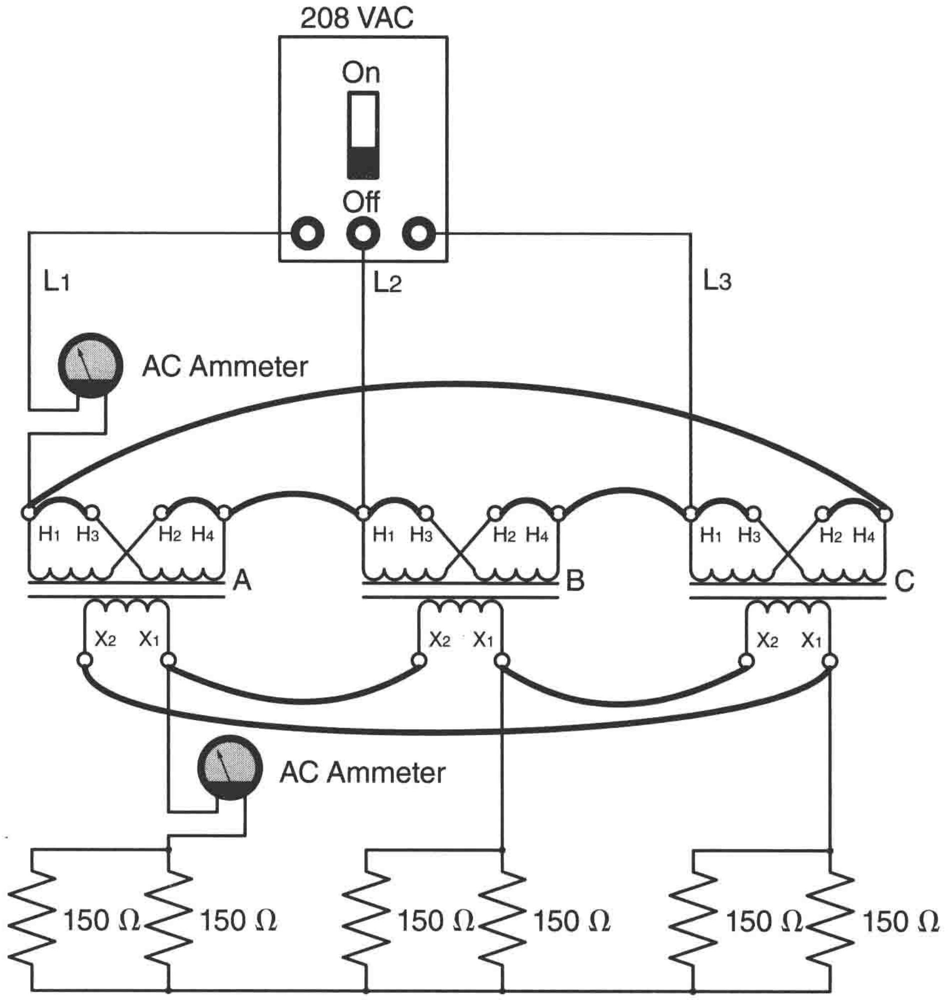


Figure 24-20 Transformers with delta connected primary, delta connected secondary, and wye connected load.

31. Using the turns-ratio of the transformer, calculate the phase current of the primary winding.

    $I_{(PHASE\ PRIMARY)}$ ________ A

32. Calculate the line current supplied to the primary. Make sure to add the excitation current to the calculation.

    $I_{(LINE\ PRIMARY)}$ ________ A

33. Turn on the power and measure the line current of the secondary and the line current of the primary. **Turn off the power**.

    $I_{(LINE\ SECONDARY)}$ ________ A

    $I_{(LINE\ PRIMARY)}$ ________ A

    Compare the measured values with the calculated values in step 29 and step 32. Are the values within 5% of each other?

    ____

34. Reconnect the load resistors to form a delta connection instead of a wye connection as shown in Figure 24-21.

35. Assuming a primary voltage of 208 volts, calculate the phase voltage of the secondary. The transformers have a ratio of 2:1.

    $E_{(PHASE\ SECONDARY)}$ ________ volts

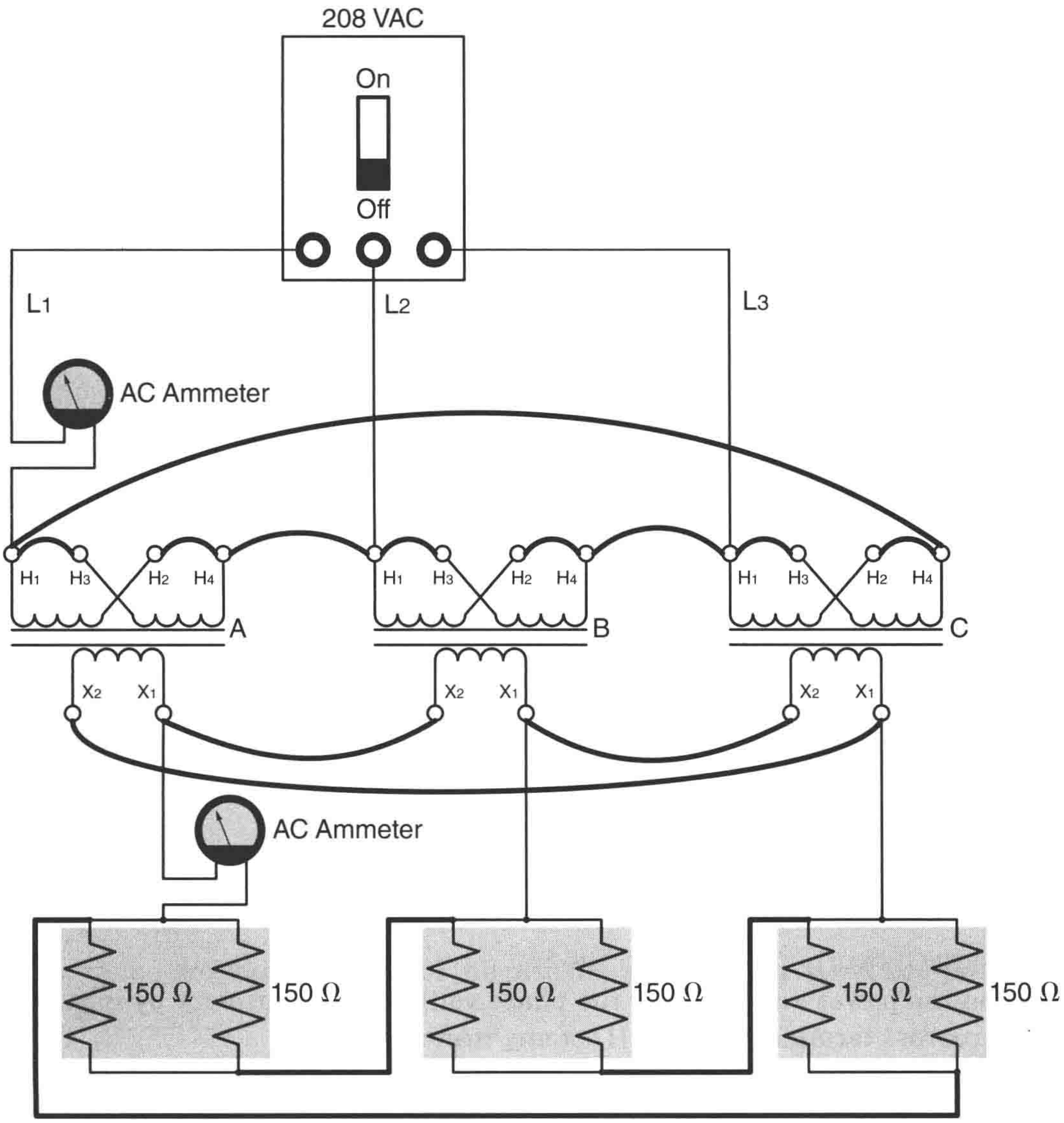


Figure 24-21 Changing the load from a wye connection to a delta connection.

36. Calculate the line voltage of the secondary.

    $E_{(LINE\ SECONDARY)}$ ___________ volts

37. Calculate the phase voltage of the delta connected load resistors.

    $E_{(PHASE\ LOAD)}$ ___________ volts

38. Calculate the phase current of the load using Ohm's law.

    $I_{(PHASE\ LOAD)}$ ___________ A

39. Calculate the line current supplied to the load by the secondary of the transformer.

    $I_{(LINE\ SECONDARY)}$ ___________ A

40. Calculate the phase current of the secondary winding.

    $I_{(PHASE\ SECONDARY)}$ ___________ A

41. Using the turns-ratio of the transformer, calculate the phase current of the primary winding.

    $I_{(PHASE\ PRIMARY)}$ ___________ A

42. Calculate the line current supplied to the primary. Make sure to add the excitation current to the calculation.

    $I_{(LINE\ PRIMARY)}$ _________ A

43. Turn on the power and measure the line current of the secondary and the line current of the primary. **Turn off the power.**

    $I_{(LINE\ SECONDARY)}$ _________ A

    $I_{(LINE\ PRIMARY)}$ _________ A

    Compare the measured values with the calculated values in step 39 and step 42. Are the values within 5% of each other?

    ____

Wye-Delta Connection (Part 2)

In the next part of the exercise, the three transformers will be connected to form a wye-delta bank. The schematic drawing of the connection is shown in Figure 24-22. Notice that all the H_4 terminals have been joined to form the wye connection. Power will be applied to the H_1 terminals. The secondary windings will remain in a delta connection.

44. Reconnect the transformers as shown in Figure 24-23. For the first part of the exercise, no load will be connected to the secondary.

45. Assuming a line voltage of 208 volts, calculate the phase voltage of the wye connected primary.

    $E_{(PHASE\ PRIMARY)}$ = _________ volts

46. The transformers have a turns-ratio of 2:1. Calculate the phase voltage of the secondary.

    $E_{(PHASE\ SECONDARY)}$ = _________ volts

47. Turn on the power and measure the phase voltage of the primary by measuring the voltage across terminals H_1 and H_4 of any transformer.

    $E_{(PHASE\ PRIMARY)}$ = _________ volts

48. Measure the phase voltage of the secondary by measuring the voltage across the X_1 and X_2 terminals of any transformer.

    $E_{(PHASE\ SECONDARY)}$ = _________ volts

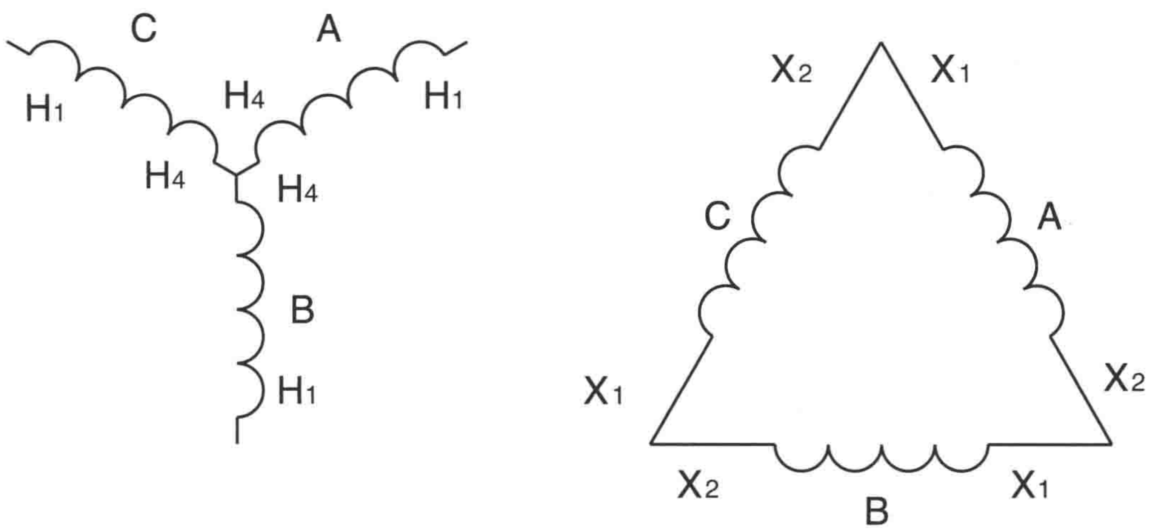


Figure 24-22 A wye-delta transformer connection.

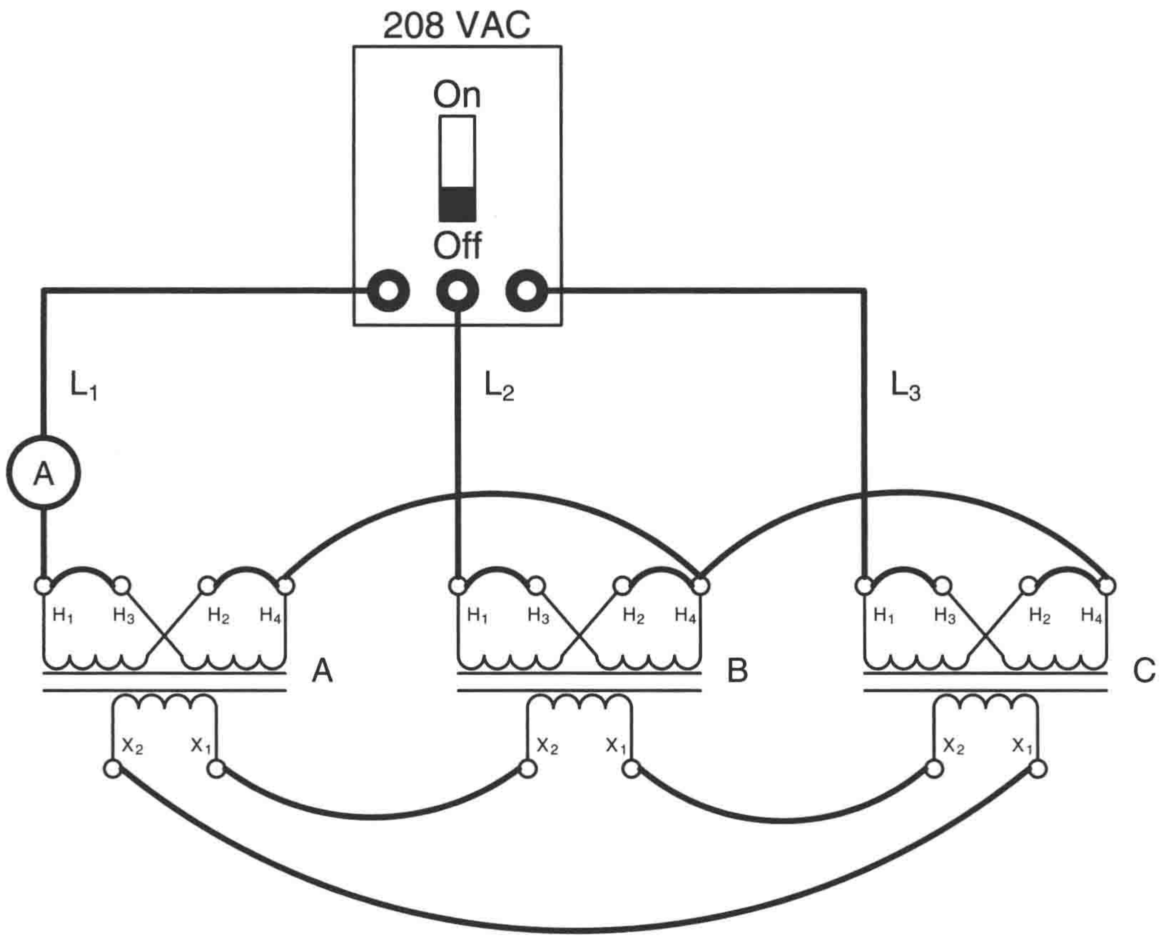


Figure 24-23 Transformer bank with a wye connected primary and delta connected secondary.

49. Measure the excitation current of the primary winding. **Turn off the power.**

    $I_{(EXC)}$ = __________ A

50. Compare the measured values of primary and secondary phase voltage with the calculated values in step 46 and step 47. Are the two values within 5% of each other?

    ____

51. Reconnect the delta connected resistor bank to the transformer secondary as shown in Figure 24-24.
52. Calculate the phase voltage of the delta connected load.

    $E_{(PHASE\ LOAD)}$ = __________ volts

53. Using Ohm's law, calculate the phase current of the load.

    $I_{(PHASE\ LOAD)}$ = __________ A

54. Calculate the line current supplied by the transformer secondary to operate the load.

$$I_{LINE} = I_{PHASE} \times 1.732$$

    $I_{(LINE\ SECONDARY)}$ = __________ A

55. Calculate the phase current of the secondary winding.

$$I_{PHASE} = \frac{I_{LINE}}{1.732}$$

    $I_{(PHASE\ SECONDARY)}$ = __________ A

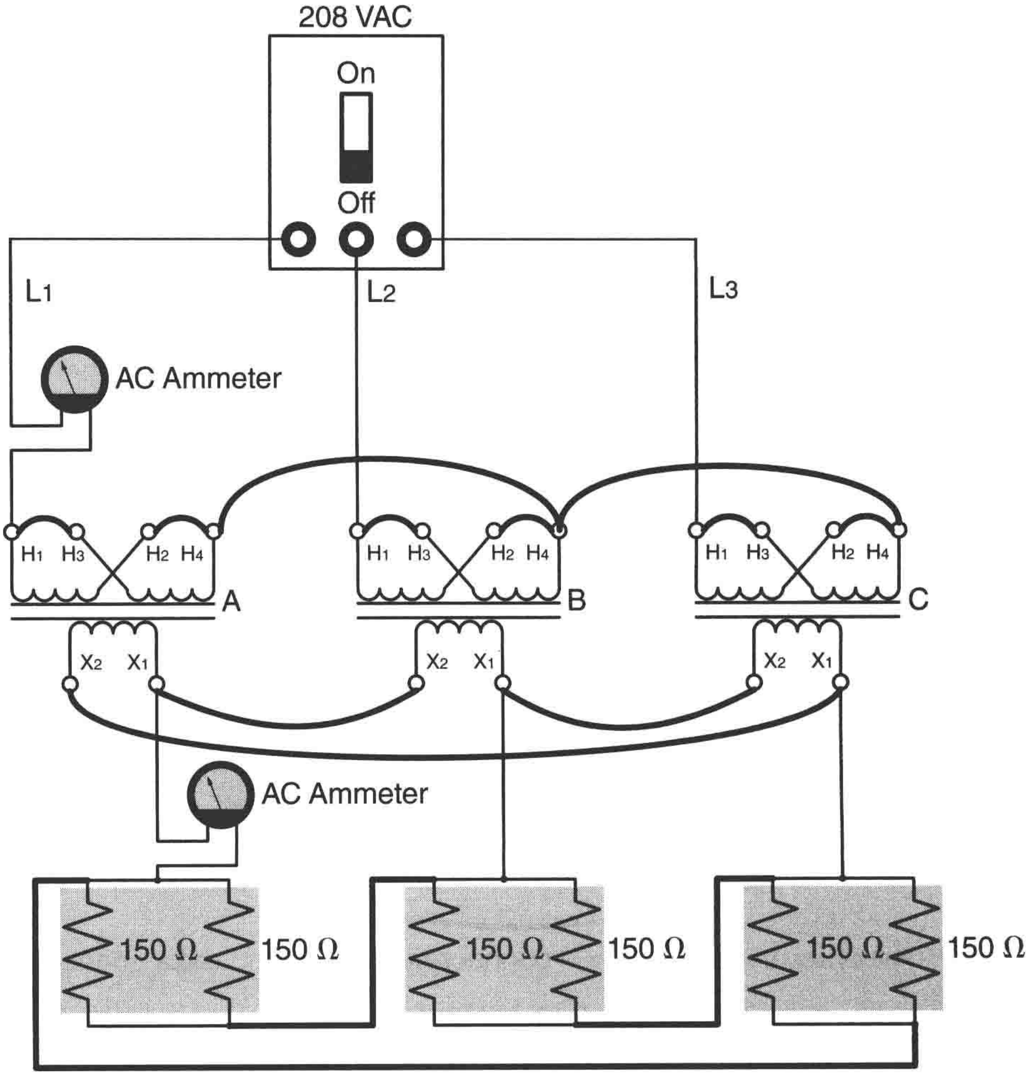


Figure 24-24 Adding load to the transformer connection.

56. Using the turns-ratio of the transformer and the phase current of the secondary winding, calculate the phase current of the primary winding.

    $I_{(\text{PHASE PRIMARY})}$ = __________ A

57. Calculate the line current supplied to the primary windings. Make certain to add the excitation current value.

    $I_{(\text{LINE PRIMARY})}$ = __________ A

58. Turn on the power and measure the secondary line current and the primary line current. **Turn off the power.**

    $I_{(\text{LINE SECONDARY})}$ = __________ A

    $I_{(\text{LINE PRIMARY})}$ = __________ A

    Compare the measured values with the calculated values in step 54 and step 57. Are the values within 5% of each other?

    ____

Wye-Wye Connection

The next section of this exercise deals with transformers connected in a wye-wye configuration. The schematic diagram for this connection is shown in Figure 24-25.

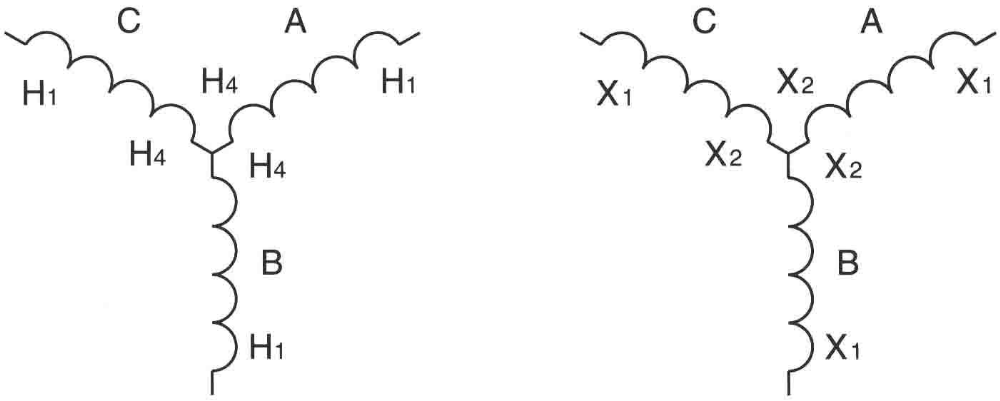


Figure 24-25 A wye-wye three-phase transformer connection.

59. Connect the circuit shown in Figure 24-26. Note that only the secondary windings of the transformers must be reconnected. The primary windings remain connected in a wye configuration and the load resistors remain connected in a delta configuration.
60. Assuming a line voltage of 208 volts, calculate the phase voltage of the primary winding. (In a wye connection, the phase voltage is less than the line voltage by a factor of 1.732.)

    $E_{(PHASE\ PRIMARY)}$ = __________ volts

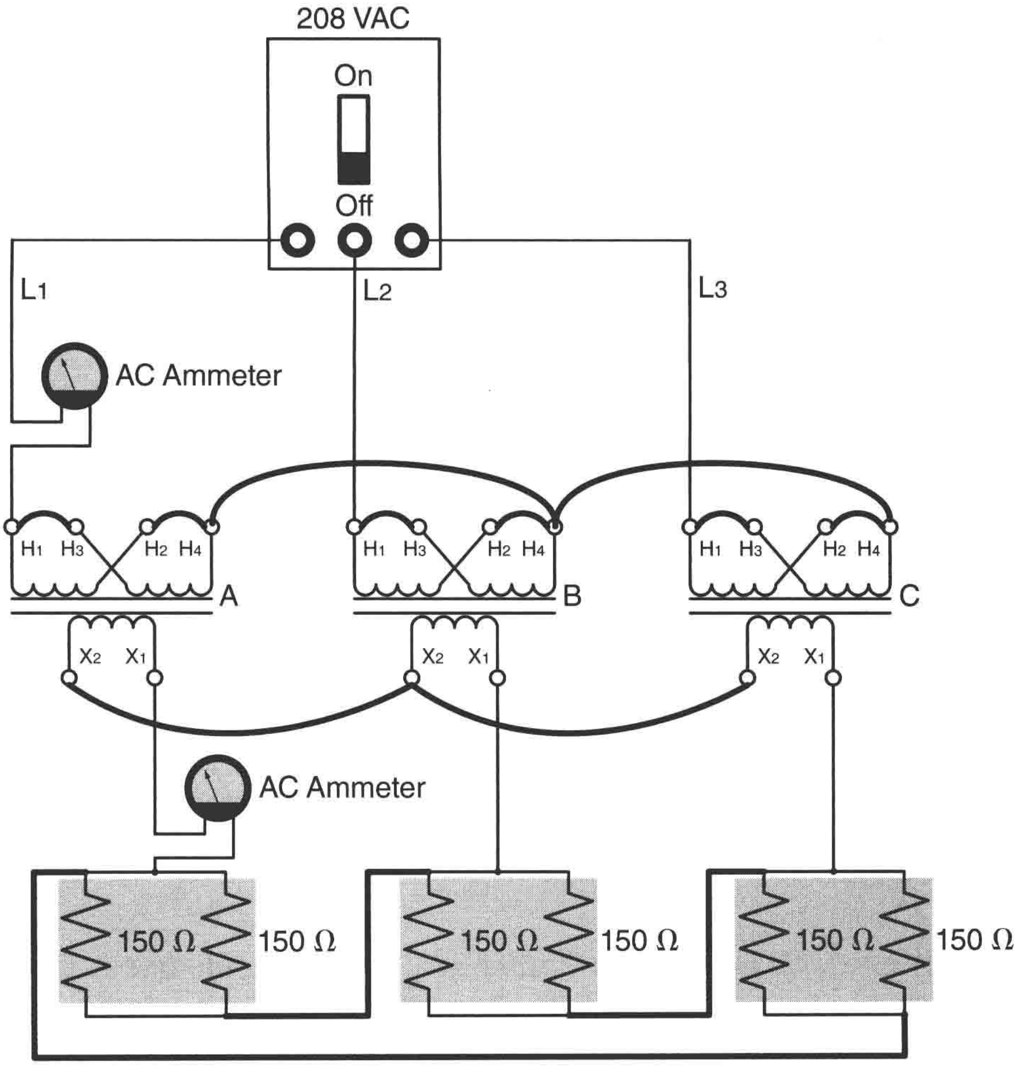


Figure 24-26 Transformers with a wye connected primary, wye connected secondary, and delta connected load.

