for plant cooling system.

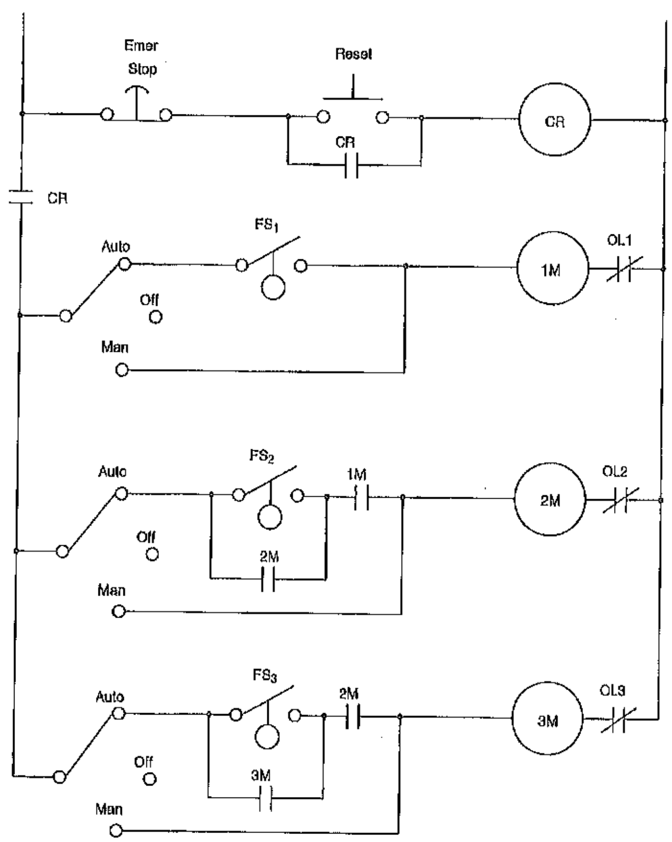


**Figure 39-3** Control circuit for three pumps.

3. ______

4. ______

5. ______

6. ______

7. ______

8. ______

9. ______

10. ______

## Describing the Circuit Operation

In the space provided, describe the operation of the circuit. Assume that in the normal state the roof storage tank is filled with water, and all the auto-off-man switches are set in the auto position. Also assume that the three motor starters control the operation of the three pumps, although the pumps are not shown on the schematic.

1. ______

2. ______

3. ______

4. ______________________________________________

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5. ______________________________________________

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6. ______________________________________________

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7. ______________________________________________

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8. ______________________________________________

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9. ______________________________________________

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10. ______________________________________________

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11. ______________________________________________

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12. ______________________________________________

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13. ______________________________________________

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14. ______________________________________________

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15. ______________________________________________

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______________________________________________

## Review Questions

To answer the following questions, refer to the circuit shown in Figure 39-3.

1. Assume that all three pumps are operating. What would be the action of the circuit if the auto-off-man switch of pump #2 were to be switched to the off position?

2. Assume that the auto-off-man switch of pump #3 is set in the manual position. What will be the operation of the circuit if float switch $FS_1$ closes?

3. Assume that the roof storage tank empties completely, but none of the pumps have started. Which of the following could not cause this condition?
   a. The emergency stop button has been pushed and the control relay is de-energized.
   b. The auto-off-man switch of pump #1 has been set in the off position.
   c. The auto-off-man switch of pump #1 has been set in the manual position.
   d. 1M coil is open.
4. Assume that all three pumps are in operation and $OL_3$ contact opens. Will this affect the operation of the other two pumps?

5. Assume that $FS_2$ float switch is defective. If the water level drops enough to close float switch $FS_3$, will pump #3 start running?

# Unit 40 Oil Pressure Pump Circuit for a Compressor

## Objectives

After studying this unit, you should be able to:

- Analyze a motor control circuit.
- List the steps of operation in a control circuit.
- Connect this circuit in the laboratory.

## LABORATORY EXERCISE

Name ______________________________ Date __________

## Materials Required

Three-phase power supply

2 motor starters

Control transformer

2 electronic timers (Dayton model 6A855) and 11-pin tube sockets

2 pilot lights

2 double-acting push buttons

In the circuit shown in Figure 40-1, the oil pump must start for some time before the compressor is started. When the start button is pressed, the oil pump should continue to run for some time after the compressor stops operating.

## List the Components

In the space provided, list the circuit components.

1. ______________________________
2. ______________________________
3. ______________________________
4. ______________________________
5. ______________________________
6. ______________________________
7. ______________________________
8. ______________________________
9. ______________________________
10. ______________________________

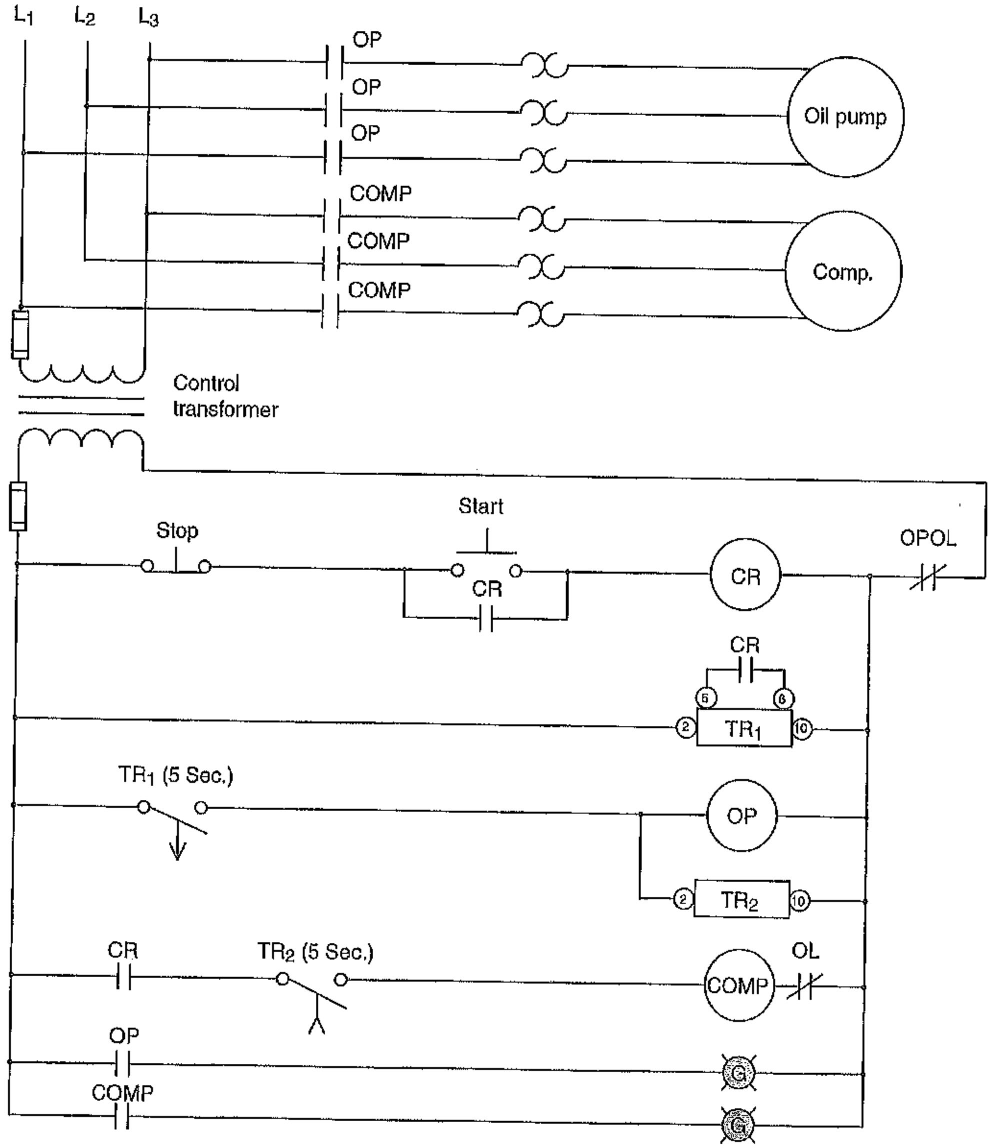


**Figure 40-1** Compressor oil pump circuit.

## Describe the Components

In the space provided, give a brief description of what function is performed by each component.