61. Calculate the phase voltage of the secondary. The transformers have a ratio of 2:1.

    $E_{(PHASE\ SECONDARY)}$ ________ volts

62. Calculate the line voltage of the secondary.

    $E_{(LINE\ SECONDARY)}$ = ________ volts

63. Calculate the phase voltage of the delta connected load resistors.

    $E_{(PHASE\ LOAD)}$ = ________ volts

64. Calculate the phase current of the load using Ohm's law.

    $I_{(PHASE\ LOAD)}$ = ________ A

65. Calculate the line current supplied to the load by the secondary of the transformer.

    $I_{(LINE\ SECONDARY)}$ = ________ A

66. Calculate the phase current of the secondary winding.

    $I_{(PHASE\ SECONDARY)}$ = ________ A

67. Using the turns-ratio of the transformer, calculate the phase current of the primary winding.

    $I_{(PHASE\ PRIMARY)}$ = ________ A

68. Calculate the line current supplied to the primary. Make sure to add the excitation current to the calculation.

    $I_{(LINE\ PRIMARY)}$ ________ A

69. Turn on the power and measure the line current of the secondary and the line current of the primary. **Turn off the power.**

    $I_{(LINE\ SECONDARY)}$ ________ A

    $I_{(LINE\ PRIMARY)}$ ________ A

    Compare the measured values with the calculated values in step 65 and step 68. Are the values within 5% of each other?

    ____

Open Delta Connection

The last connection to be made is the open delta. The open delta connection requires the use of only two transformers to supply three-phase power to a load. The schematic diagram for an open delta connection is shown in Figure 24-27. It should be noted that

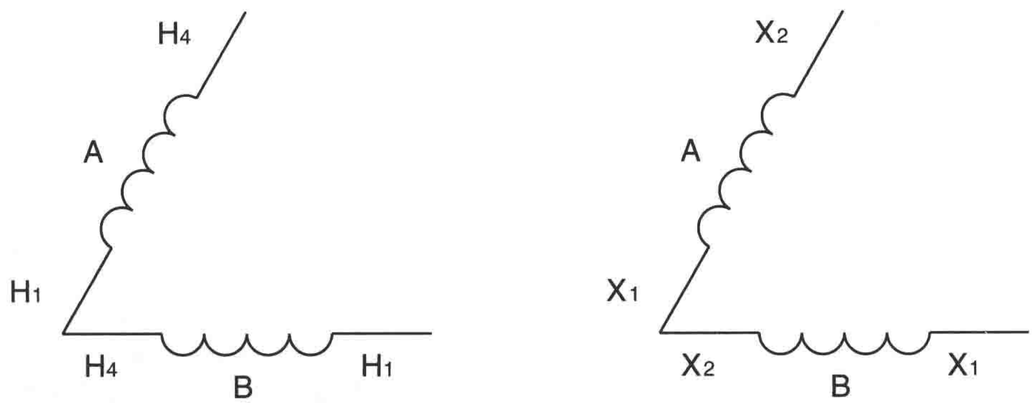


Figure 24-27 Open delta connection.

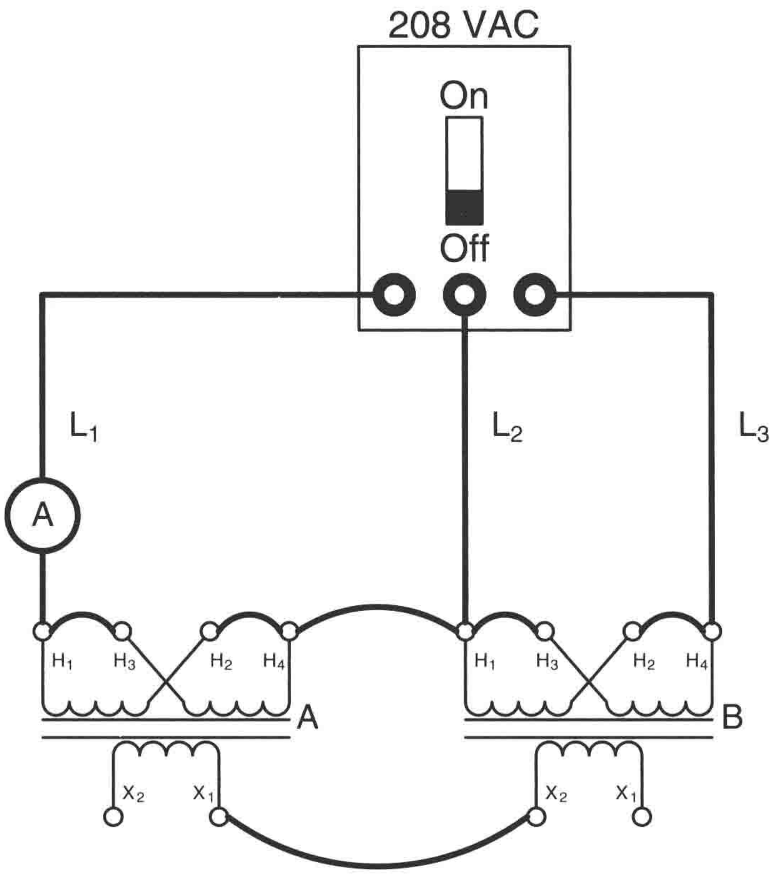


Figure 24-28 Two transformers connected in an open delta.

the open delta connection can supply on 86.6% of the combined kVA capacity of the two transformers.

70. Connect the circuit shown in Figure 24-28. Do not connect a load to the transformer at this time.
71. Assuming an applied voltage of 208 volts, calculate the phase voltage of the primary winding.

    $E_{(PHASE\ PRIMARY)}$ = __________ volts
72. Calculate the phase voltage of the secondary windings.

    $E_{(PHASE\ SECONDARY)}$ = __________ volts
73. Turn on the power and measure the primary phase voltage and secondary phase voltage.

    $E_{(PHASE\ PRIMARY)}$ = __________ volts

    $E_{(PHASE\ SECONDARY)}$ = __________ volts

    Compare the measured values with the calculated values in step 71 and step 72. Are the values within 5% of each other?

    ____
74. Measure the excitation current of the primary winding. **Turn off the power.**

    $I_{(EXC)}$ = __________ A
75. Connect three 150-ohm resistors in a delta configuration. Connect the load resistors to the transformer secondary as shown in Figure 24-29.
76. Calculate the line voltage of the secondary.

    $E_{(LINE\ SECONDARY)}$ =__________ volts

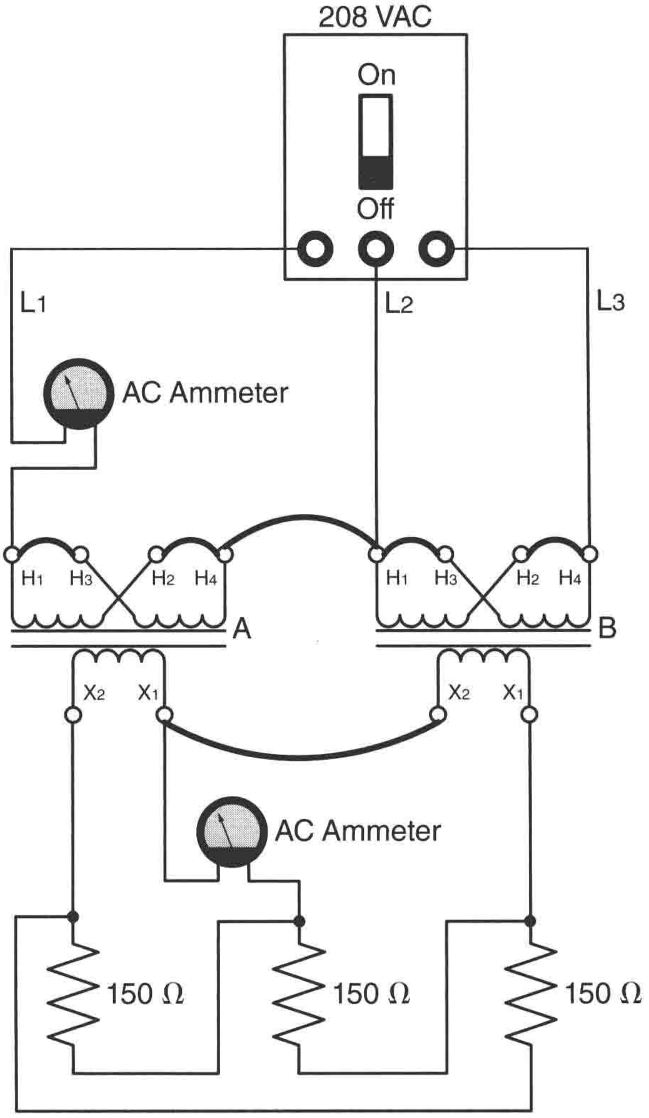


Figure 24-29 Connecting a three-phase load to the transformer bank.

77. Calculate the phase voltage of the delta connected load resistors.

    $E_{(PHASE\ LOAD)}$ =__________ volts

78. Calculate the phase current of the load using Ohm's law.

    $I_{(PHASE\ LOAD)}$ =__________ A

79. Calculate the line current supplied to the load by the secondary of the transformer.

    $I_{(LINE\ SECONDARY)}$ =__________ A

80. Calculate the phase current of the secondary winding.

    $I_{(PHASE\ SECONDARY)}$ =__________ A

81. Using the turns-ratio of the transformer, calculate the phase current of the primary winding.

    $I_{(PHASE\ PRIMARY)}$ =__________ A

82. Calculate the line current supplied to the primary. Make sure to add the excitation current to the calculation.

    $I_{(LINE\ PRIMARY)}$ __________ A

83. Turn on the power and measure the line current of the secondary and the line current of the primary. **Turn off the power.**

$I_{(LINE\ SECONDARY)}$ ________ A

$I_{(LINE\ PRIMARY)}$ ________ A

Compare the measured values with the calculated values in step 79 and step 82. Are the values within 5% of each other?

____

84. Disconnect the circuit and return the components to their proper place.

Review Questions

1. How many transformers are needed to make an open delta connection?

____

2. Two transformers rated at 100 kVA each are connected in an open delta connection. What is the total output power that can be supplied by this bank?

____

3. When computing values of voltage and current for a three-phase transformer, should the line values of voltage and current be used or the phase values?

____

Refer to Figure 24-30 to answer the following questions:

4. Assume a line voltage of 2,400 volts is connected to the primary of the three-phase transformer and the line voltage of the secondary is 240 volts. What is the turns-ratio of the transformer?

____

5. Assume the load has an impedance of 3.5 Ω per phase. What is the line current provided by the transformer secondary?

____

6. How much current is flowing through the secondary winding?

____

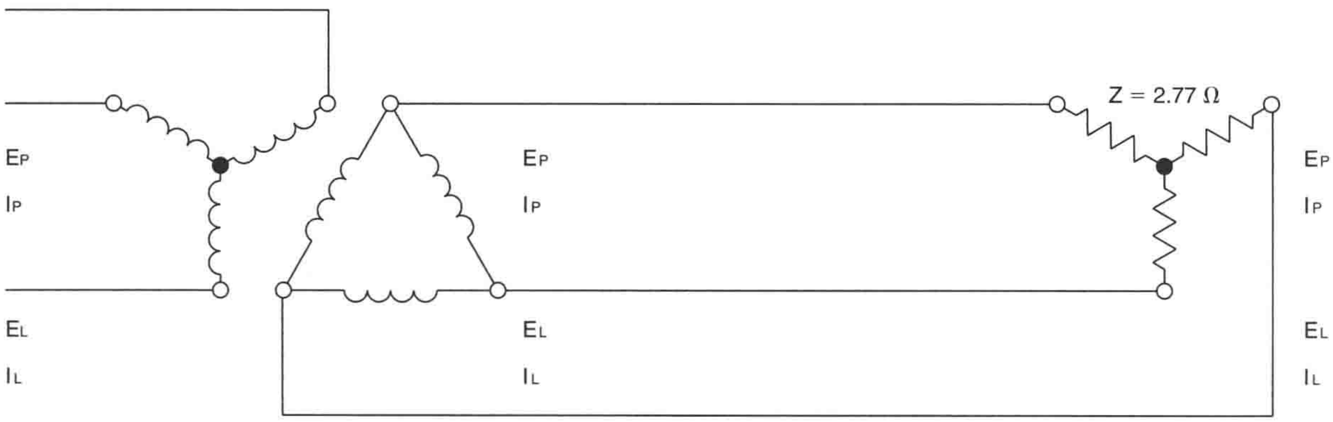


Figure 24-30 Example #1: Three-phase transformer calculation.

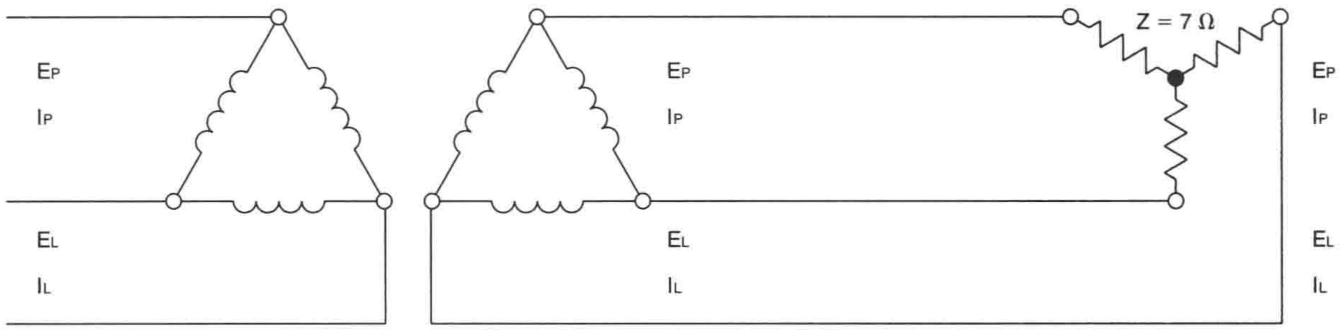


Figure 24-31 Example #2: Three-phase transformer calculation.

7. How much current is flowing through the primary winding?

____

Refer to Figure 24-31 to answer the following questions:

8. Assume a line voltage of 12,470 volts is connected to the primary of the transformer and the line voltage of the secondary is 480 volts. What is the turns-ratio of the transformer?

____

9. Assume the load has an impedance of 6 Ω per phase. What is the secondary line current?

____

10. How much current is flowing in the secondary winding?

____

11. How much current is flowing in the primary winding?

____

12. What is the line current of the primary?

____

Unit 25 Three-Phase Motors

Objectives

After studying this unit, you should be able to:

- Determine if a 9 lead dual voltage three-phase motor is connected wye or delta.
- Test continuity of motor windings.
- Test motor windings for poor insulation.
- Connect a dual voltage 9 lead three-phase motor.

Many three-phase squirrel cage motors are designed in such a manner that they can be connected to 240 or 480 volts. The majority of these motors have 9 "T" leads at the terminal connection box. The manner in which these T leads are connected determines if the motor will operate on 240 or 480 volts.

Wye and Delta Connections

There are two basic ways of connecting the stator windings for three-phase dual voltage motors: wye and delta. The standard numbering for stator windings of both wye and delta connected motors is shown in Figure 25-1. Stator windings are numbered by starting at an outer point with #1 and proceeding around in an ever-decreasing spiral. Notice that the opposite end of the winding that begins with #1 is #4. The opposite end of the winding that begins with #2 is #5. These numbers have been standardized and are used by most manufacturers.

High- and Low-Voltage Connections

When a motor is to be connected for high-voltage operation (generally 480 to 575 volts), the windings are connected in series, as shown in Figure 25-2. In a series circuit the sum of

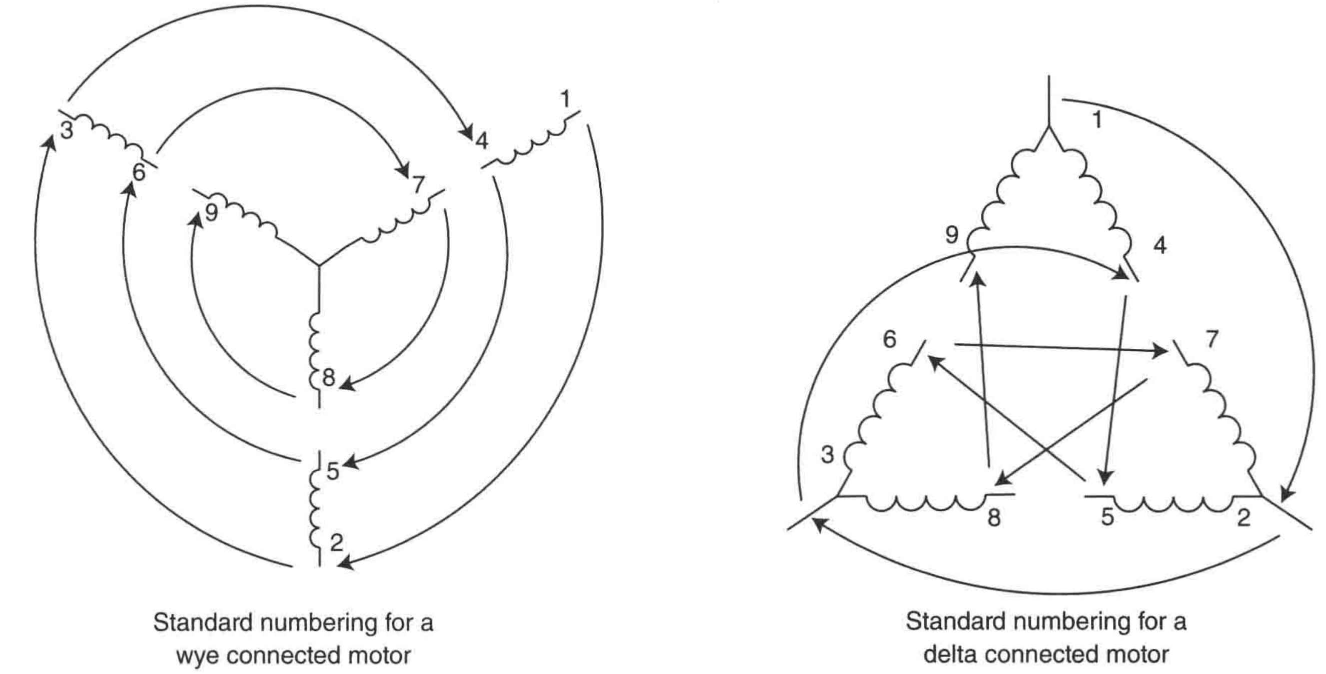


Figure 25-1 Standard numbering for three-phase motors.

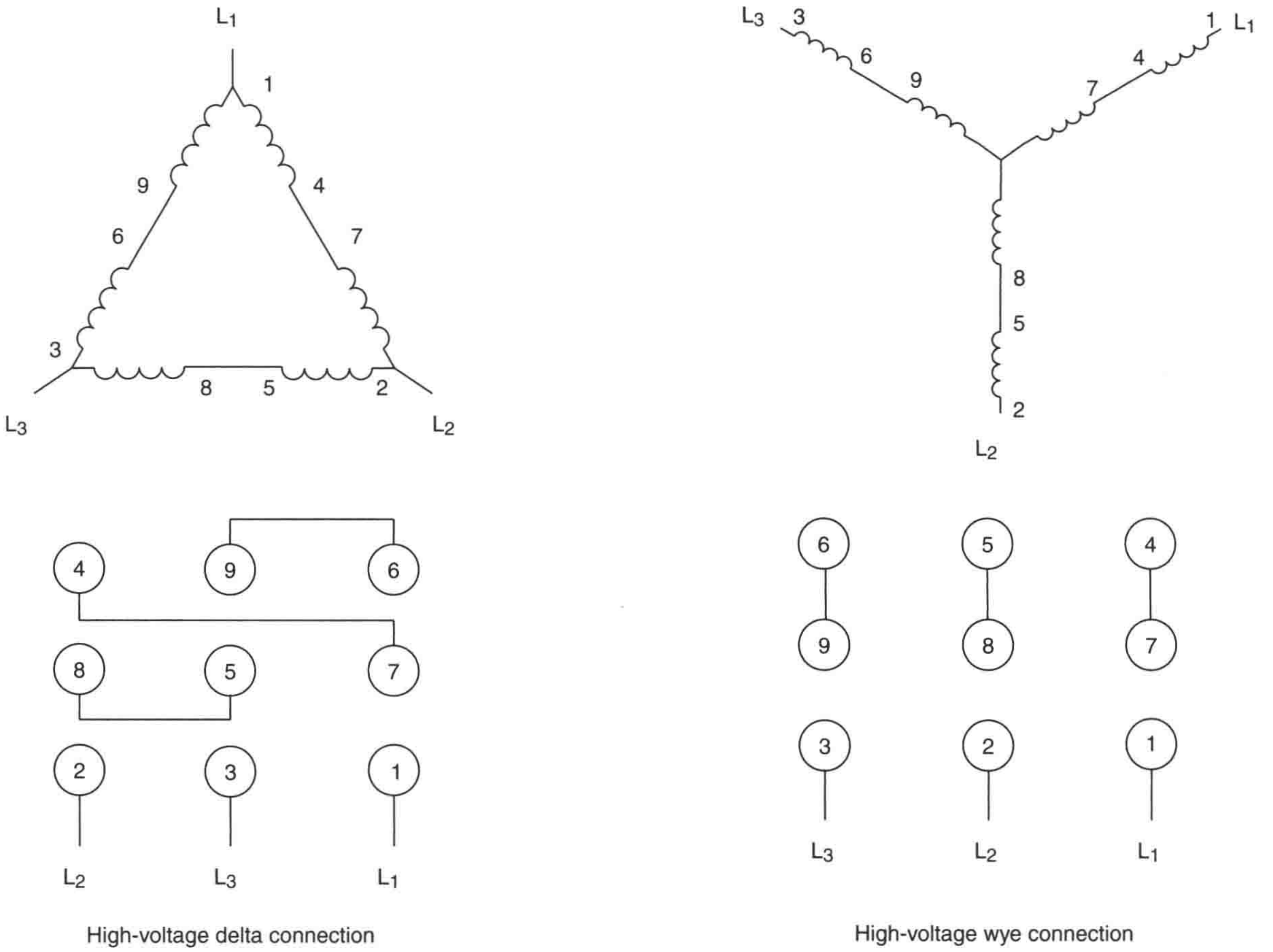


Figure 25-2 High-voltage connections.

the voltage drops across the components must equal the applied voltage. If 480 volts were to be connected across the delta connected motor, each of the windings of that phase would have voltage drop of 240 volts.

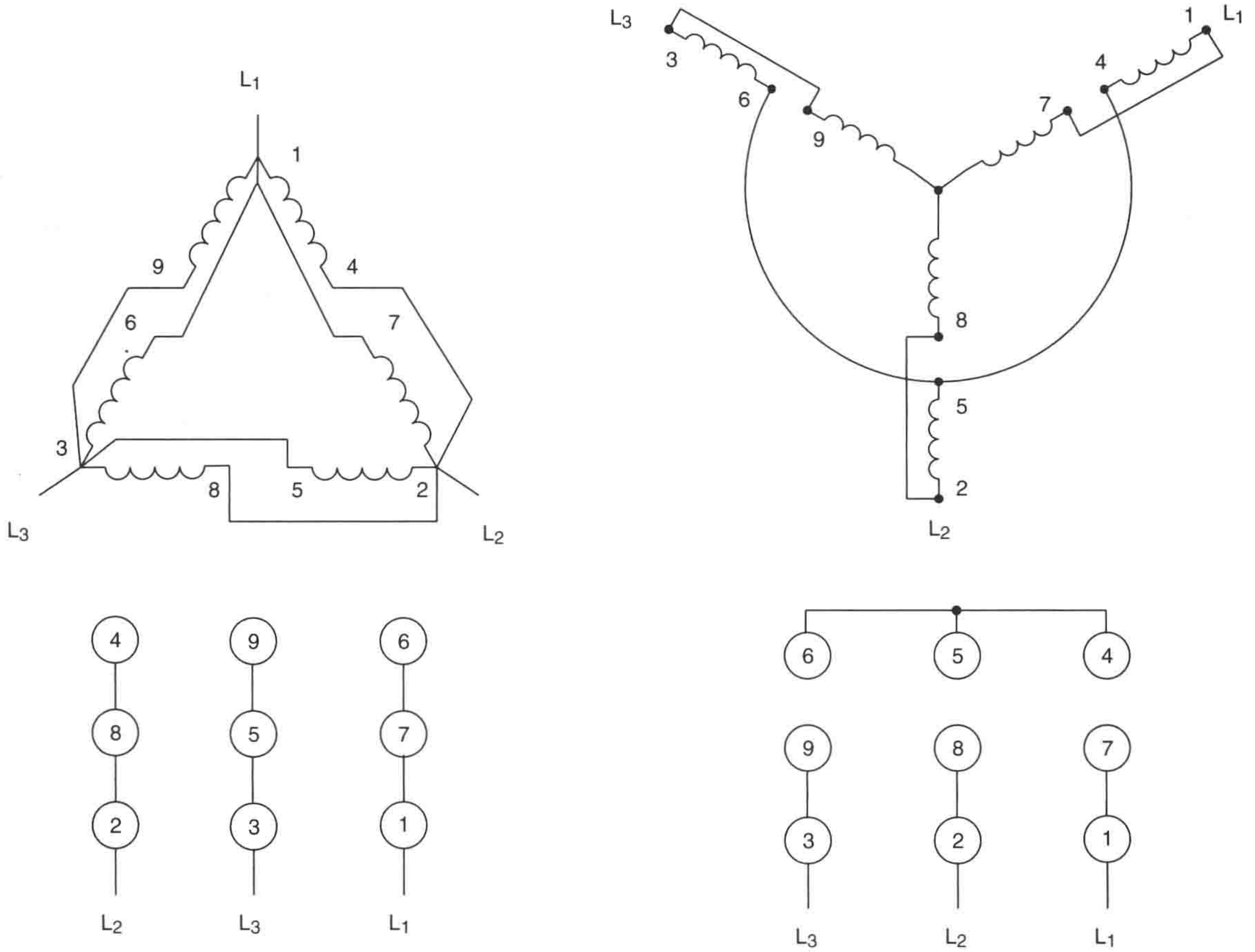
When a motor is to be connected to operate on low voltage (generally 240 to 208 volts), the stator windings are connected in parallel, as shown in Figure 25-3. Components connected in parallel have the same voltage applied to them. Therefore, if 208 volts are connected to the motor, all stator windings would have an applied voltage of 208 volts.

Determining If the Windings Are Connected Wye or Delta

An ohmmeter can be used to determine if a 9 lead motor is connected in wye or delta. In a wye connected motor, the opposite ends of leads 7, 8, and 9 are connected together, as shown in Figure 25-1. If an ohmmeter indicates continuity between these three leads, the motor is wye connected. In a delta connected motor, the ohmmeter should indicate continuity between 1, 4, and 9; 2, 5, and 7; and 3, 6, and 8.

Testing Stator Windings

To test the condition of the insulation of stator windings, it is necessary to use an ohmmeter that can supply a high voltage and measure high resistance. This device is a megohmmeter or megger, as shown in Figure 25-4. The megger measures the resistance



Low-voltage delta connection

Low-voltage wye connection

Figure 25-3 Low-voltage connections.

Courtesy of Megger®

Figure 25-4 Hand-crank megger.

of the insulation. To test the motor, connect one megger lead to the case of the motor and the other to one of the motor line leads (it is assumed that the motor is connected for high or low voltage). The meter should indicate several million ohms of resistance. A low resistance reading indicates a motor that may fail in the near future. Low readings can also be caused by moisture in the stator winding. If a motor is left standing in a high humidity climate for long periods without being operated, moisture can form in the stator. If this is the case, it may be necessary to place the motor in a warm, dry environment until the moisture evaporates.

LABORATORY EXERCISE

Name ____ Date __________

Materials Required

1 9 lead dual voltage three-phase motor

1 208-volt three-phase power supply

1 ohmmeter

1 megohmmeter

1. Using the 9 lead three-phase motor provided, separate all nine leads.
2. Use an ohmmeter to test for continuity between T7, T8, and T9. Does the meter indicate continuity between these leads?

   Yes/no ______________
3. If the answer to step 2 is yes, proceed to step 4. If the answer is no, skip step 4.
4. Use the ohmmeter to test for continuity between the following T leads. Write yes beside the leads that indicate continuity and no beside the ones that do not.

T1-T2 ________	T1-T3 ________	T1-T4 ________	T1-T5 ________
T1-T6 ________	T1-T7 ________	T1-T8 ________	T1-T9 ________
T2-T3 ________	T2-T4 ________	T2-T5 ________	T2-T6 ________
T2-T7 ________	T2-T8 ________	T2-T9 ________	T3-T4 ________
T3-T5 ________	T3-T6 ________	T3-T7 ________	T3-T8 ________
T3-T9 ________	T4-T5 ________	T4-T6 ________	T4-T7 ________
T4-T8 ________	T4-T9 ________	T5-T6 ________	T5-T7 ________
T5-T8 ________	T5-T9 ________	T6-T7 ________	T6-T8 ________
T6-T9 ________	T7-T8 ________	T7-T9 ________	T8-T9 ________

5. Compare the continuity readings with the schematic drawing of a 9 lead wye connected motor shown in Figure 25-1. Do the readings confirm the connection diagram?

   Yes/no ______________

6. Use a megohmmeter to test the insulation of the stator windings. Set the megger output voltage for a value close to the rated voltage of the motor. Connect one lead of the megger to the case of the motor. Measure the resistance between the motor case and each of the following:

   T1-case _________ Ω   T2-case _________ Ω

   T3-case _________ Ω   T7-case _________ Ω

7. Connect the motor for low-voltage operation. Refer to the connection diagram on the motor nameplate or the diagram shown in Figure 25-3 for a low-voltage wye connection.
8. Connect the motor to a 208 volt, three-phase power source.
9. Turn on the power and notice the direction of rotation. Viewing the motor from the rear, does the motor turn in a clockwise or counterclockwise direction?

   ____

10. **Turn off the power supply.**
11. Reverse two of the line leads connected to the motor.
12. Turn on the power and notice the direction of rotation. Did the motor reverse its direction of rotation?

    Yes/no _____________

13. **Turn off the power supply** and disconnect the motor. Return the components to their proper place.

Review Questions

1. What are the two ways that the stator windings of three-phase motors can be connected?

   ____

2. An ohmmeter reveals that a 9 lead dual voltage motor has continuity between T7, T8, and T9. Is the motor wye or delta connected?

   ____

3. An ohmmeter reveals that there is continuity between T1 and T4. Does this indicate a wye connected motor?

   ____

4. An ohmmeter reveals continuity between T5 and T7. Does this indicate a delta connected motor?

   ____

5. A 9 lead dual voltage motor is to be connected for high-voltage operation. An ohmmeter test indicates that the stator windings are delta connected. To which T lead(s) should T5 be connected?

   ____

6. A 9 lead dual voltage motor is to be connected for low-voltage operation. An ohmmeter test indicates that the motor is delta connected. To which T lead(s) should T6 be connected?

   ____

7. A 9 lead dual voltage motor is to be connected for low-voltage operation. An ohmmeter test reveals that the motor is delta connected. To which T lead(s) should T2 be connected?

___

8. A 9 lead dual voltage motor is to be connected for low-voltage operation. An ohmmeter test reveals that the motor is wye connected. To which T lead(s) should T4 be connected?

___

9. What piece of test equipment should be used to test the insulation of the stator winding?

___

10. How is the direction of rotation of a three-phase motor reversed?

___

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, as 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.

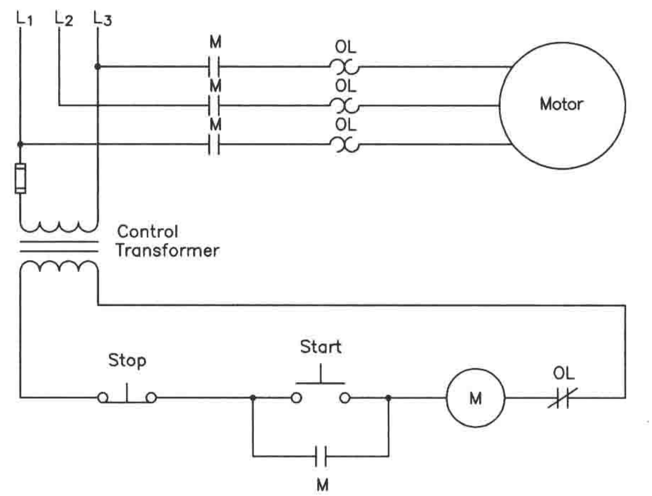


Figure 26-1 Schematic diagram of a basic start-stop push-button control circuit.

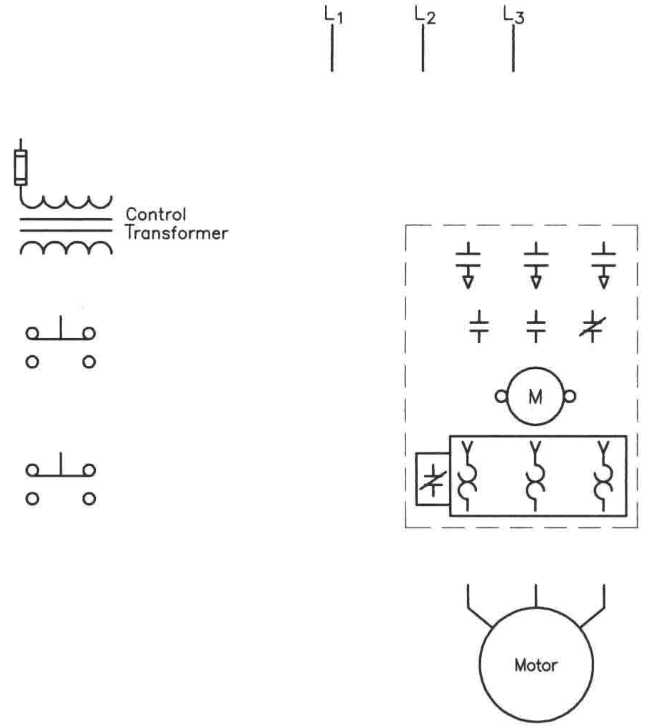


Figure 26-2 Components of the basic start-stop control circuit.

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.

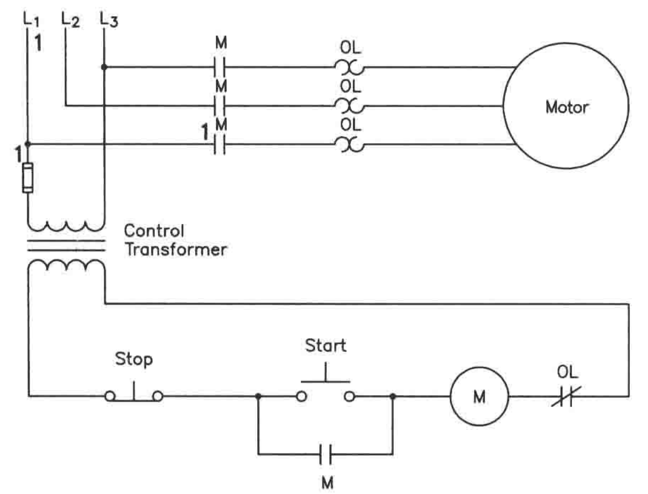


Figure 26-3 The number 1 is placed beside each component connected to L_1.

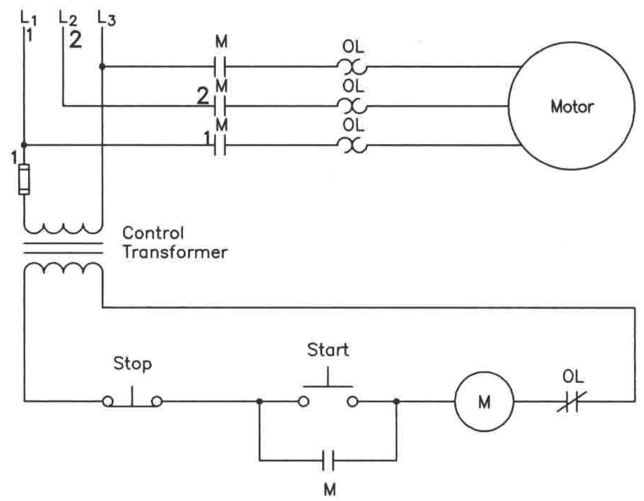


Figure 26-4 A number 2 is placed beside each component connected to L_2.

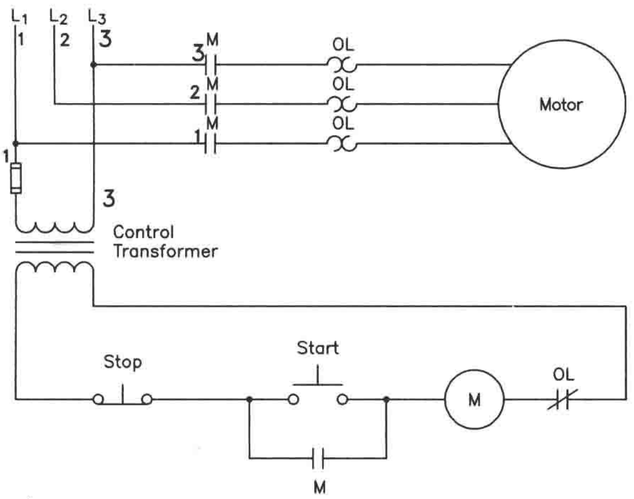


Figure 26-5 A number 3 is placed beside each component connected to L_3.

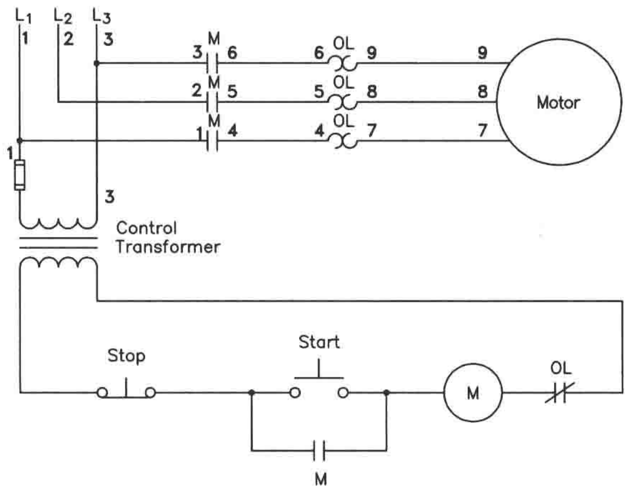


Figure 26-6 The number changes each time you proceed across a component.

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

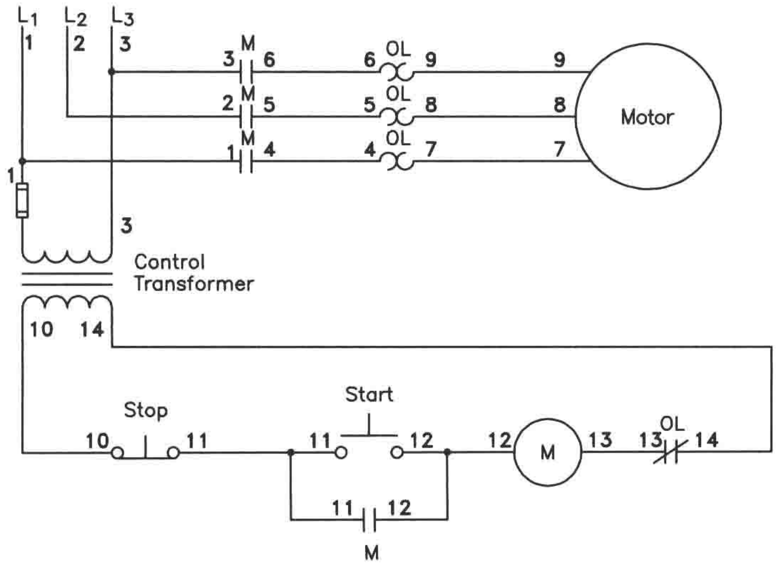


Figure 26-7 Numbers are placed beside all components.

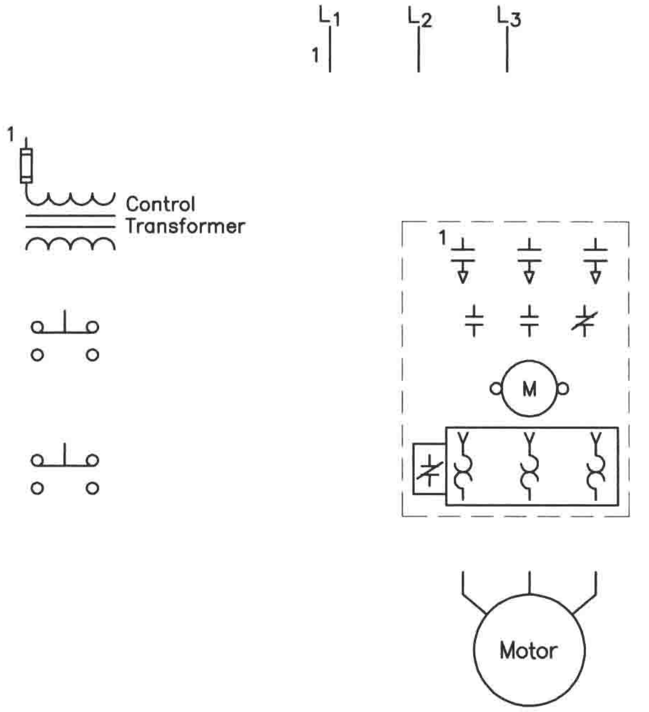


Figure 26-8 A 1 is placed beside L_1, the control transformer fuse, and M load contact.

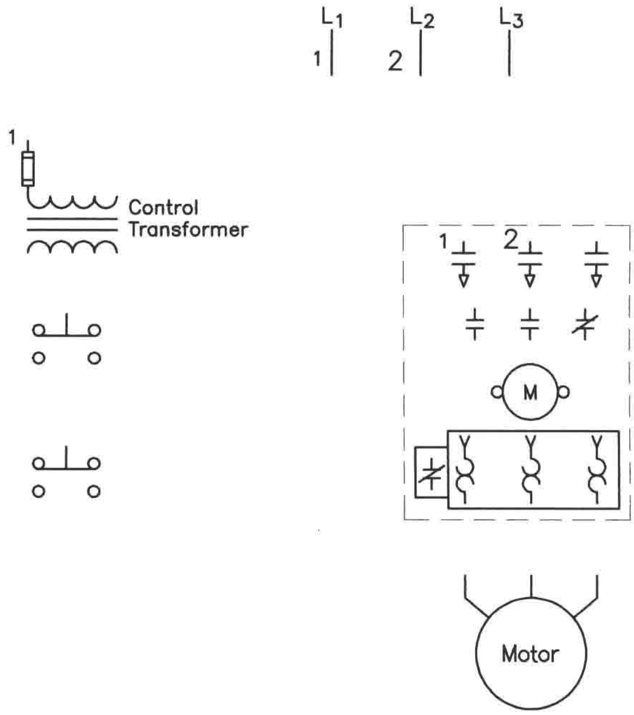


Figure 26-9 The number 2 is placed beside L_2 and the second load contact on M starter.

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

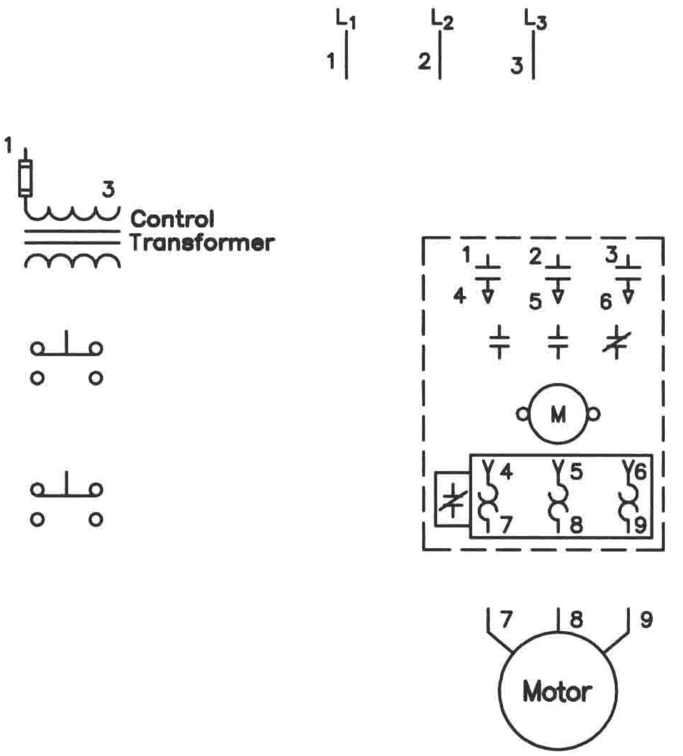


Figure 26-10 Placing numbers 3, 4, 5, 6, 7, 8, and 9 beside the proper components.

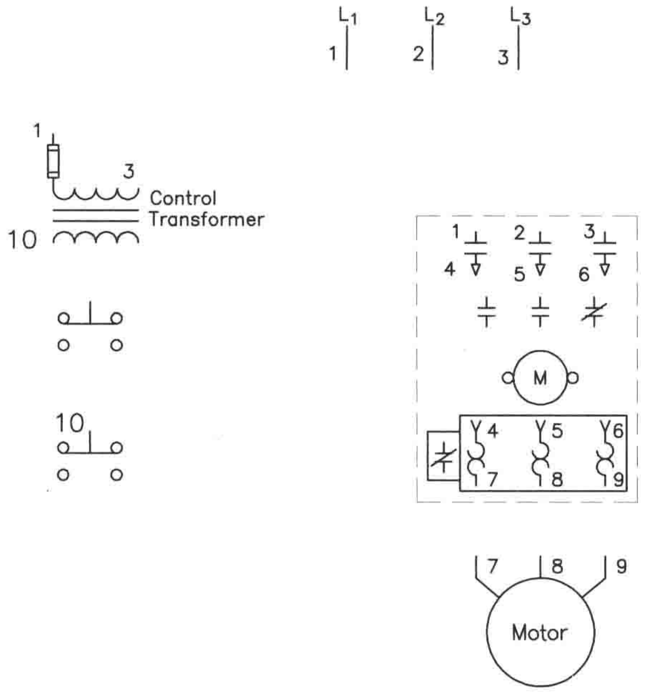


Figure 26-11 Wire number 10 connects from the transformer secondary to the stop button.

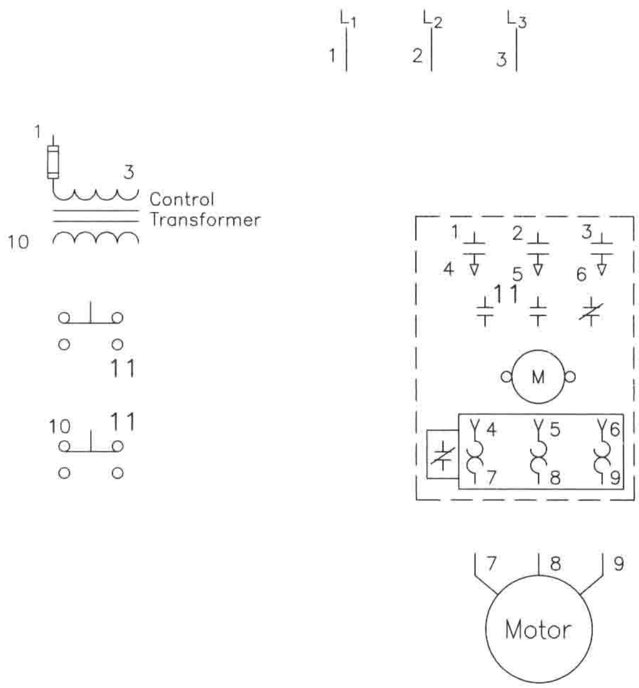


Figure 26-12 Number 11 connects to the stop button, start button, and holding contact.

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).

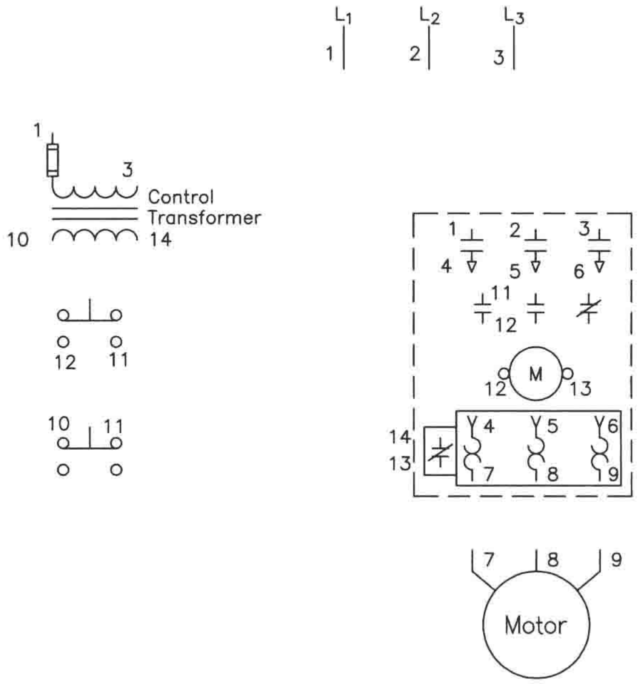


Figure 26-13 All components have been numbered.

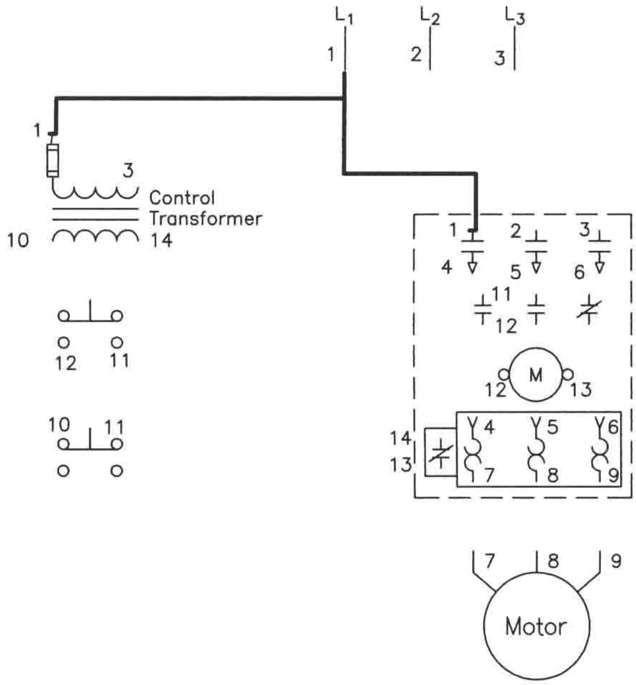


Figure 26-14 Connecting all components numbered with a 1 together.