1. ______________________________

______________________________

2. ______________________________

______________________________

3. ______________________________

______________________________

4. ______________________________

______________________________

5. ______________________________

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6. ______________________________

7. ______________________________

8. ______________________________

9. ______________________________

10. ______________________________

## Circuit Operation

In the space provided, describe the operation of the circuit in a step-by-step sequence.

1. ______________________________

2. ______________________________

3. ______________________________

4. ______________________________

5. ______________________________

6. ______________________________

7. ______________________________

8. ______________________________

9. ______________________________

10. ______________________________

11. ______________________________

12. ______________________________

13. ______________________________

14. ______________________________________________

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15. ______________________________________________

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## Connecting the Circuit

1. Connect the circuit shown in Figure 40-1.
2. After checking with the instructor, turn on the power and test the circuit for proper operation.
3. **Turn off the power** and disconnect the circuit. Return the components to their proper location.

## Review Questions

To answer the following questions, refer to the circuit shown in Figure 40-1.

1. Assume that the start button is pressed and the oil pump starts operating. After a delay of 5 seconds, the COMP pilot light turns on, but the compressor motor does not start. Which of the following could cause this condition?
   a. $TR_2$ timer is defective.
   b. COMP starter coil is defective.
   c. The compressor motor is defective.
   d. All of the above.
2. Assume that the circuit is in operation. When the stop button is pressed, both the compressor and oil pump stop operating immediately. Which of the following could cause this condition?
   a. CR relay is defective.
   b. $TR_1$ timer is defective.
   c. OP starter is defective.
   d. Timer $TR_2$ is defective.
3. When the start button is pressed, the oil pump starts operating immediately. After a delay of 5 seconds, the oil pump motor turns off. An electrician finds that the control transformer fuse is blown. Which of the following could cause this condition?
   a. $TR_1$ coil is shorted.
   b. OP coil is shorted.
   c. $TR_2$ coil is shorted.
   d. COMP coil is shorted.
4. When the start button is pressed, the oil pump motor starts operating immediately. After a long time delay, it is determined that the compressor motor will not start. Which of the following could not cause this condition?
   a. OP coil is defective.
   b. $TR_2$ coil is defective.
   c. COMP coil is defective.
   d. The compressor overload contact is open.

5. When the start button is pressed, the oil pump motor starts operating immediately. When the start button is released, however, the oil pump motor turns off. The operator then presses the start button and holds it down for a period of 10 seconds. This time the oil pump motor starts operating immediately, but the compressor motor never starts. When the start button is released, the oil pump motor again immediately turns off. Which of the following could cause this condition?
   a. CR coil is defective.
   b. $TR_1$ coil is defective.
   c. $TR_2$ coil is defective.
   d. COMP coil is defective.

# Unit 41 Autotransformer Starter

## Objectives

After studying this unit, you should be able to:

- Discuss the operation of an autotransformer starter.
- Explain the operation of an autotransformer starter.
- Connect an autotransformer starter in the laboratory.

Autotransformer starters are used to reduce the amount of inrush current when starting a large motor. The autotransformer starter accomplishes this by reducing the voltage applied to the motor during the starting period. If the voltage is reduced by one-half, the current will be reduced by one-half, and the torque will be reduced to one-fourth of normal.

There are several different ways to construct an autotransformer starter. Some use three transformers, and others use two transformers. In this experiment two transformers connected as an open delta will be used. Two 0.5 kVA control transformers will be employed. Since these transformers are to be used as autotransformers, only the high-voltage windings will be connected. The low-voltage windings ($X_1$ and $X_2$) will not be used in this experiment. The high-voltage windings can be identified by the markings on the terminal leads of $H_1$ through $H_4$. These high-voltage windings are to be connected in series by connecting a jumper between terminals $H_2$ and $H_3$. This jumpered point provides a center tap for the entire winding.