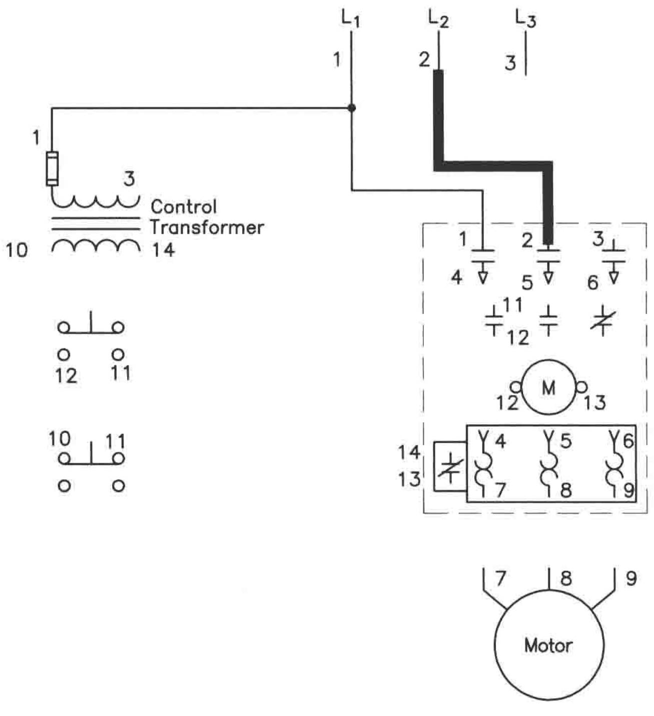


Figure 26-15 Connecting all components numbered with a 2 together.

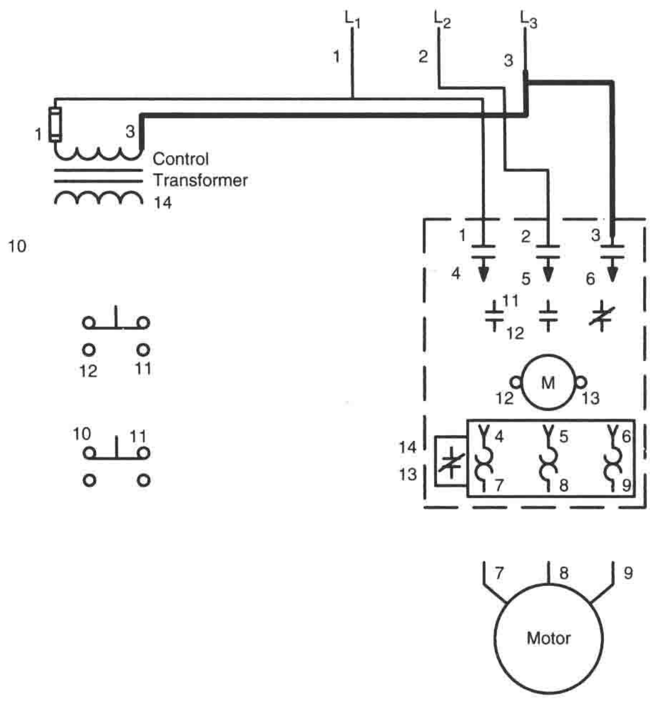


Figure 26-16 Connecting all components numbered with a 3 together.

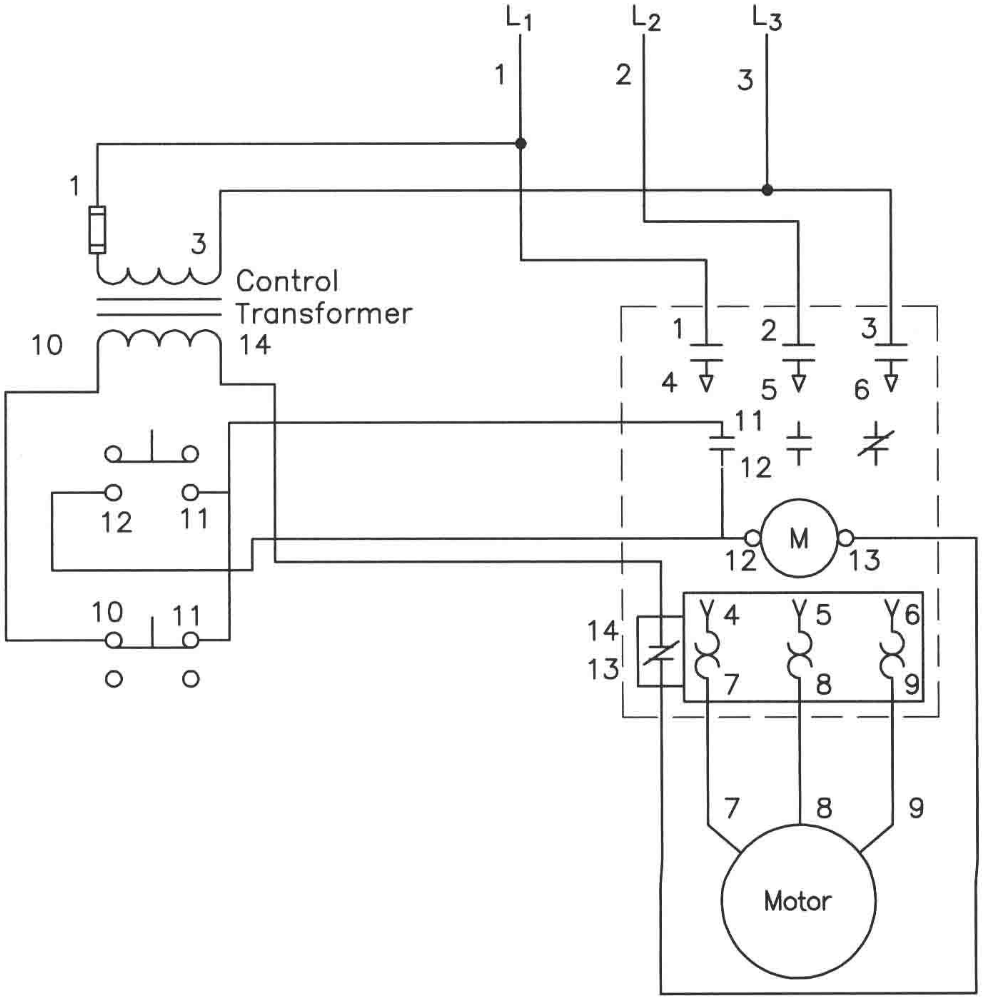


Figure 26-17 Completing the wiring diagram.

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?

____

____

____

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.

______

______

______

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?

______

______

______

5. Explain the difference between load and auxiliary contacts.

______

______

______

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.

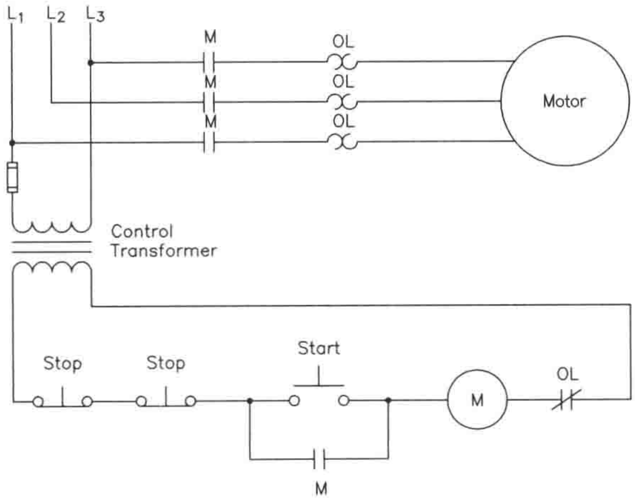


Figure 27-1 Adding a stop button to the circuit.

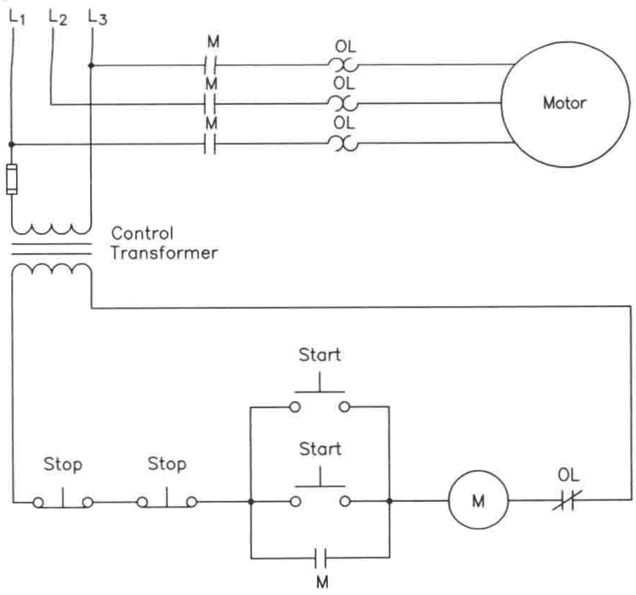


Figure 27-2 A second start button is added to the circuit.

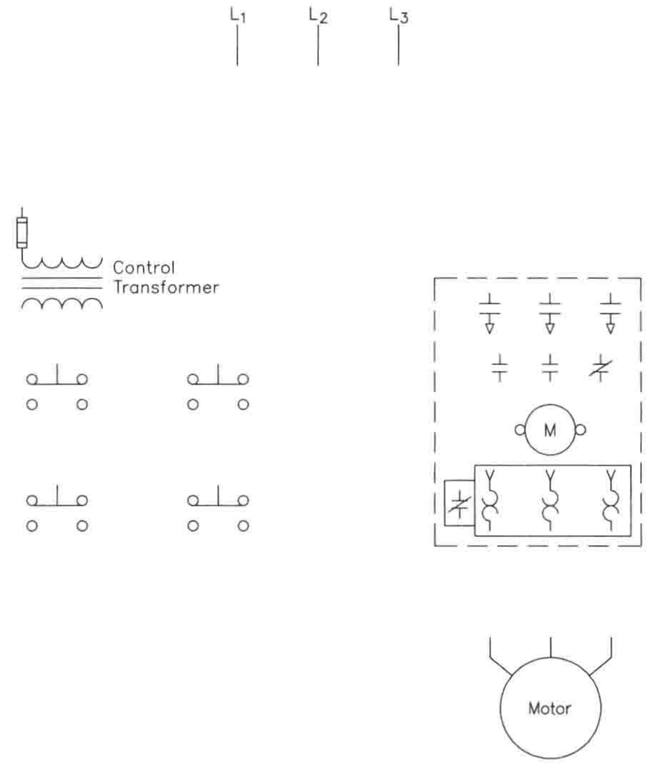


Figure 27-3 Components needed to produce a wiring diagram.

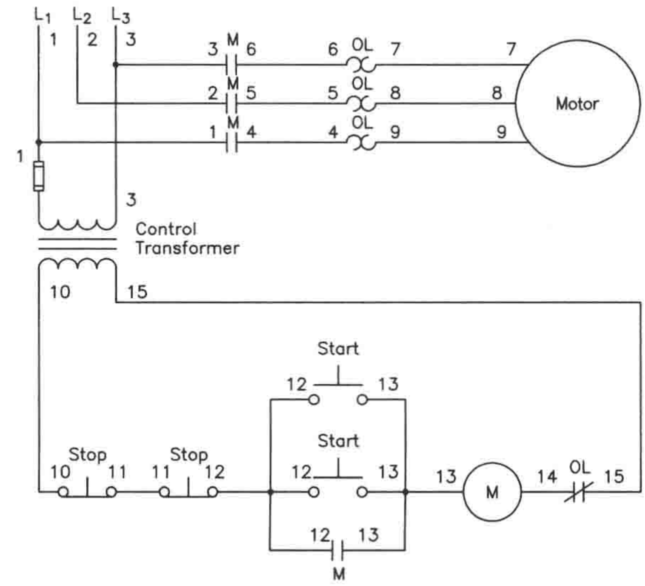


Figure 27-4 Numbering the schematic diagram.

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.

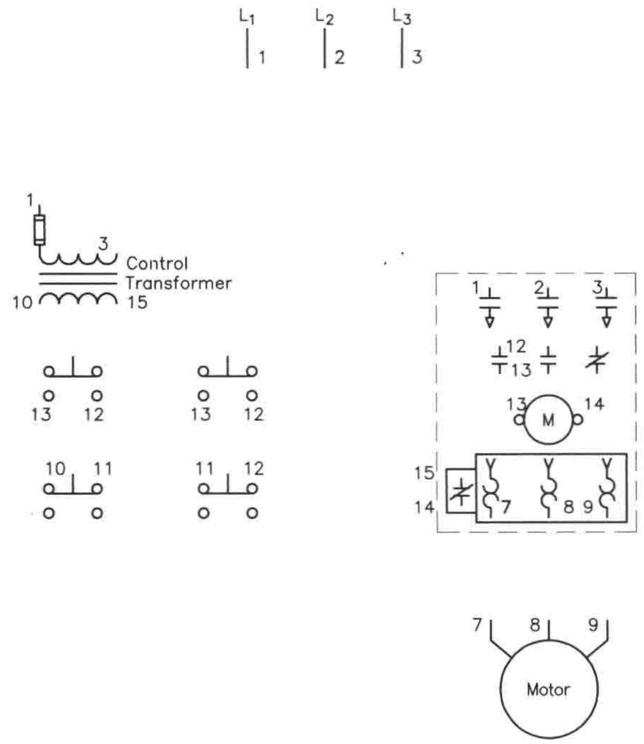


Figure 27-5 Numbering the components.

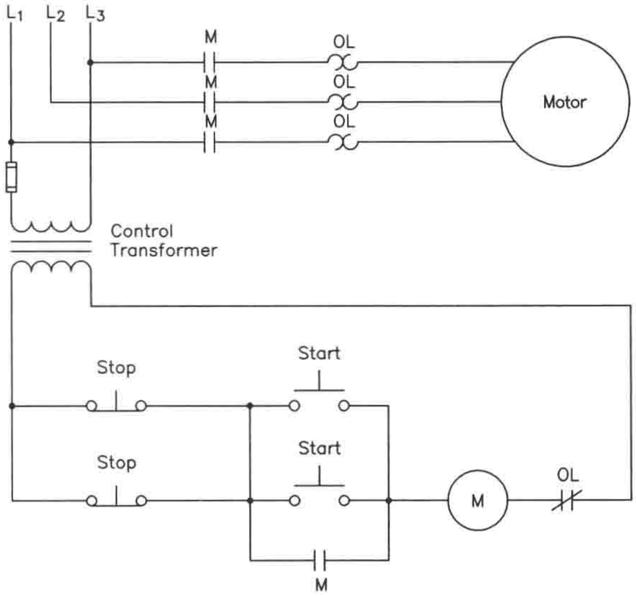


Figure 27-6 The stop buttons are connected in parallel.

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?

   ____

   ____

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?

   ____

   ____

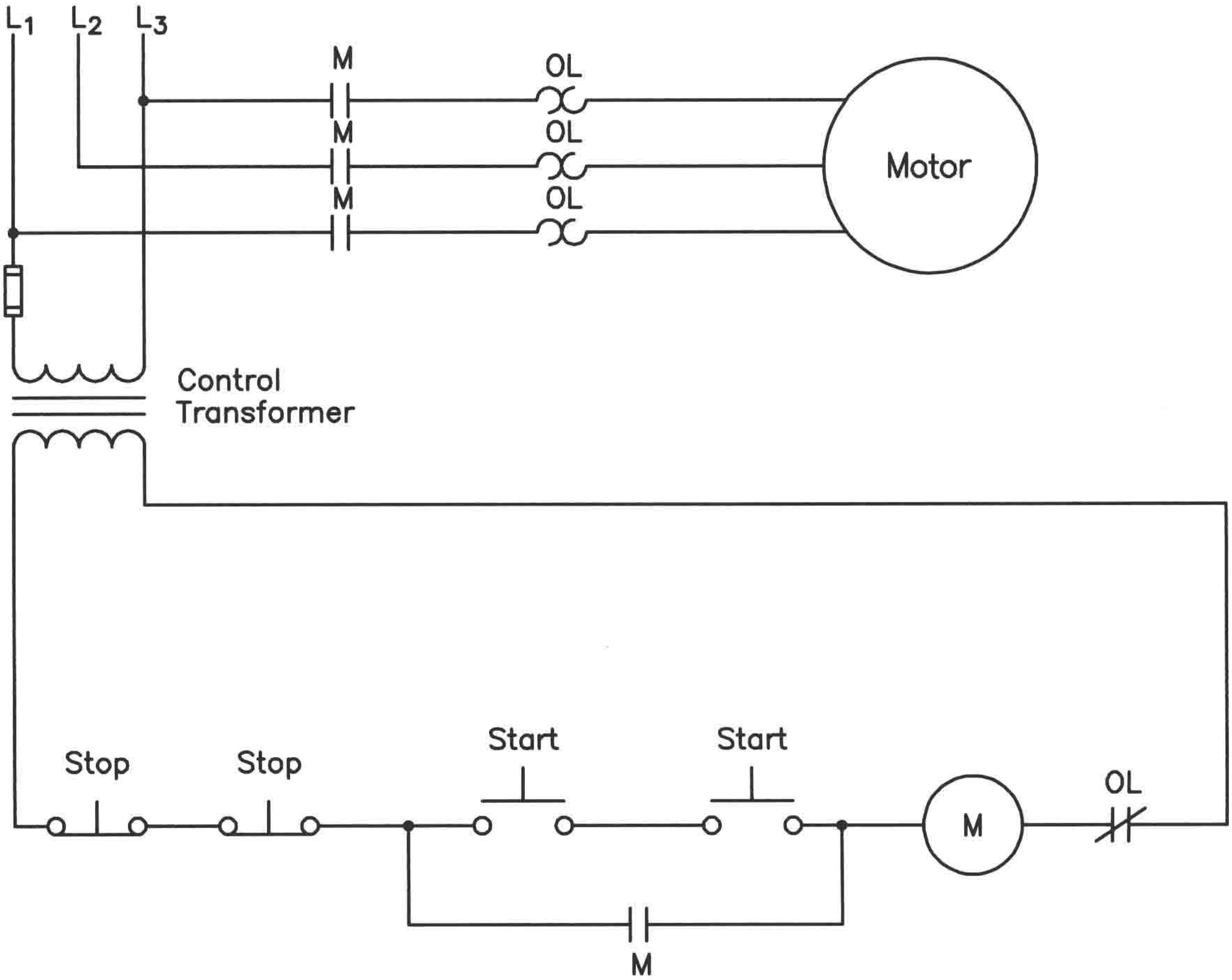


Figure 27-7 The start buttons are connected in series.

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.

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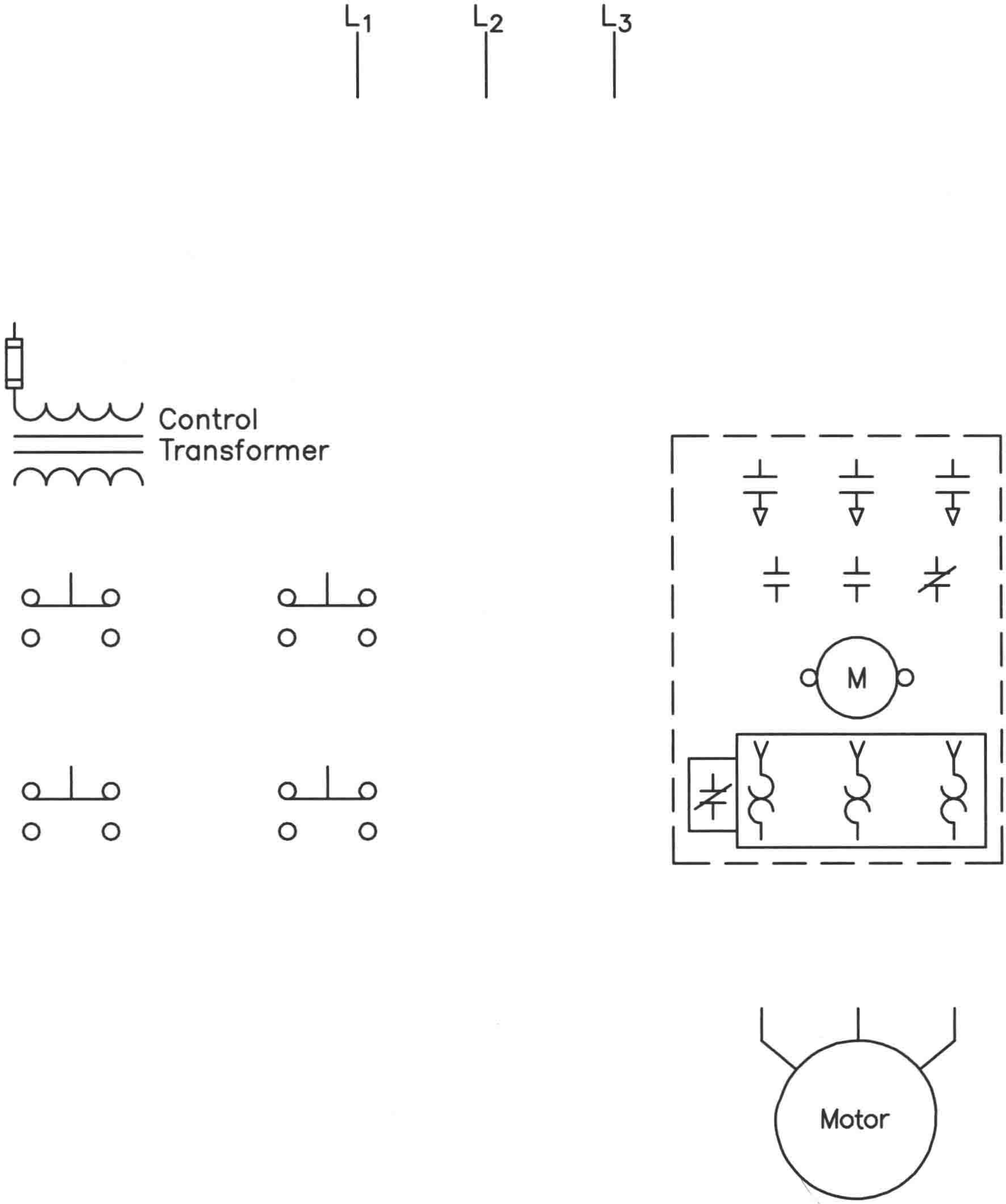

Figure 27-8 Add wire numbers to these components.

Unit 28 Forward-Reverse Control

Objectives

After studying this unit, you should be able to:

- Discuss cautions that must be observed in reversing circuits.
- Explain how to reverse a three-phase motor.
- Discuss interlocking methods.
- Connect a forward-reverse motor control circuit.

The direction of rotation of any three-phase motor can be reversed by changing any two motor T leads. Since the motor is connected to the power line regardless of which direction it operates, a separate contactor is needed for each direction. Since only one motor is in operation, however, only one overload relay is needed to protect the motor. True reversing controllers contain two separate contactors and one overload relay built into one unit.

Interlocking

Interlocking prevents some action from taking place until some other action has been performed. In the case of reversing starters, interlocking is used to prevent both contactors from being energized at the same time. This would result in two of the three-phase lines being shorted together. Interlocking forces one contactor to be de-energized before the other one can be energized.

Most reversing controllers contain mechanical interlocks as well as electrical interlocks. Mechanical interlocking is accomplished by using the contactors to operate a mechanical lever that prevents the other contactor from closing, while the other is energized.

Electrical interlocking is accomplished by connecting the normally closed auxiliary contacts on one contactor in series with the coil of the other contactor (Figure 28-1). Assume that the forward push button is pressed and F coil energizes. This causes all F contacts to change position. The three F load contacts close and connect the motor to the line. The normally open F auxiliary contact closes to maintain the circuit when the forward push button is released, and the normally closed F auxiliary contact connected in series with R coil opens (Figure 28-2). (*Note*: Figure 28-2 illustrates the circuit as it is when the forward starter has been energized. Schematics of this type are used throughout this laboratory manual to help students understand how relay logic operates. This can lead to confusion, however, because contacts that are connected normally open will be shown closed and normally closed contacts will be shown open. To help avoid confusion, normally open contacts that are closed during the stage the circuit is in at that moment will use double lines to indicate the contact is now closed. Contacts that are normally closed, but open at that stage of circuit operation, will show a line at the edges of the contact, but the contact will be open in the middle, as shown in Figure 28-3.)

If the opposite direction of rotation is desired, the stop button must be pressed first. If the reverse push button were to be pressed first, the now open F auxiliary contact connected in series with R coil would prevent a complete circuit from being established. Once the stop button has been pressed, however, F coil de-energizes and all F contacts return to their normal position. The reverse push button can now be pressed to energize R coil (Figure 28-4).