## Obtaining Enough Contacts

A schematic diagram of this connection is shown in Figure 41-1. Notice that there are a total of five starting contactor (SC) load contacts needed during the starting period. Contactors that contain five load contacts can be purchased, but they are difficult to obtain and they are expensive. For this reason, two three-phase contactors will be used to provide the needed load contacts. This can be accomplished by connecting the coil of $SC_1$ and $SC_2$ contactors in parallel with each other.

## Circuit Operation

When the start button is pressed, coils CR, TR, $SC_1$, and $SC_2$ energize. When the $SC_1$ and $SC_2$ load contacts close, the motor is connected to the center tap of the open delta autotransformer. Since the transformers have been center tapped, the motor is connected to half of the line voltage. A basic schematic diagram of this connection is shown in Figure 41-2. The normally closed $SC_1$ and $SC_2$ auxiliary contacts connected in series with the R coil open to provide interlock and prevent the R contactor from energizing as long as $SC_1$ or $SC_2$ is energized.

After some time, TR timer reaches the end of its timing sequence and the two timed TR contacts change position. The normally closed TR contact connected in series with coils $SC_1$ and $SC_2$ opens and de-energizes these contactors. This causes all $SC_1$ and $SC_2$ load contacts to open and disconnect the autotransformer from the line. The normally closed $SC_1$ and $SC_2$ auxiliary contacts connected in series with R coil reclose.