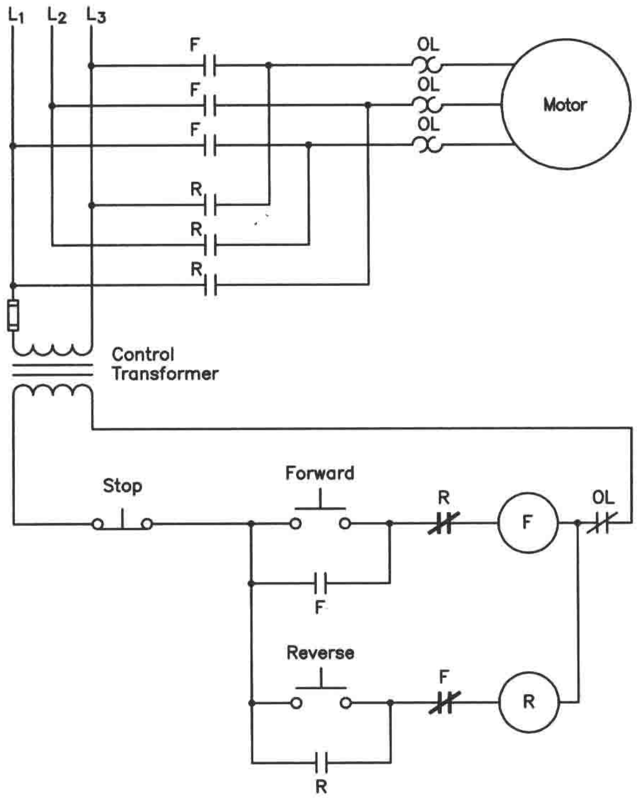

Figure 28-1 Forward-reverse control with interlock.

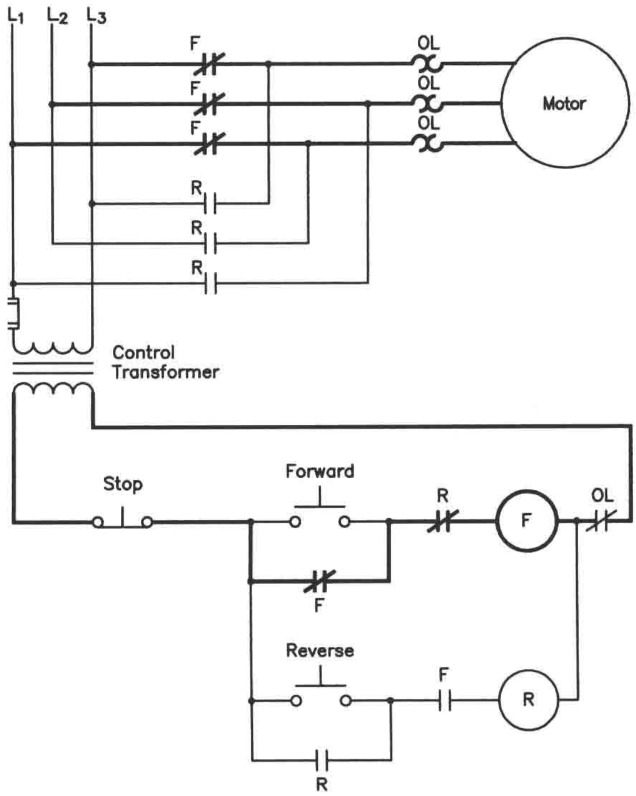

Figure 28-2 Motor operating in the forward direction.

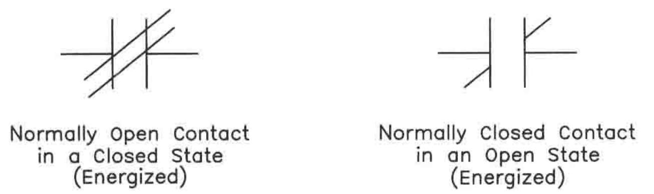

Figure 28-3 Contacts to illustrate circuit logic.

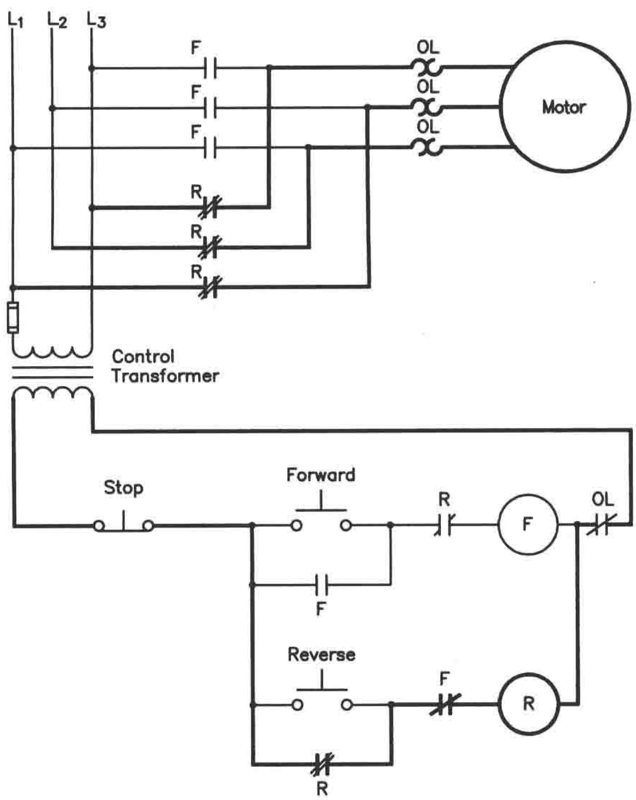

Figure 28-4 Motor operating in the reverse direction.

When R coil energizes, all R contacts change position. The three R load contacts close and connect the motor to the line. Notice, however, that two of the motor T leads are connected to different lines. The normally closed R auxiliary contact opens to prevent the possibility of F coil being energized until R coil is de-energized.

LABORATORY EXERCISE

Name ____ Date __________

Materials Required

Three-phase power supply

Control transformer

One of the following:

1. A three-phase reversing starter
2. Two three-phase contactors with at least one normally open and one normally closed auxiliary contact on each contactor; one three-phase overload relay or three single-phase overload relays

Three-phase squirrel cage motor or simulated motor load

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

Developing a Wiring Diagram

The same basic procedure will be used to develop a wiring diagram from the schematic as was followed in the previous experiments. The components needed to construct this circuit are shown in Figure 28-5. In this example it will be assumed that two contactors and a separate three-phase overload relay will be used.

The first step is to place wire numbers on the schematic diagram. A suggested numbering sequence is shown in Figure 28-6. The next step is to place the wire numbers beside the corresponding components of the wiring diagram (Figure 28-7).

Wiring the Circuit

1. Using the components listed at the beginning of this unit, connect a forward-reverse control circuit with interlocks. Connect the control section of the circuit before connecting the load section. This will permit the control circuit to be tested without the possibility of shorting two of the three-phase lines together.
2. After checking with the instructor, turn on the power and test the control section of the circuit for proper operation.
3. **Turn off the power** and complete the wiring by connecting the load portion of the circuit.
4. Turn on the power and test the motor for proper operation.
5. **Turn off the power** and disconnect the circuit. Return the components to their proper place.

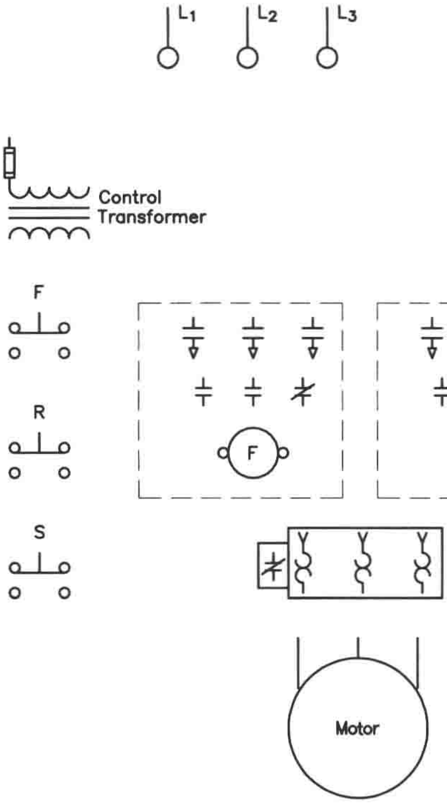

Figure 28-5 Components needed to construct a reversing circuit.

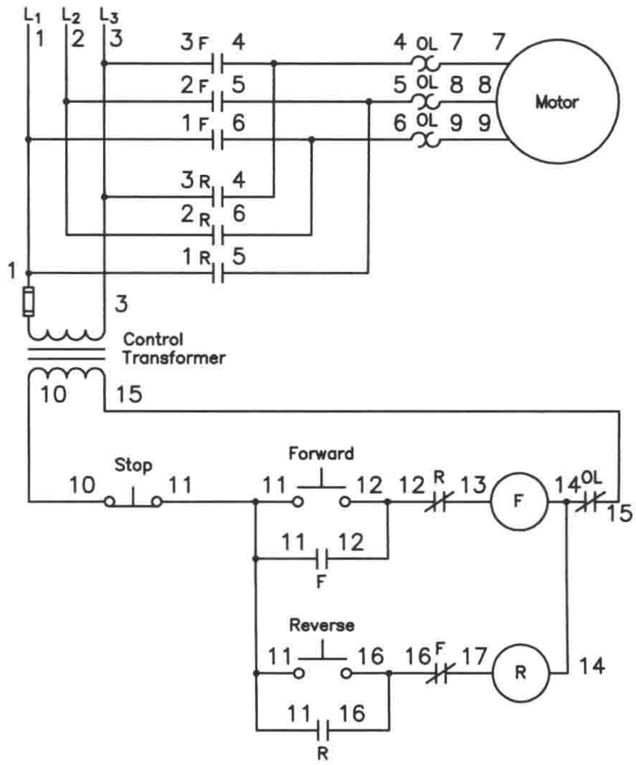

Figure 28-6 Placing wire numbers on the schematic.

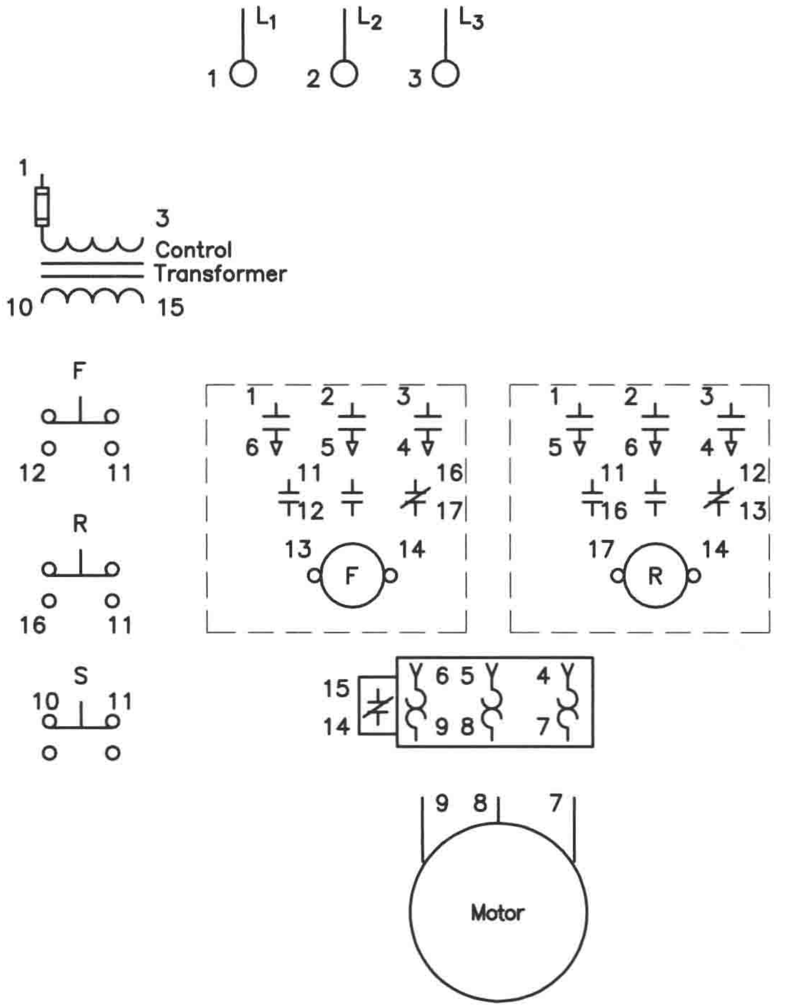

Figure 28-7 Placing corresponding wire numbers on the components.

Review Questions

1. How can the direction of rotation of a three-phase motor be changed?

2. What is interlocking?

3. Referring to the schematic shown in Figure 28-1, how would the circuit operate if the normally closed R contact connected in series with F coil were to be connected normally open?

4. What would be the danger, if any, if the circuit were to be wired as stated in review question 3?

5. How would the circuit operate if the normally closed auxiliary contacts were to be connected so that F contact was connected in series with F coil and R contact was connected in series with R coil (Figure 28-8)?

6. Assume that the circuit shown in Figure 28-1 were to be connected as shown in Figure 28-9. In what way would the operation of the circuit be different, if at all?

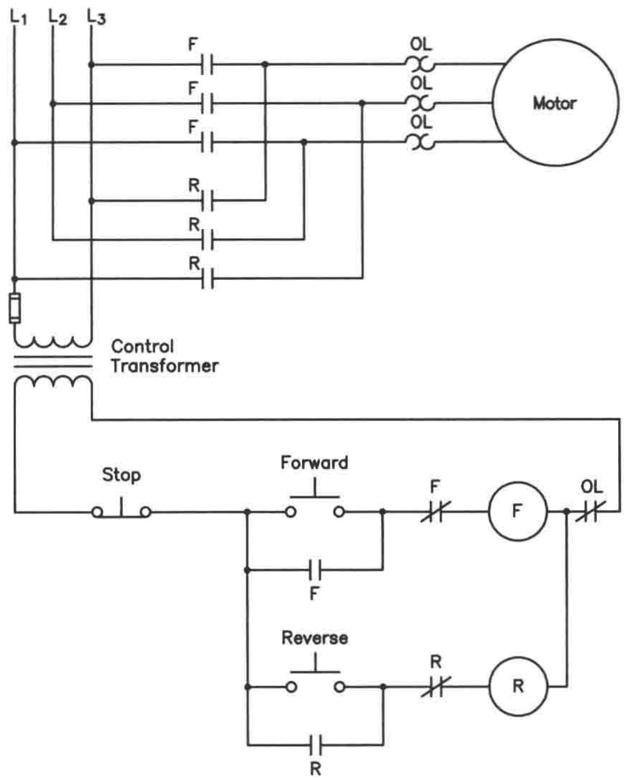

Figure 28-8 F and R normally open auxiliary contacts are connected incorrectly.

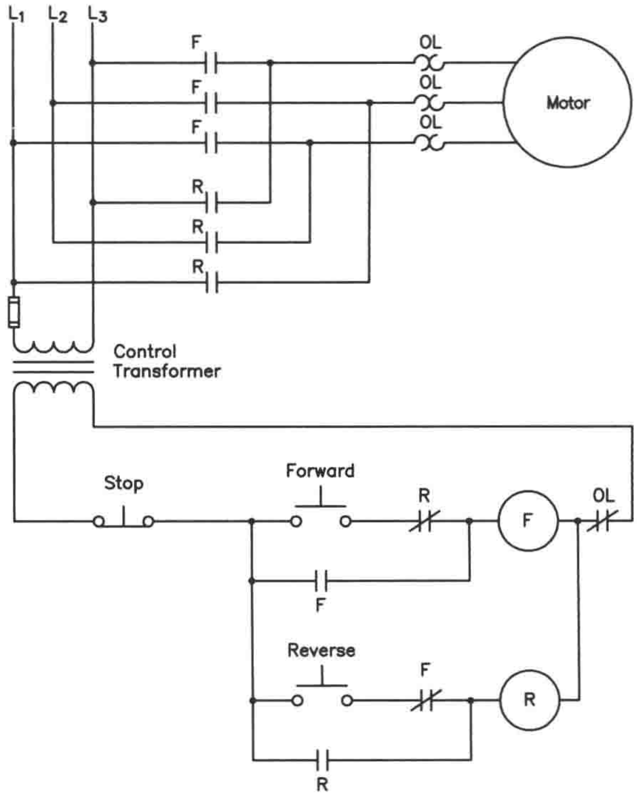

Figure 28-9 The position of the holding contacts has been changed.

Unit 29 Sequence Control

Objectives

After studying this unit, you should be able to:

- Define sequence control.
- Discuss methods of obtaining sequence control.
- Connect a control circuit for three motors that must be started in a predetermined sequence.

LABORATORY EXERCISE

Name ______________________________ Date __________

Materials Required

Three-phase power supply

Control transformer

3 motor starters containing at least three load contacts and two normally open auxiliary contacts

3 squirrel cage motors or three simulated motor loads

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

Sequence control forces a circuit to operate in a predetermined manner. In this experiment three motors are to be started in sequence from 1 to 3. The requirements for the circuit are as follows:

1. The motors must start in sequence from #1 to #3. For example, motor #1 must be started before motor #2 can be started, and motor #2 must start before motor #3 can be started. Motor #2 cannot start before motor #1, and motor #3 cannot start before motor #2.
2. Each motor is started by a separate push button.
3. One stop button will stop all motors.
4. An overload on any motor will stop all three motors.

As a general rule, there is more than one way to design a circuit that will meet the specified requirements, just as there is generally more than one road that can be taken to reach a destination. One design that will meet the requirements is shown in Figure 29-1. Since the logic of the circuit is of primary interest, the load contacts and motors are not shown. In this circuit, push button #1 must be pressed before power can be provided to push button #2. When motor starter #1 energizes, the normally open auxiliary contact 1M closes, providing power to coil 1M and to push button #2. Motor starter #2 can now be started by pressing push button #2. Once motor starter #2 energizes, auxiliary contact 2M closes and provides power to coil 2M and push button #3. If the stop button should be pressed or any overload contact open, power will be interrupted to all starters.

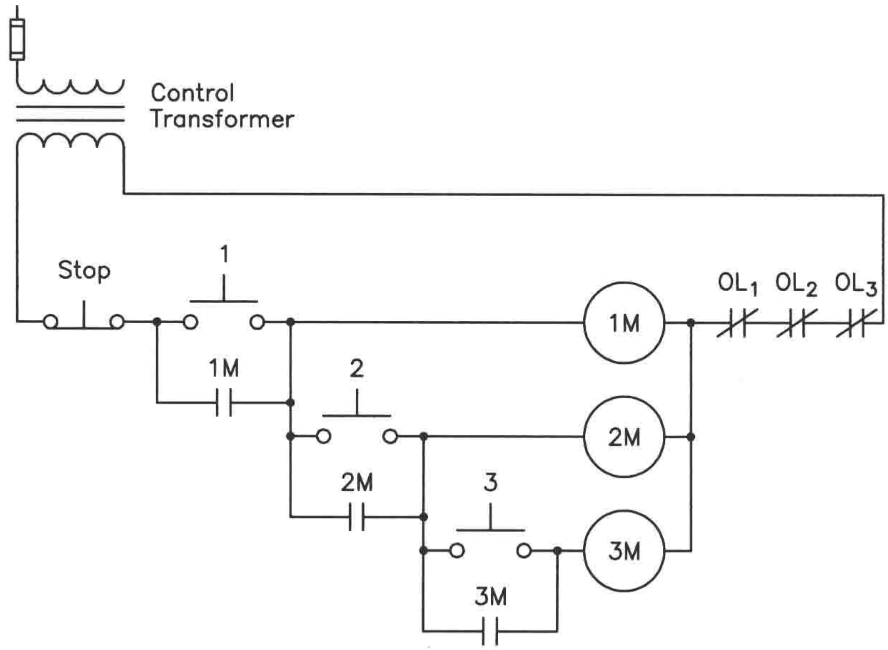

Figure 29-1 First example of starting the motors in sequence.

A Second Circuit for Sequence Control

A second method of providing sequence control is shown in Figure 29-2. In this circuit, normally open auxiliary contacts located on motor starters 1M and 2M are used to ensure

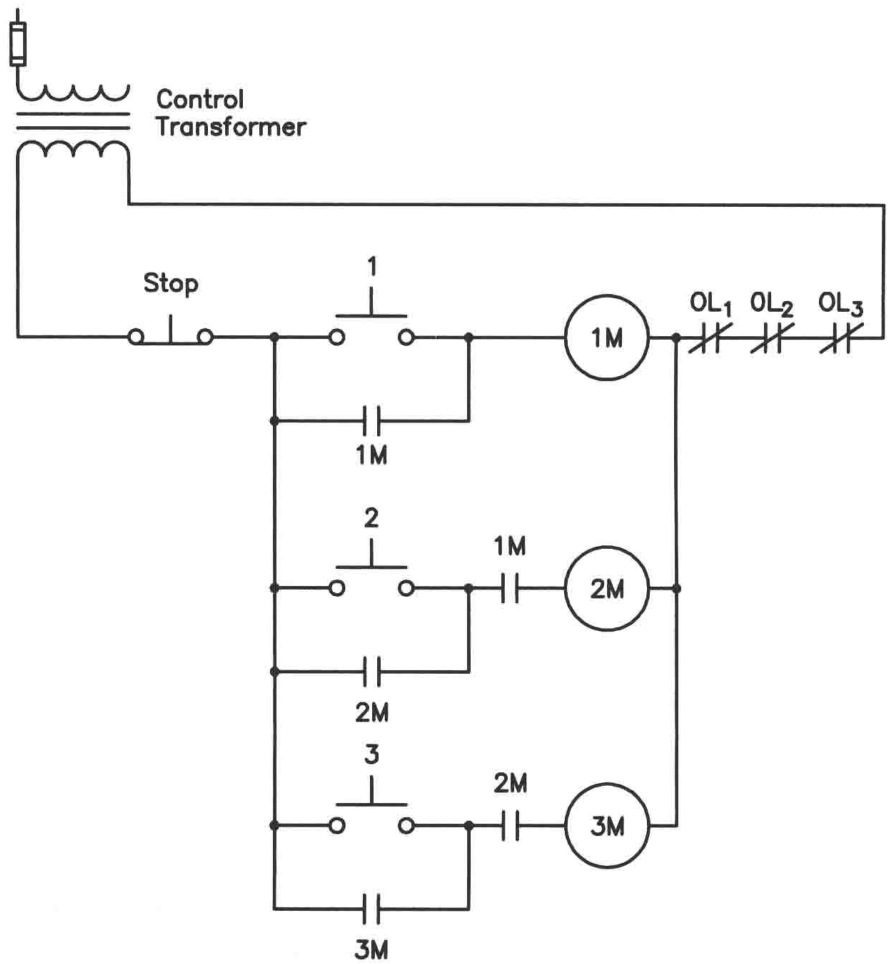

Figure 29-2 A second circuit for sequence control.

that the three motors start in the proper sequence. A normally open 1M auxiliary contact connected in series with starter coil 2M prevents motor #2 from starting before motor #1, and a normally open 2M auxiliary contact connected in series with coil 3M prevents motor #3 from starting before motor #2. If the stop button should be pressed or if any overload contact should open, power will be interrupted to all starters.

Developing a Wiring Diagram

The schematic shown in Figure 29-2 is shown with the motors in Figure 29-3. A drawing of the components needed to connect this circuit is shown in Figure 29-4. The schematic diagram, Figure 29-3, is shown with wire numbers in Figure 29-5. The components with corresponding wire numbers are shown in Figure 29-6.

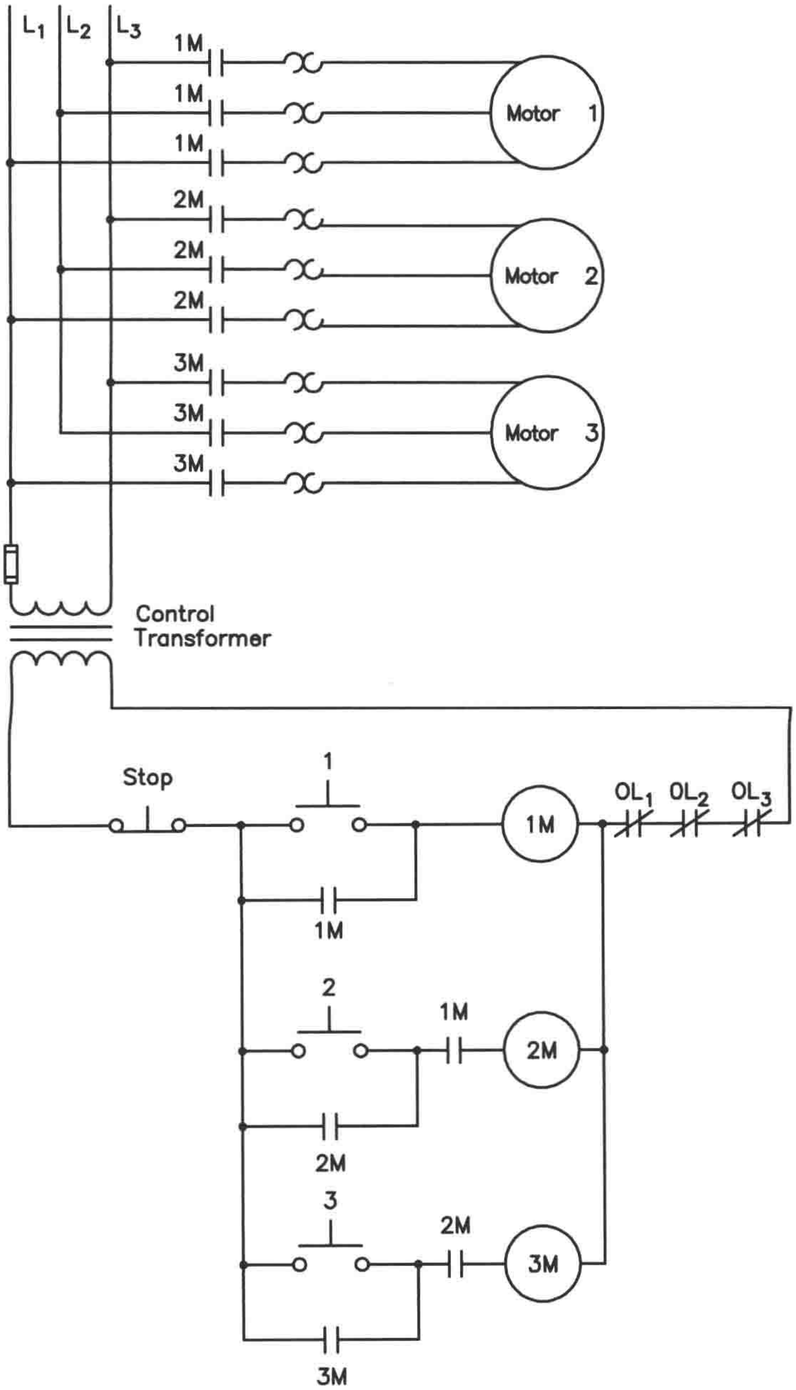

Figure 29-3 Sequence control with motors.

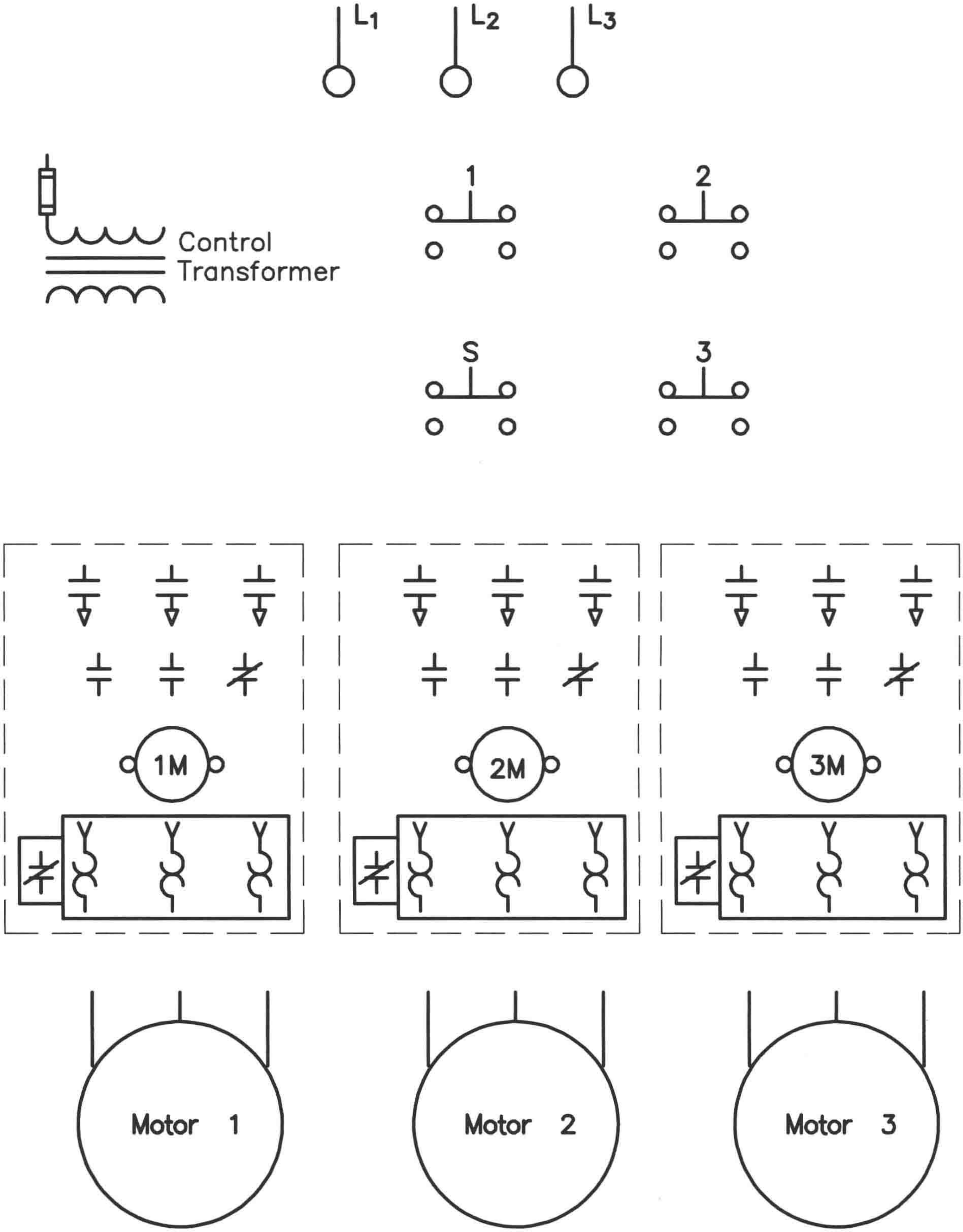

Figure 29-4 Components needed to connect the circuit.

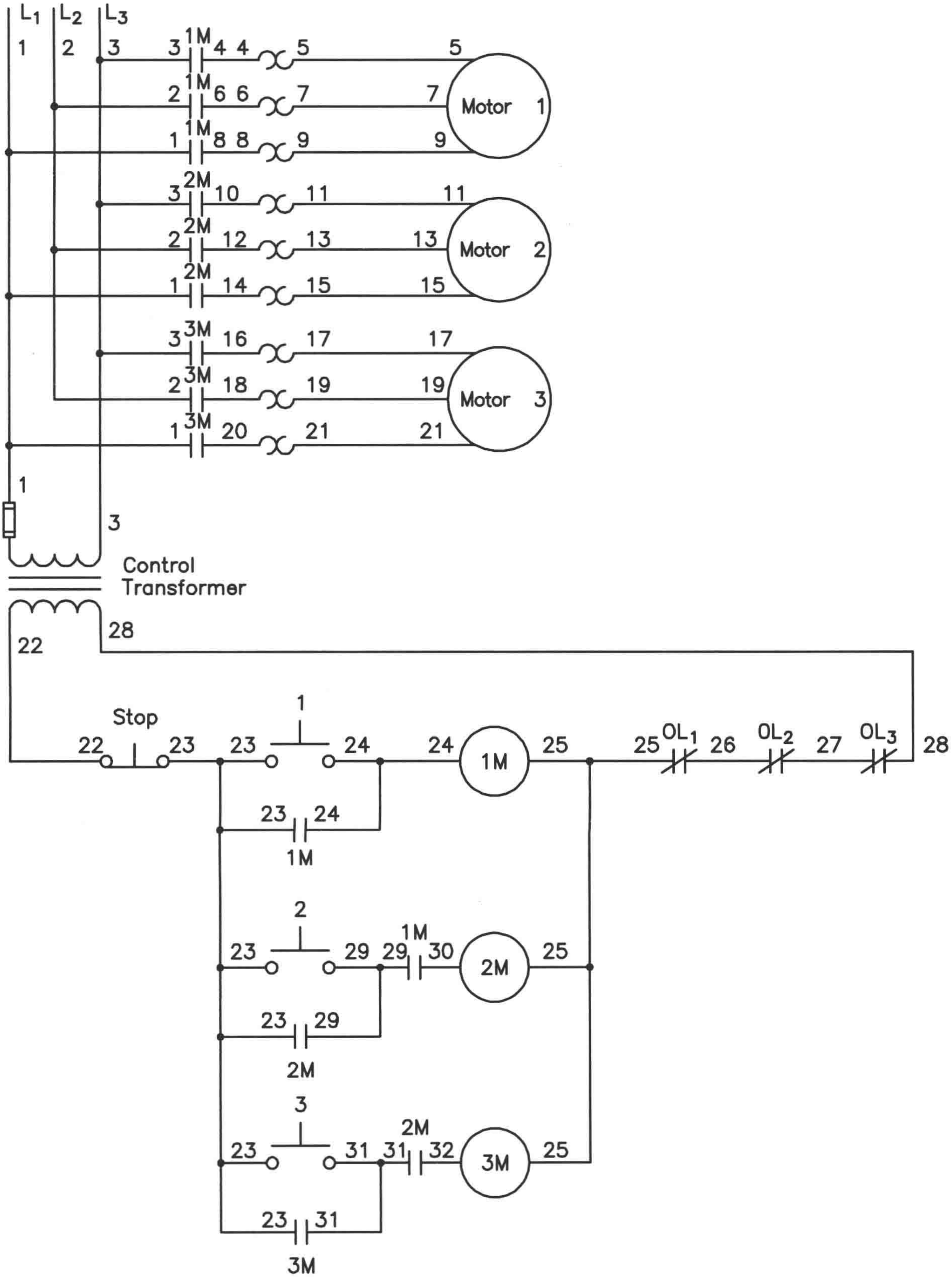

Figure 29-5 Numbering the schematic.

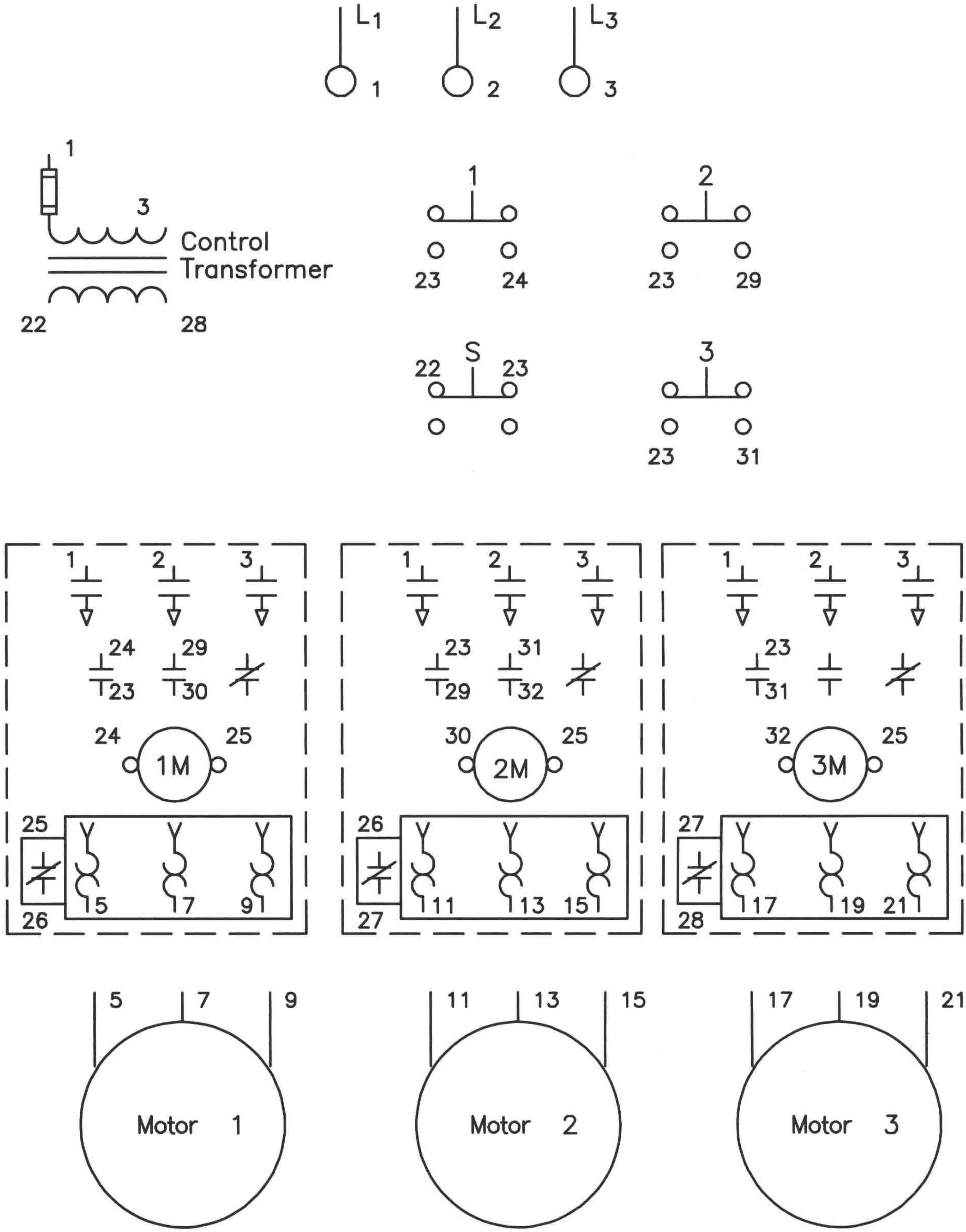

Figure 29-6 Numbering the components.

Connecting the Circuit

1. Using the materials listed at the beginning of this experiment, connect the circuit shown in Figure 29-5. Follow the number sequence shown.
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.
4. Using the schematic diagram shown in Figure 29-1, add wire numbers to the schematic.
5. Place these wire numbers beside the proper components shown in Figure 29-4.
6. Connect the circuit shown in Figure 29-1 by following the wire numbers placed on the schematic.
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 places.

Review Questions

1. What is the purpose of sequence control?

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2. Refer to the schematic diagram in Figure 29-5. Assume that the 1M contact located between wire numbers 29 and 30 had been connected normally closed instead of normally open. How would this circuit operate?

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3. Assume that all three motors shown in Figure 29-5 are running. Now assume that the stop button is pressed and motors 1 and 2 stop running, but motor 3 continues to operate. Which of the following could cause this problem?
   a. Stop button is shorted.
   b. *2M contact between wire numbers 31 and 32 is hung closed.*
   c. The 3M load contacts are welded shut.
   d. The normally open 3M contact between wire numbers 23 and 31 is hung closed.
4. Referring to Figure 29-5, assume that the normally open 2M contact located between wire numbers 23 and 29 is welded closed. Also assume that none of the motors are running. What would happen if:
   a. The #2 push button were to be pressed before the #1 push button?

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   b. The #1 push button were to be pressed first?

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5. In the control circuit shown in Figure 29-2, if an overload occurs on any motor, all

three motors will stop running. In the space provided in Figure 29-7, redesign the circuit so that the motors must still start in sequence from 1 to 3, but an overload on any motor will stop only that motor. If an overload should occur on motor 1, for example, motors 2 and 3 would continue to operate.

Figure 29-7 Circuit redesign.

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 these 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 de-energizes and

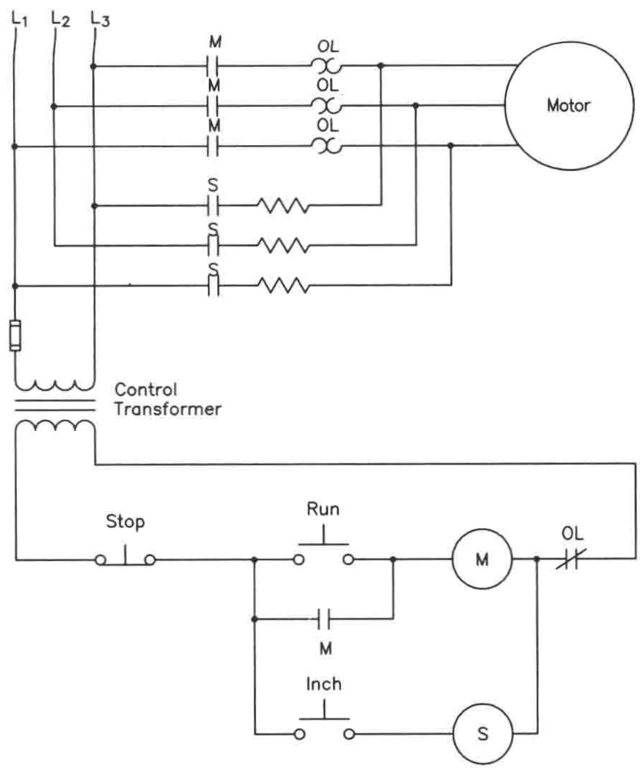


Figure 30-1 Inching control circuit.

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

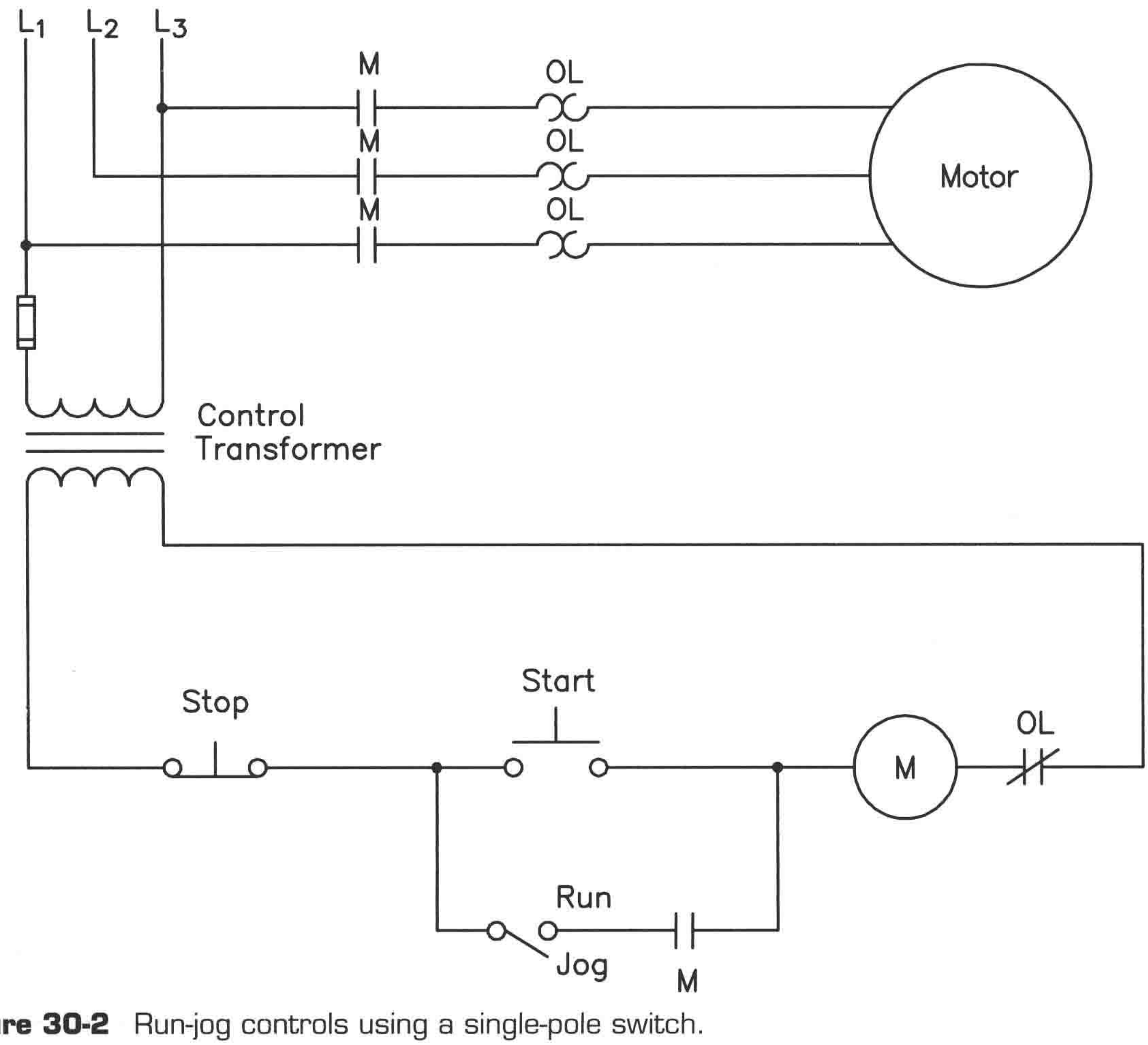


Figure 30-2 Run-jog controls using a single-pole switch.

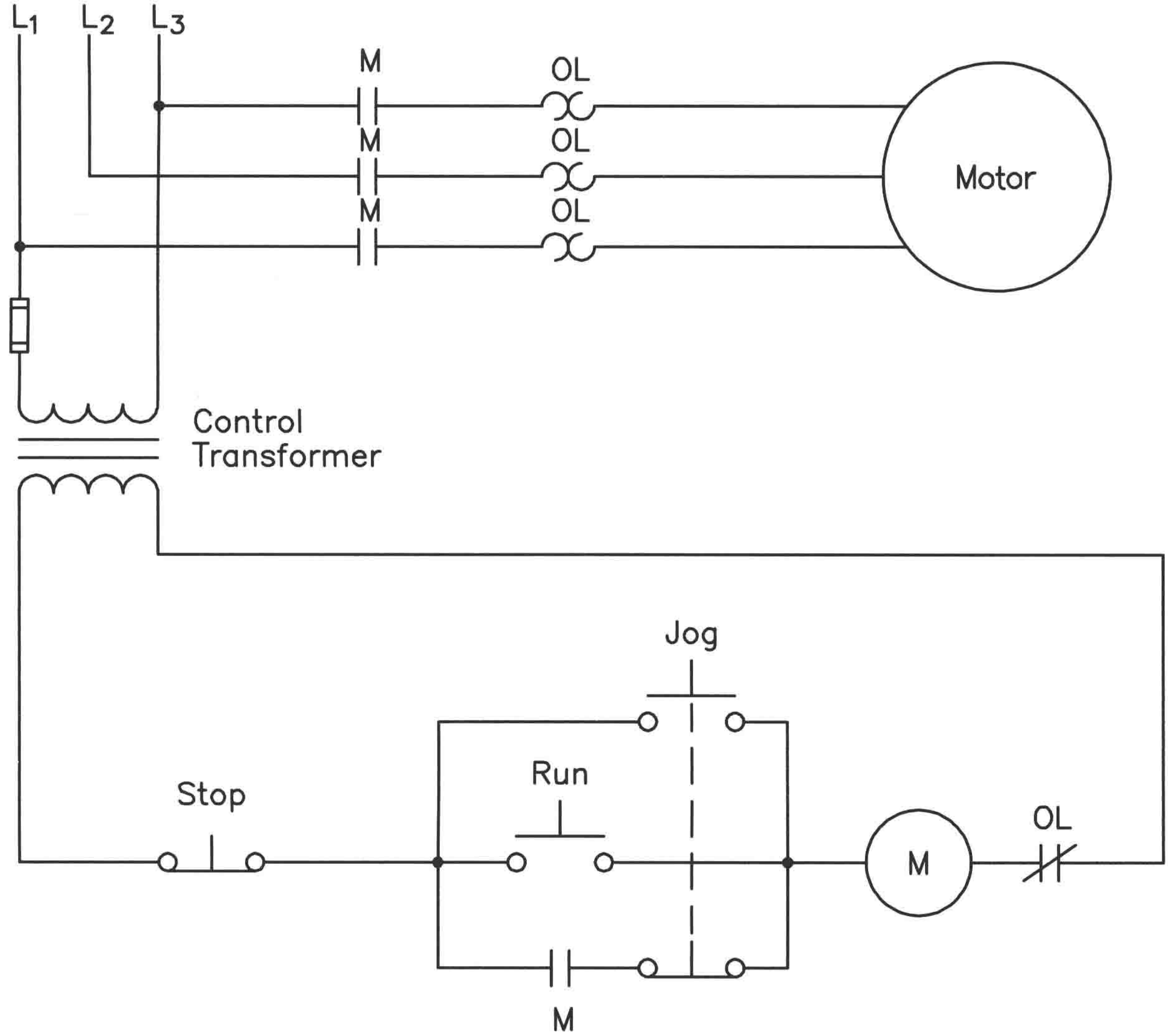


Figure 30-3 Jogging control using a double-acting push button.

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.

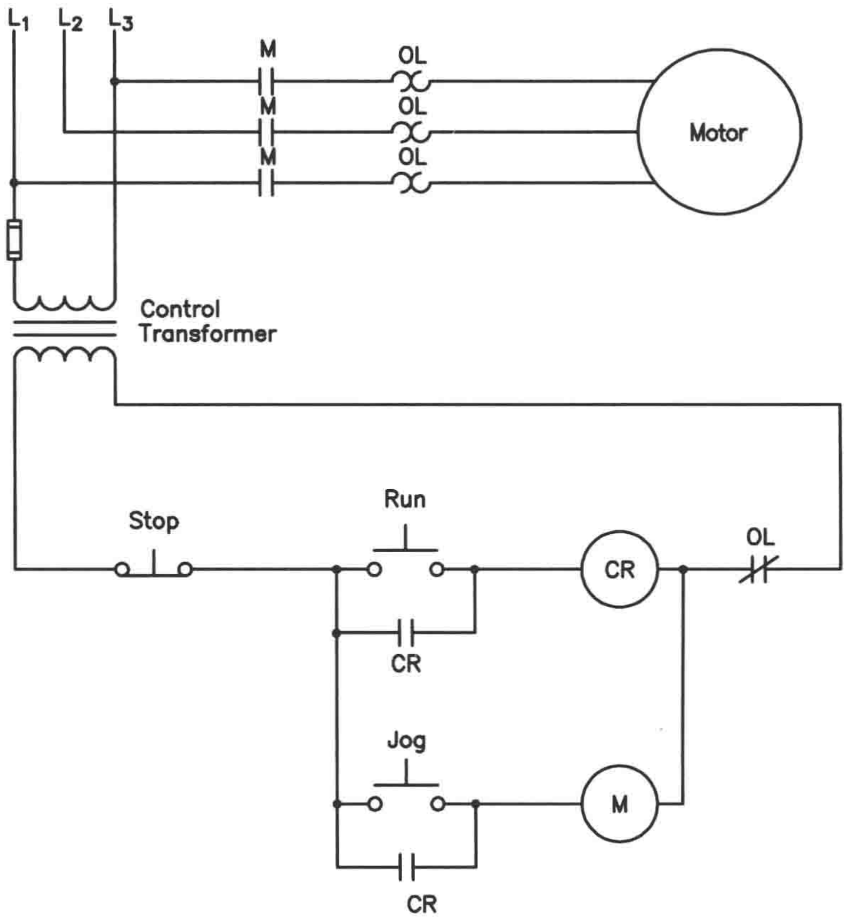


Figure 30-4 Run-jog control using a control relay.

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.