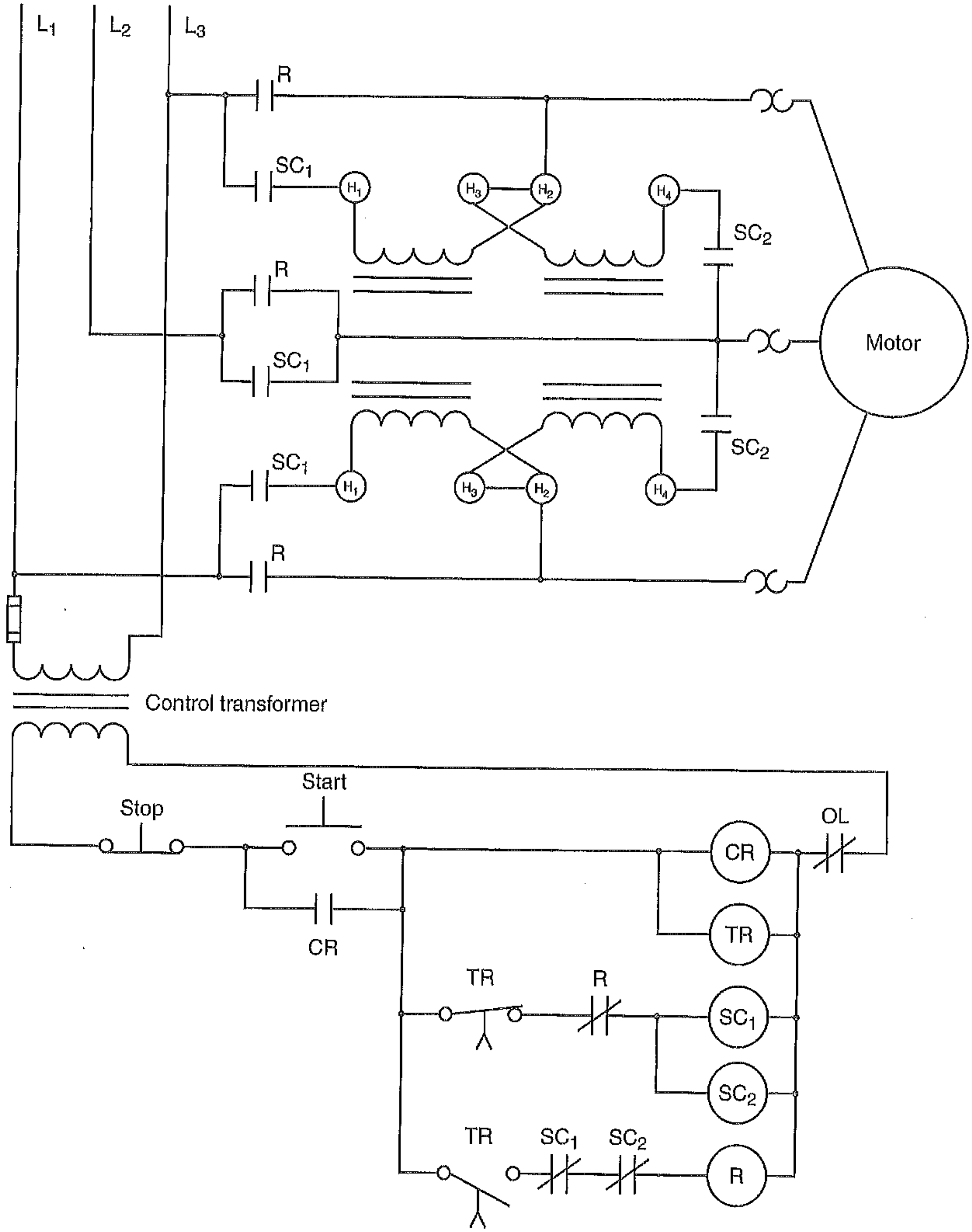


**Figure 41-1** Autotransformer starter.

When the normally open TR contact connected in series with R coil closes, the R contactor energizes and closes all R load contacts. This connects the motor directly to the power line. The normally closed R auxiliary contact connected in series with coils $SC_1$ and $SC_2$ opens to provide interlock. The motor will continue to run until the stop button is pressed or an overload occurs.

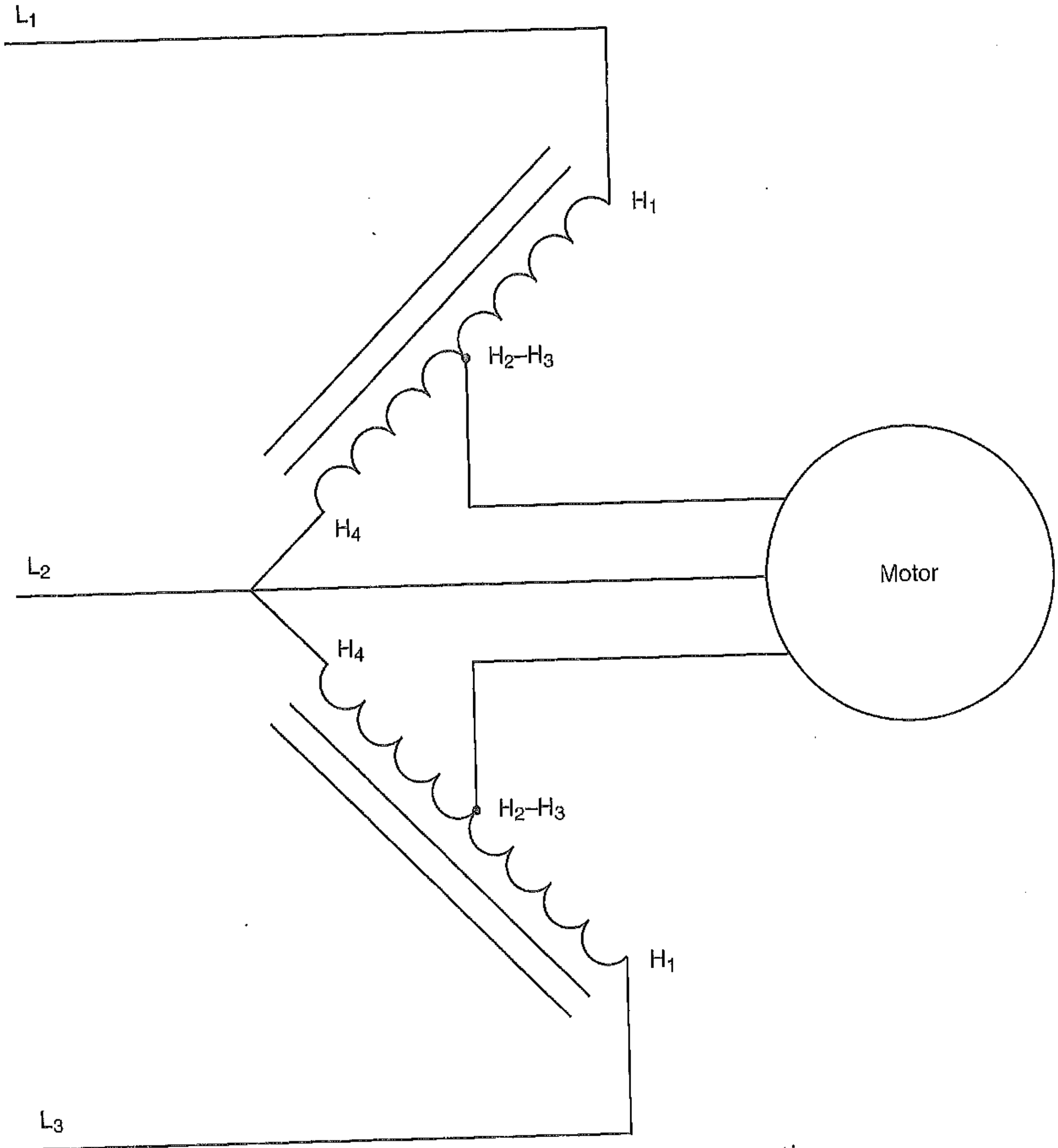


**Figure 41-2** Schematic diagram of a basic autotransformer connection.

## LABORATORY EXERCISE

### Materials Required

Three-phase power supply

Control transformer

3 three-phase contactors with at least one normally open and one normally closed auxiliary contact

2 0.5-kVA control transformers (480/240-120)

Three-phase motor or equivalent motor load

On-delay timer (Dayton model 6A855 or equivalent) and 11-pin tube socket

8-pin control relay and 8-pin tube socket

2 double-acting push buttons (N.O./N.C. on each button)

Three-phase overload relay or three single-phase overload relays with the overload contacts connected in series

*(In this circuit it is possible to replace the two SC contactors with a single contactor that contains five load contacts, if one is available. Also, if true contactors are not available, it is permissible to use motor starters for the two SC contactors.)*

1. Assuming that relay CR is an 8-pin control relay, and that timer TR is a Dayton model 6A855, place pin numbers beside the components of CR and TR in Figure 41-1. Circle the pin numbers to distinguish them from wire numbers.
2. Place wire numbers beside all circuit components in Figure 41-1.
3. Place corresponding wire numbers beside the components shown in Figure 41-3. Make certain to make the connection between $H_2$ and $H_3$ on the high-voltage side of the control transformers.
4. Connect the control section of the circuit shown in Figure 41-1.
5. Set the timing relay for a delay of 5 seconds.
6. Turn on the power and test the control section of the circuit for proper operation.
7. **Turn off the power.**
8. Connect the load section of the circuit.
9. Turn on the power and test the circuit for proper operation. (Note: Connect a voltmeter across the motor or equivalent motor load terminals and monitor the voltage. When the circuit is first energized, the voltage applied to the motor should be one-half the full-line value. After a delay of 5 seconds, the voltage should increase to full value.)
10. **Turn off the power** and disconnect the circuit. Return the components to their proper places.

## Review Questions

1. How does the autotransformer reduce the amount of starting current to a motor?

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2. Is the autotransformer used in this experiment connected as a wye, delta, or open delta?