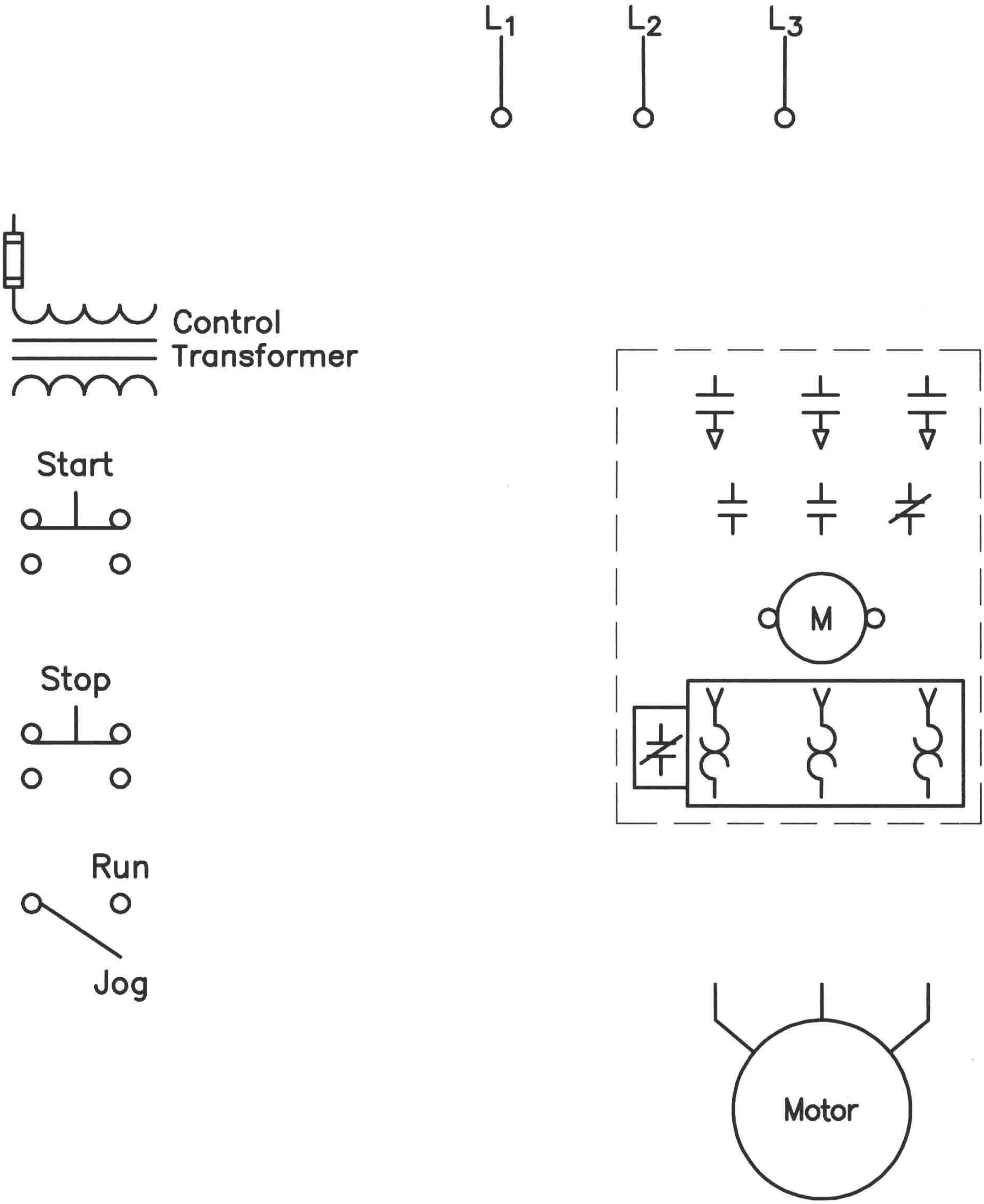


Figure 30-5 Components needed to connect circuit 1.

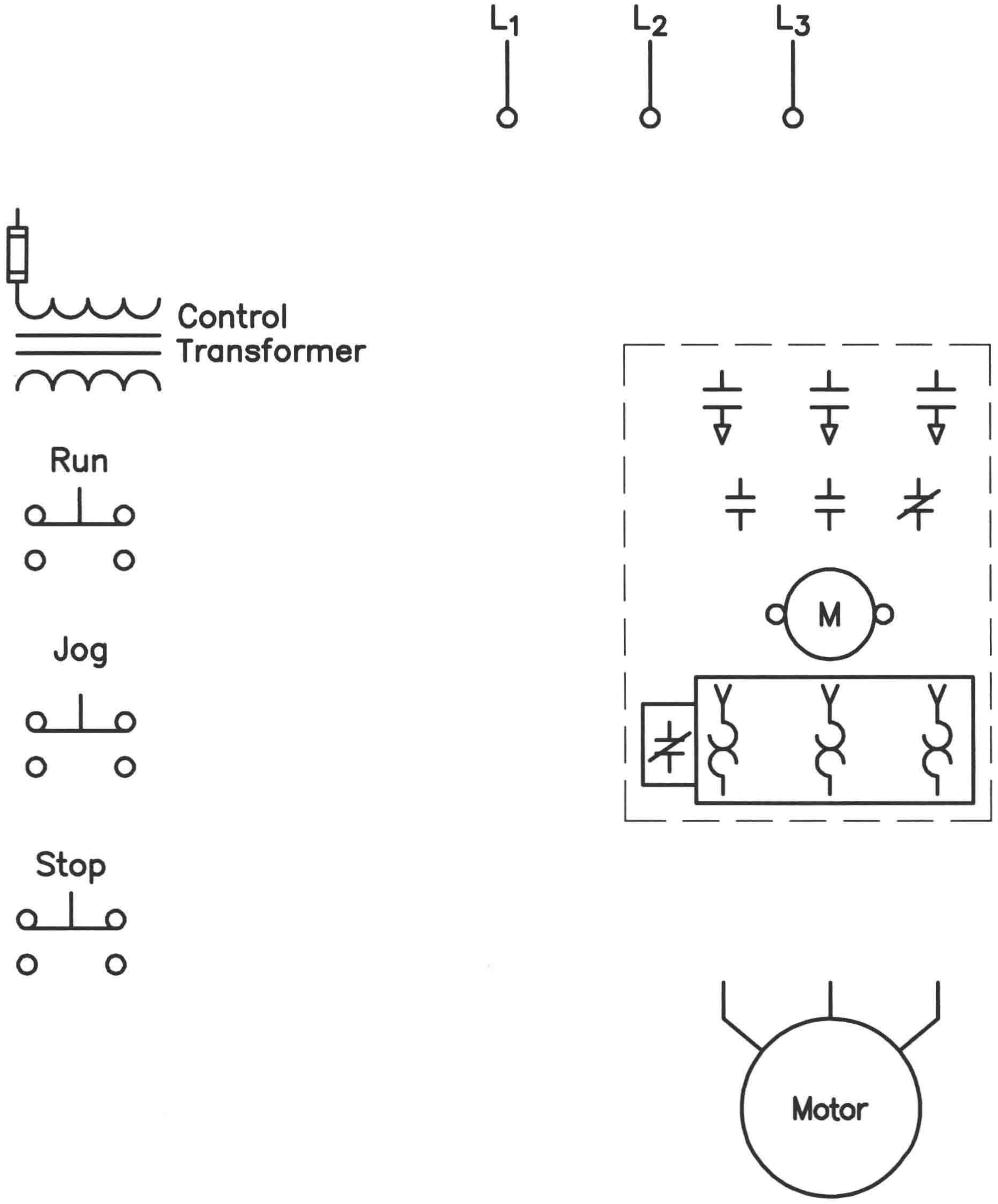
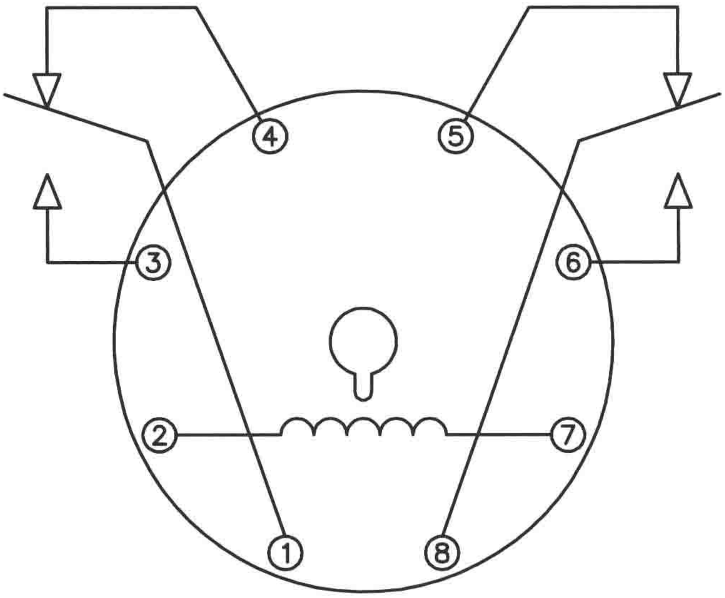
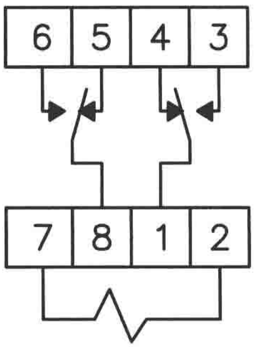


Figure 30-6 Components needed to connect the second run-jog circuit.



Typical in Connection for an 8-pin Pelay



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.

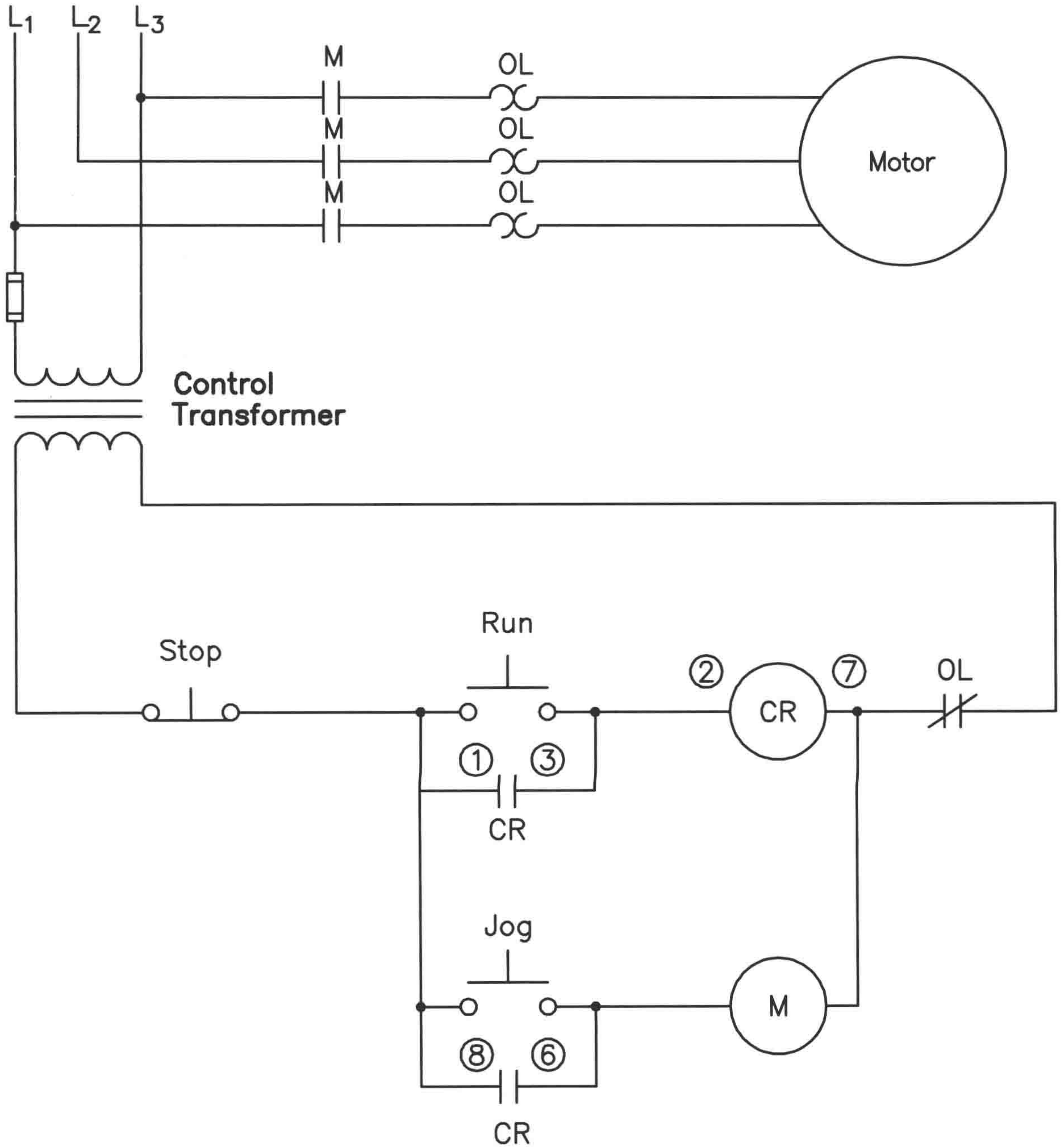


Figure 30-8 Adding pin numbers aids in connecting the circuit.

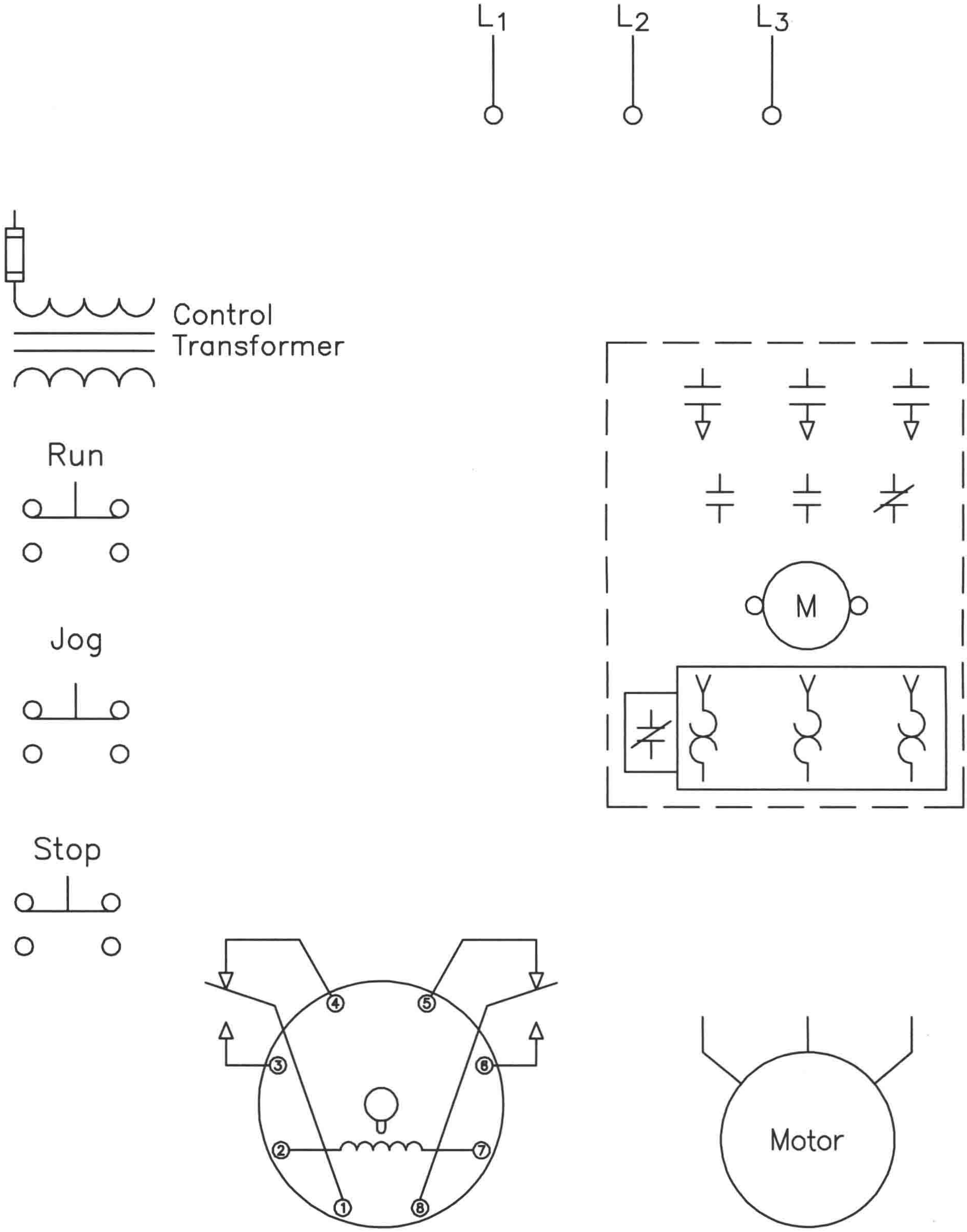


Figure 30-9 Components for circuit.

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.

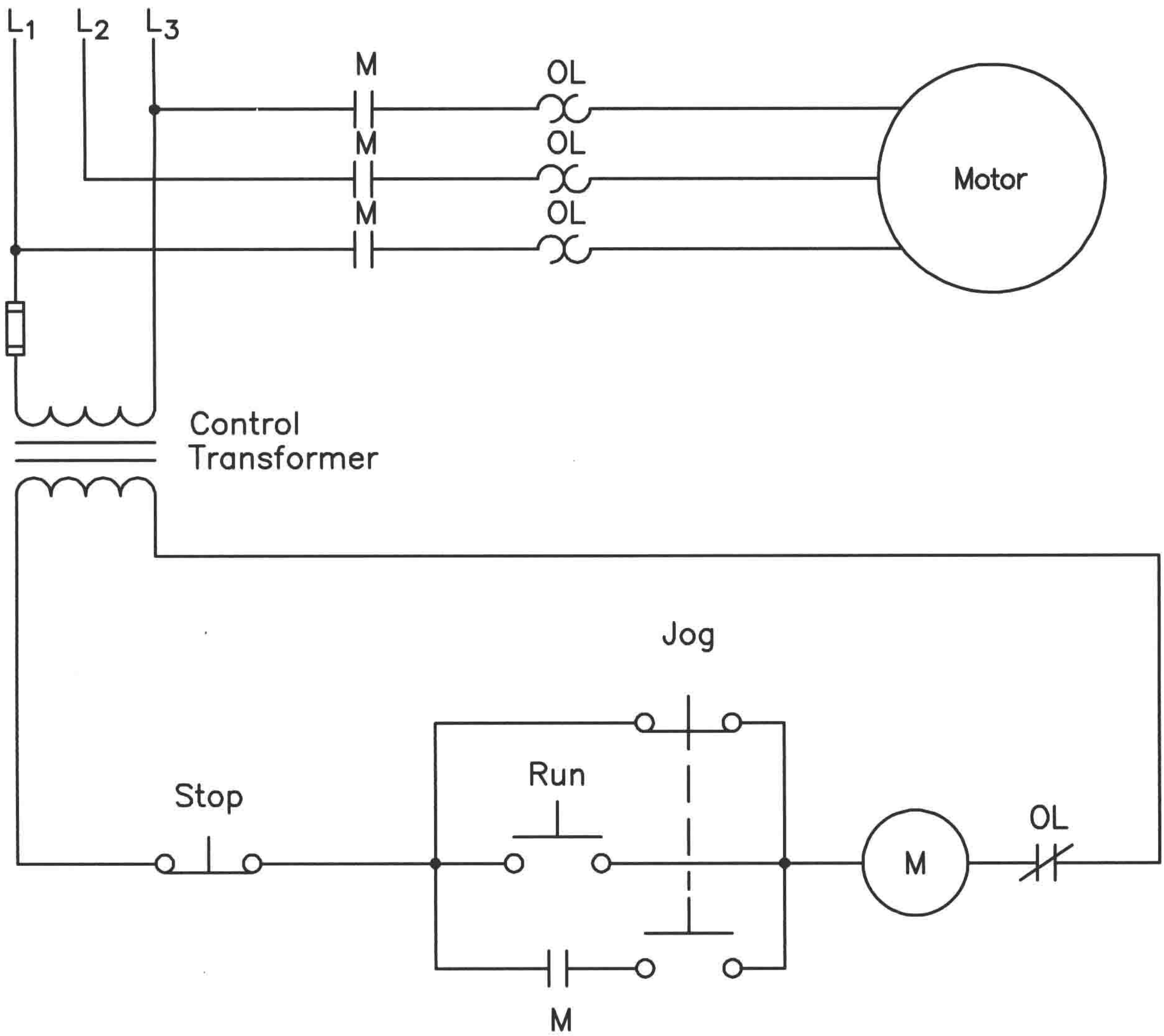


Figure 30-10 Jog button has been connected incorrectly.

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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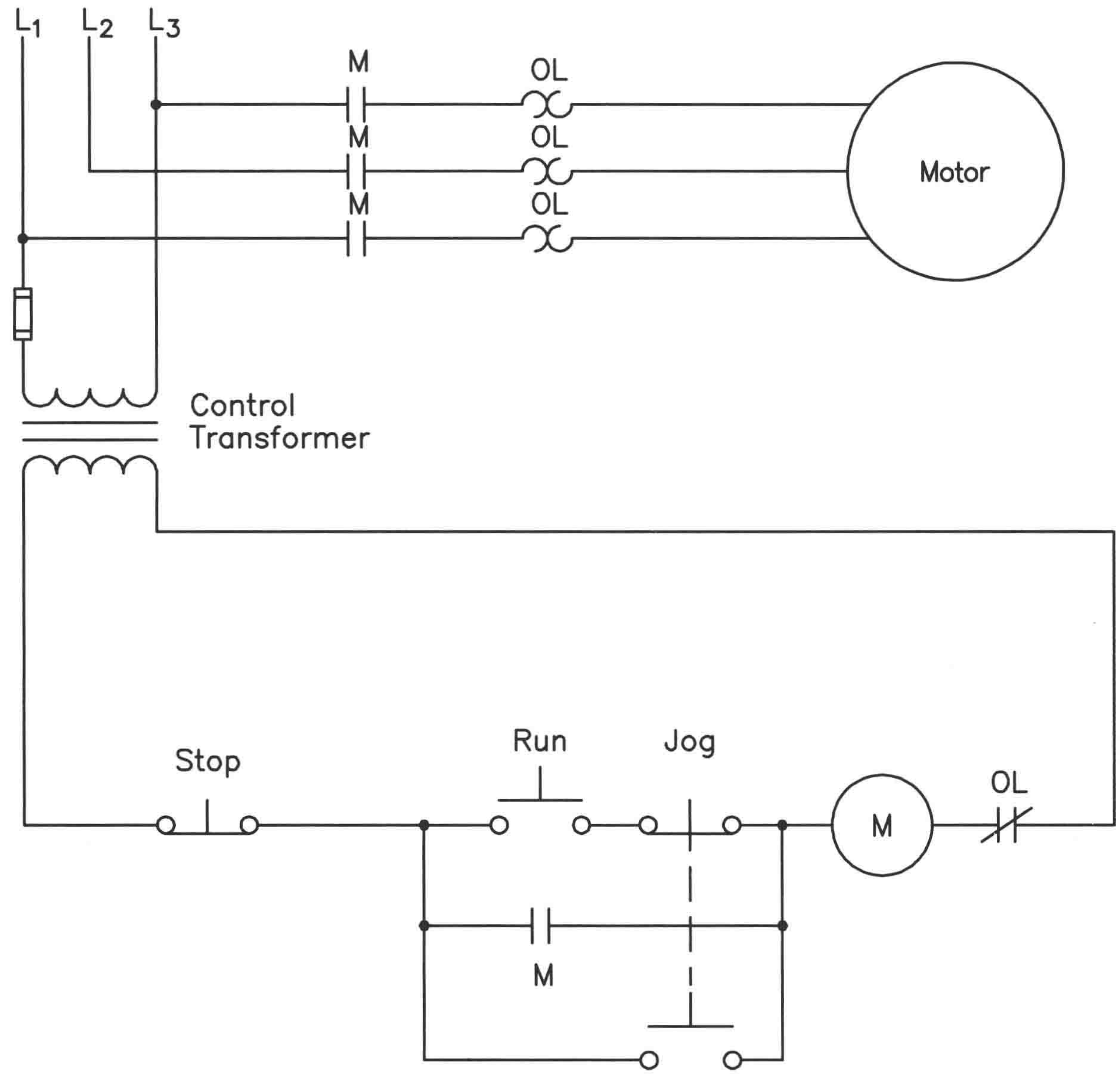

Figure 30-11 Push button has been connected incorrectly.

5. In the space provided in Figure 30-12, design a run-jog circuit to the following specfications:
   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, 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.