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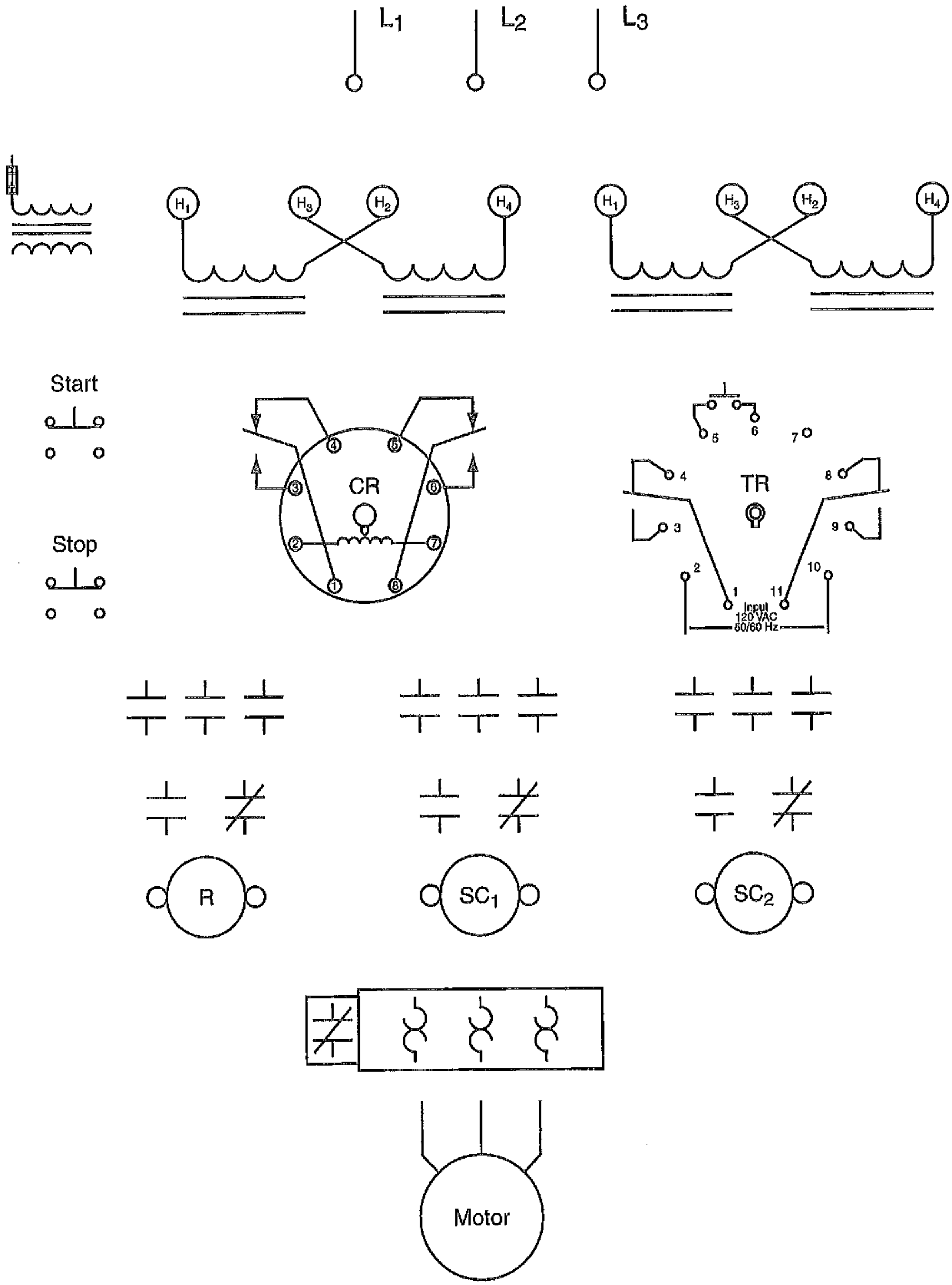


**Figure 41-3** Developing a wiring diagram.

3. What is the advantage, if any, of using an open delta connection as opposed to a closed delta or wye?

________________________________________

________________________________________

________________________________________

4. Assume that the line-to-line voltage in Figure 41-1 is 480 volts. Also assume that when the start button is pressed, the motor starts with 240 volts applied to the motor. When the start button is released, however, the motor stops running. Which of the following could cause this problem?

   a. $SC_1$ coil is open.

   b. CR coil is open.

   c. TR coil is open.

   d. The stop push button is open.

5. Refer to the circuit shown in Figure 41-1. When the start button is pressed, nothing happens for 5 seconds. After 5 seconds, the motor suddenly starts with full voltage connected to it. Which of the following could cause this problem?

   a. CR coil is open.

   b. TR coil is open.

   c. R coil is open.

   d. R normally closed auxiliary contact is open.