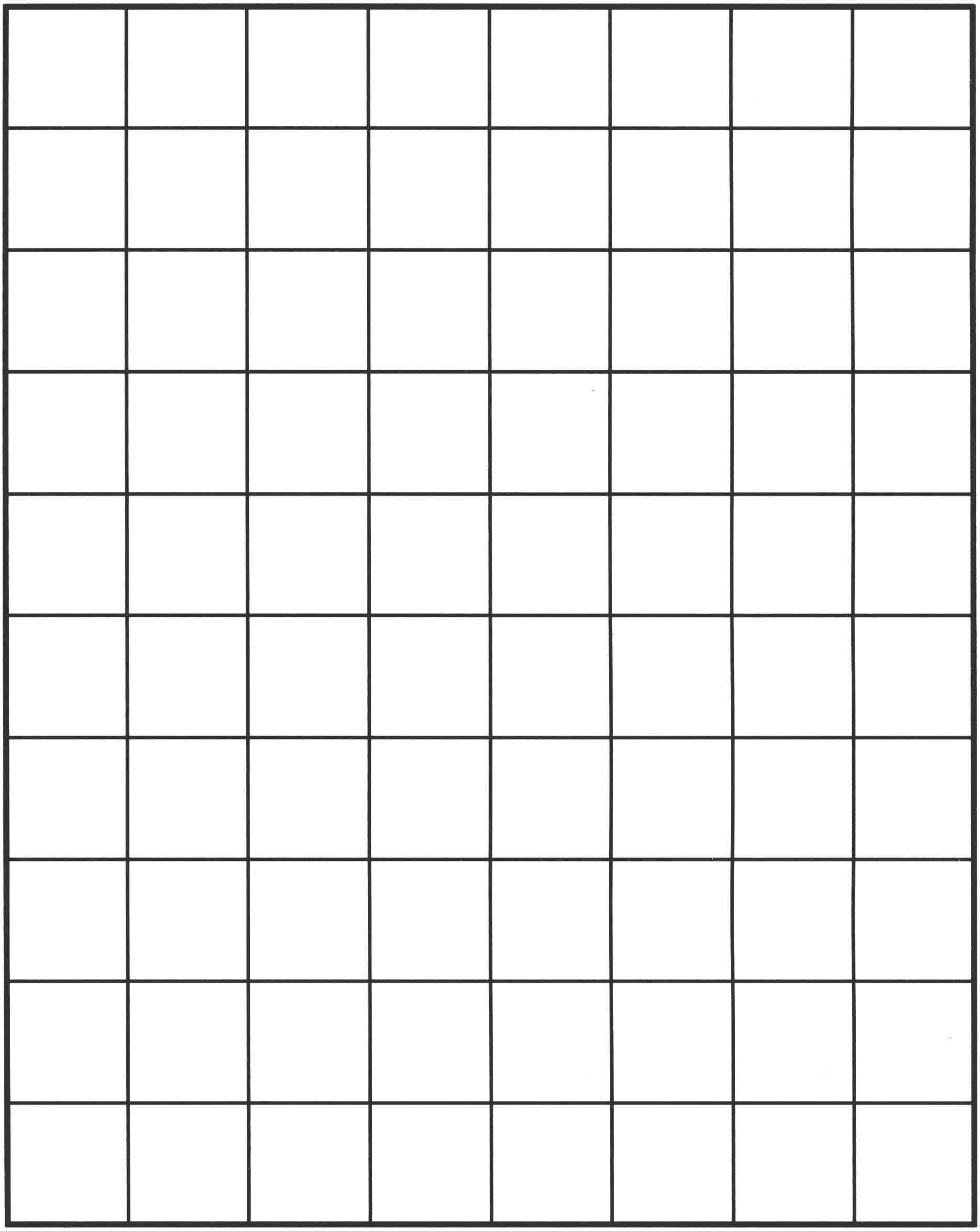

Figure 30-12 Circuit design.

Unit 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, whereas 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

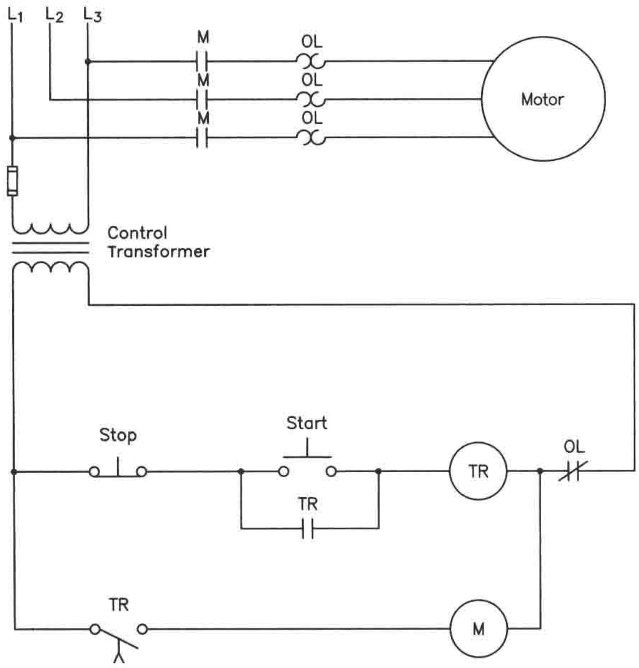

Figure 31-3 An instantaneous timer contact is used as the holding contact.

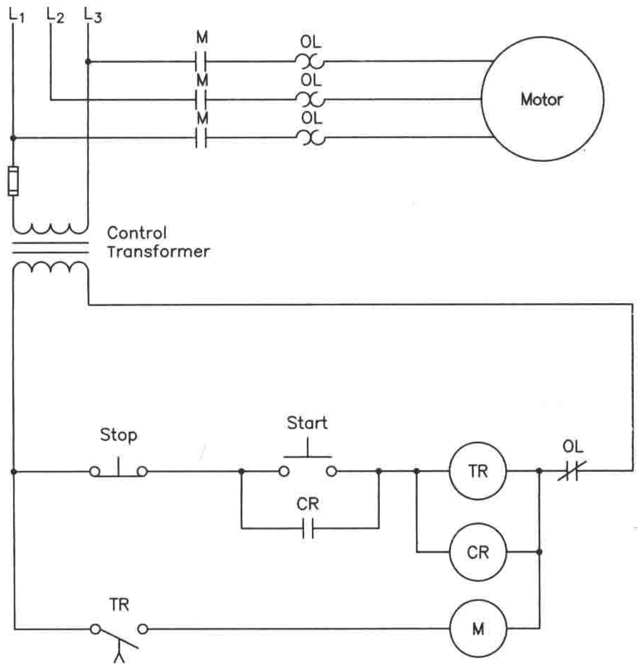

Figure 31-4 control relay furnishes the instantaneous contact.

type of needle valve is generally used to regulate the airflow and thereby regulate the time delay. Pneumatic timers are simple in the way 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).

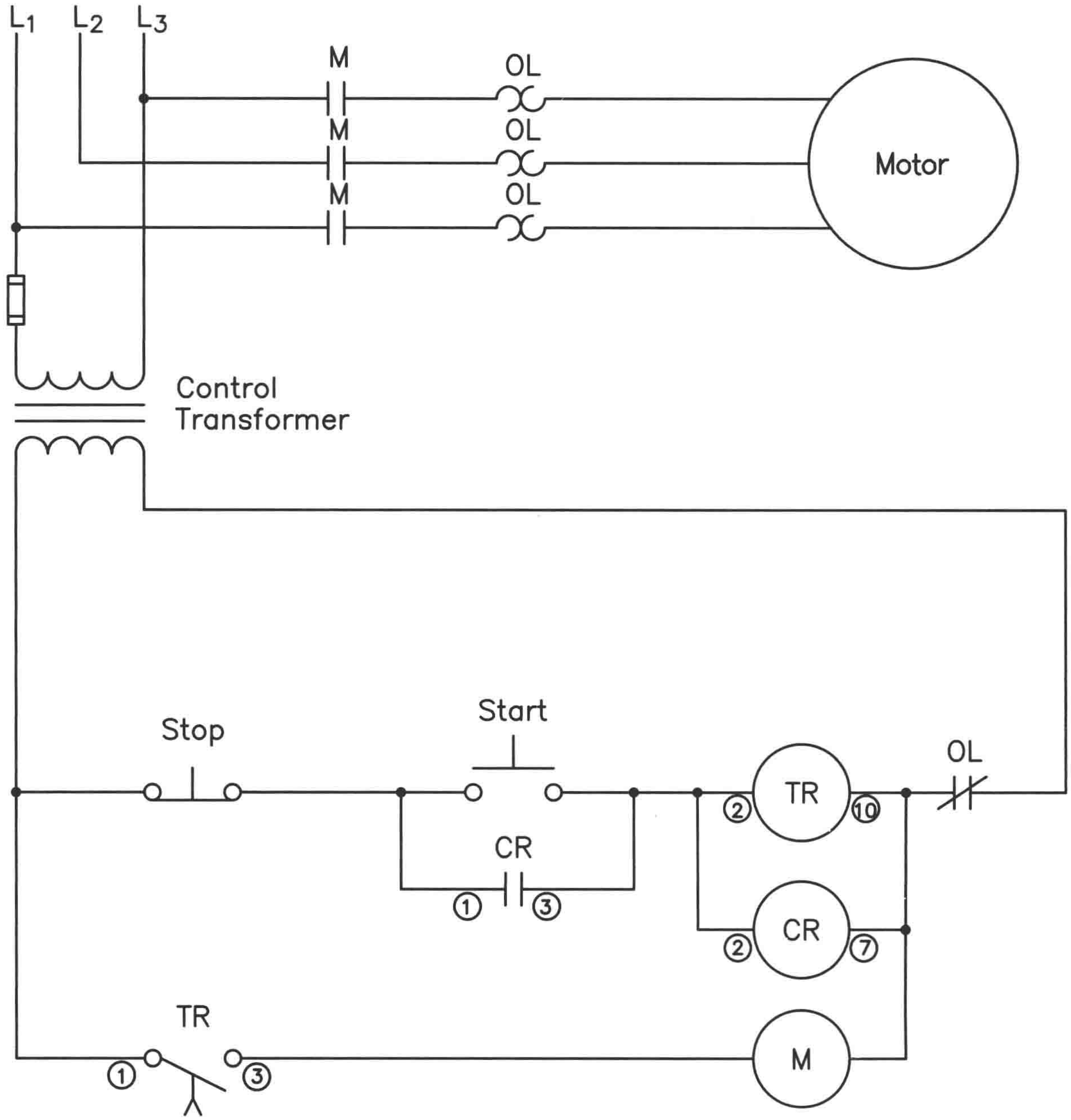

Figure 31-5 Placing pin numbers beside the components.

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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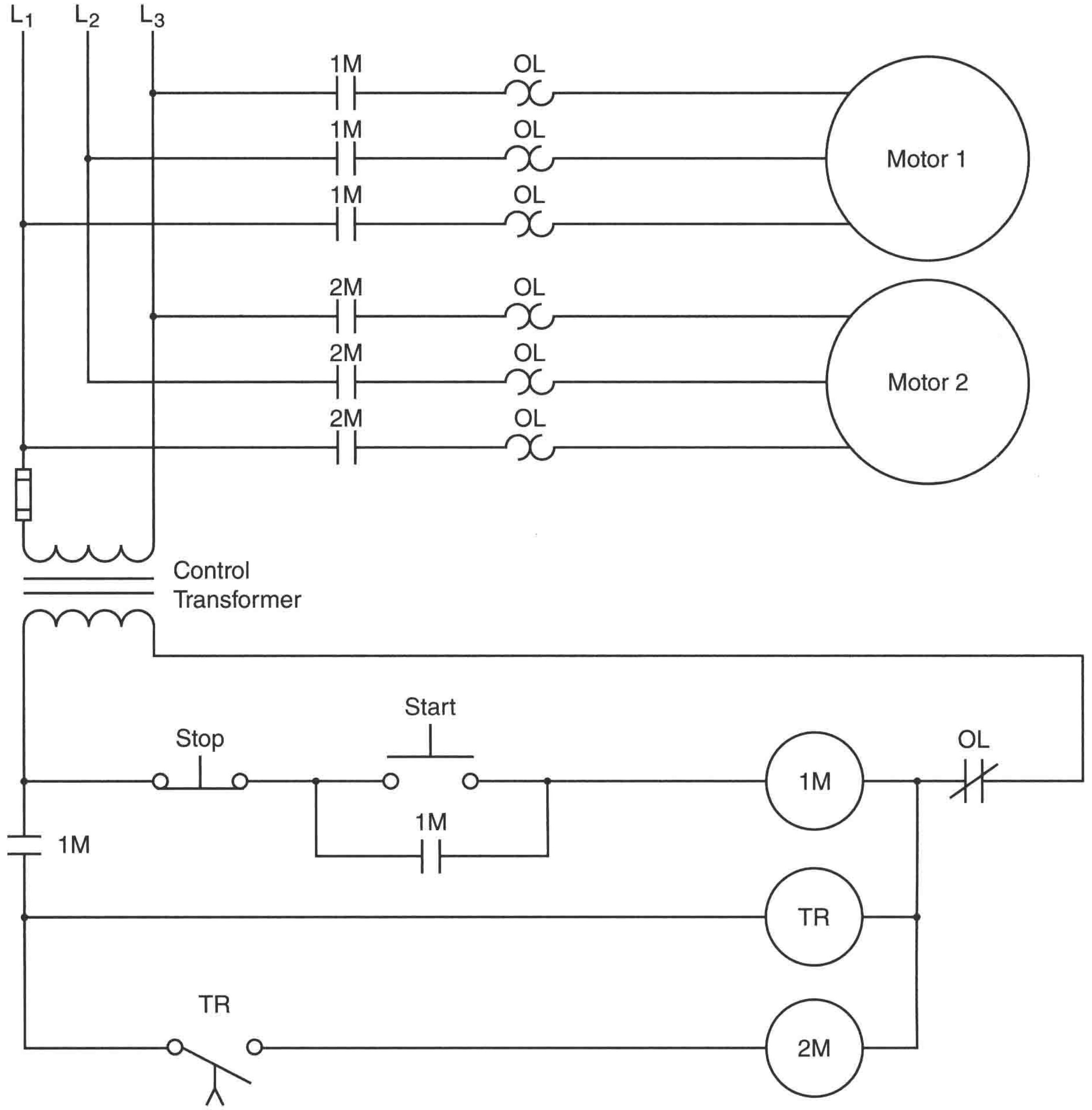

Figure 31-6 Motor 2 starts after motor 1.

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.

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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?

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

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.)

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

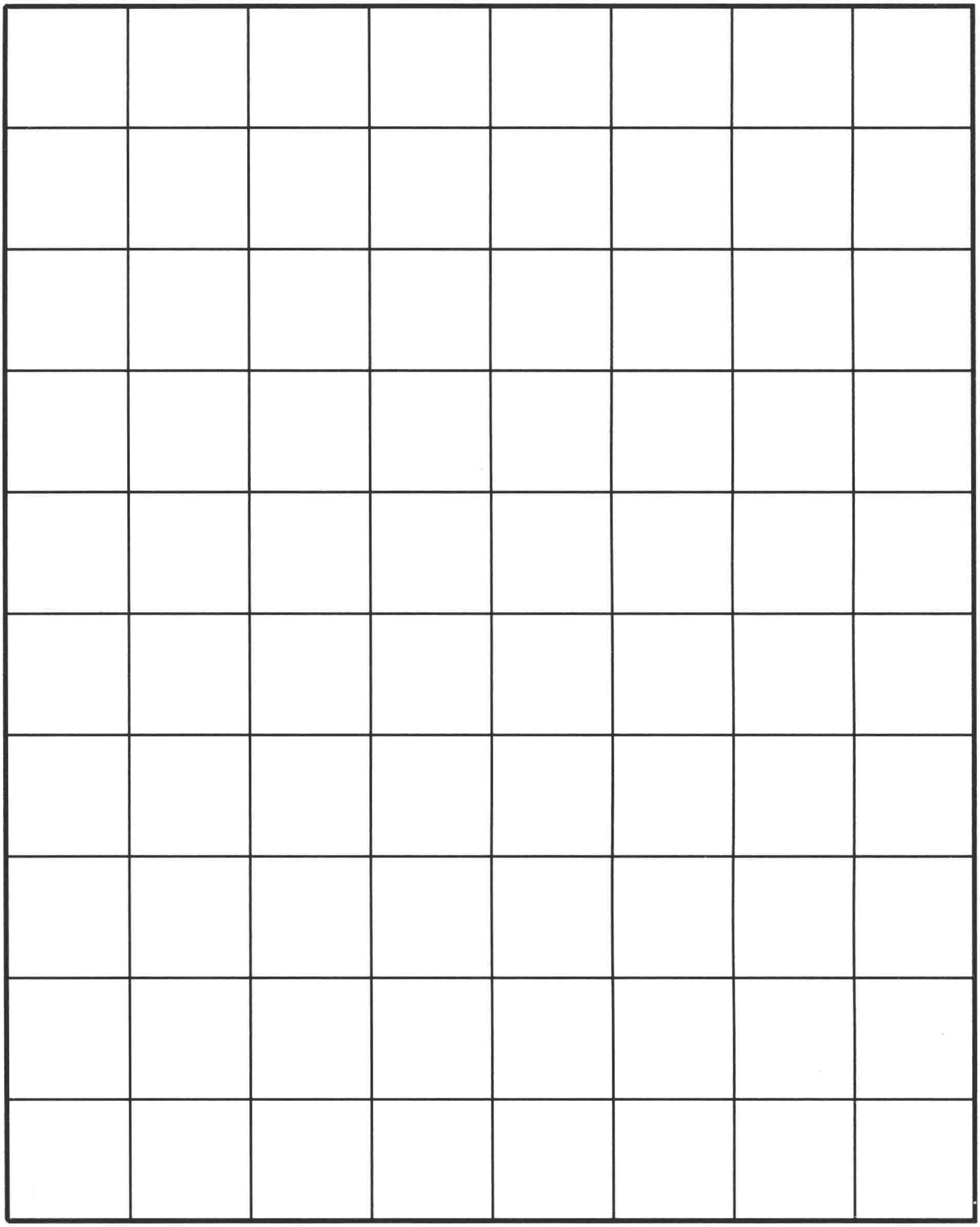

Figure 31-7 Circuit redesign.

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

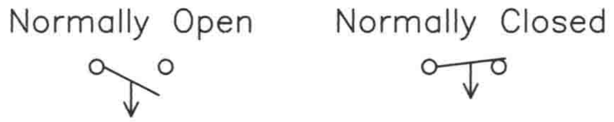

Figure 32-1 NEMA standard symbols for off-delay contacts.

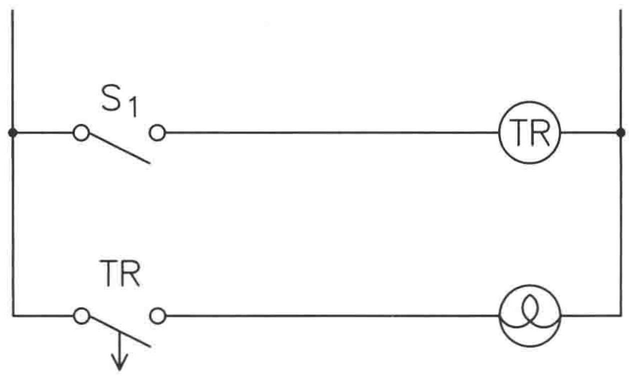

Figure 32-2 Basic operation of an off-delay timer.

closed 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.

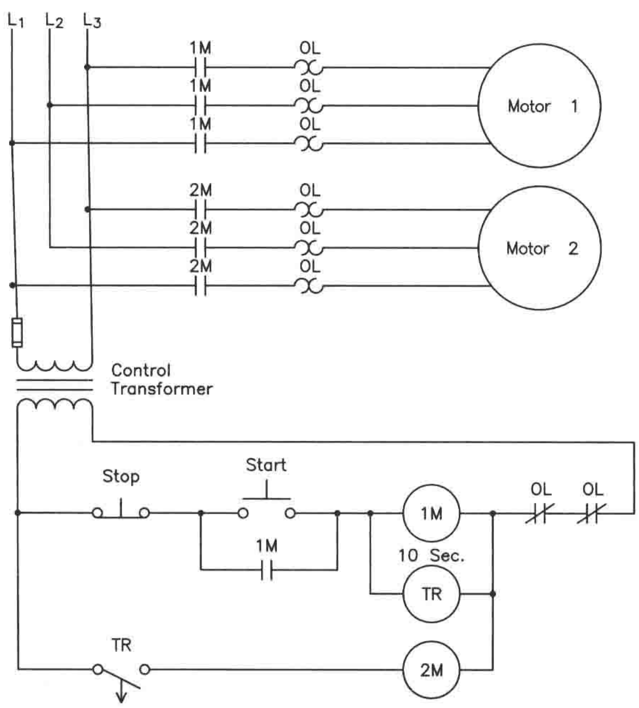

Figure 32-3 Off-delay motor circuit using pneumatic timer.

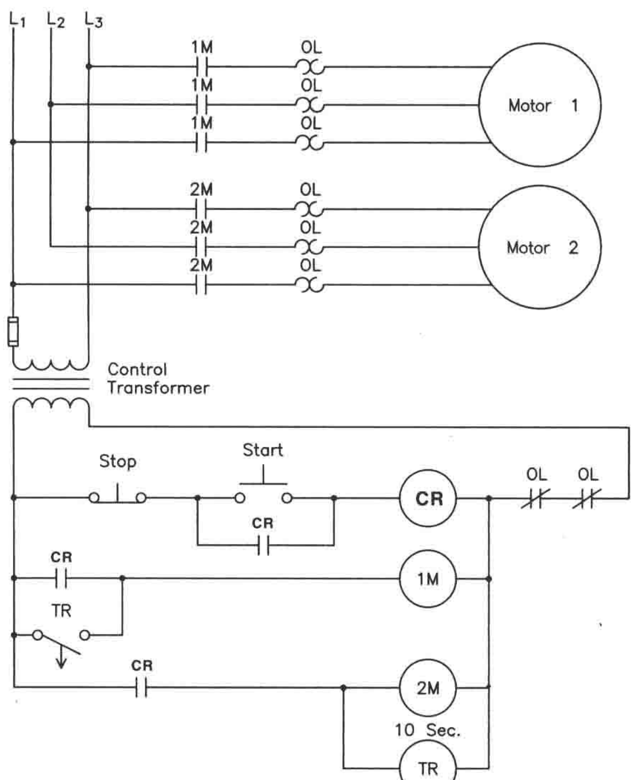

Figure 32-4 Motor 1 stops after motor 2.

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

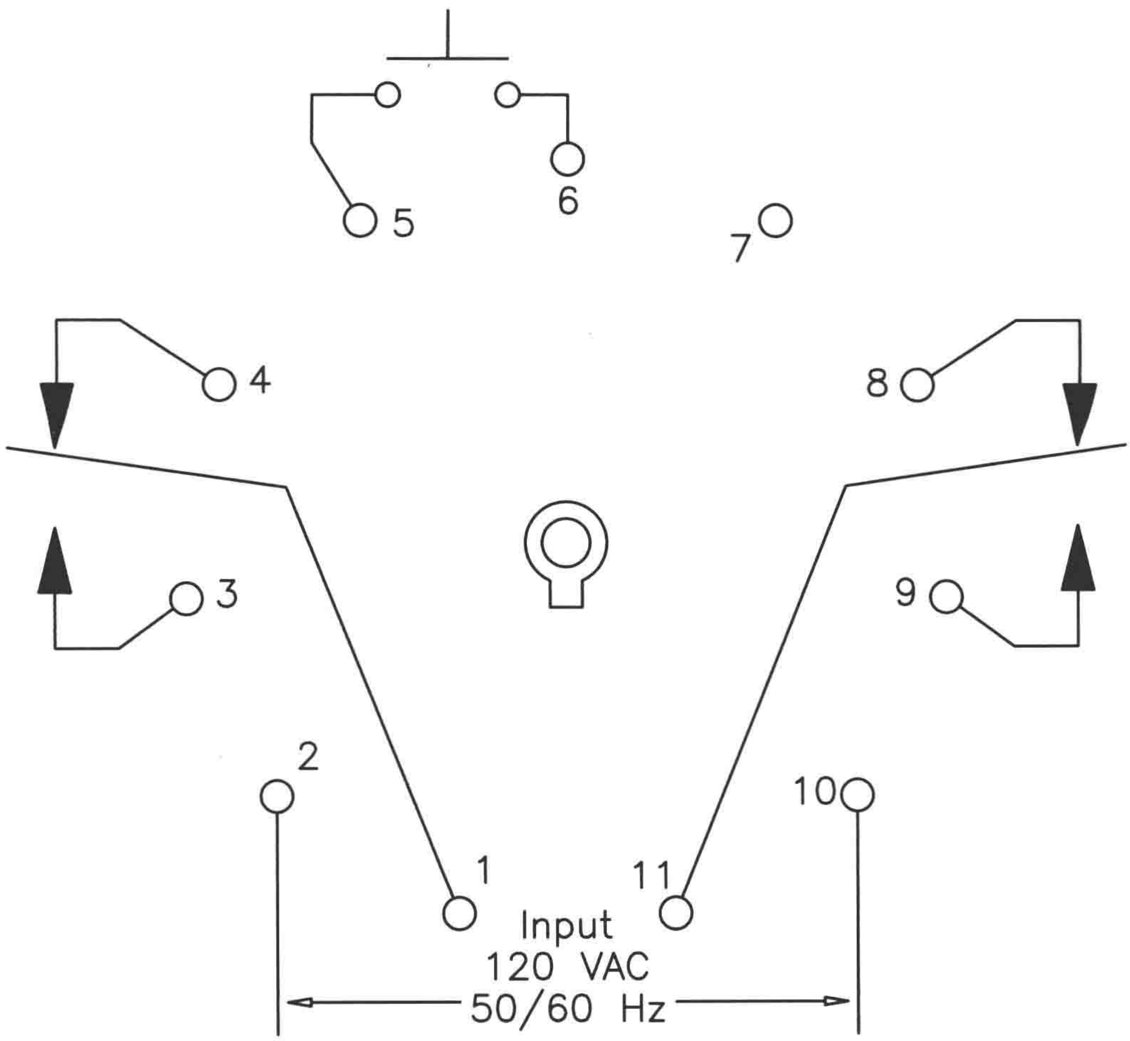

Figure 32-5 Connection diagram for a Dayton model 6A855 timer.

particular timer uses pins 5 and 6 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.

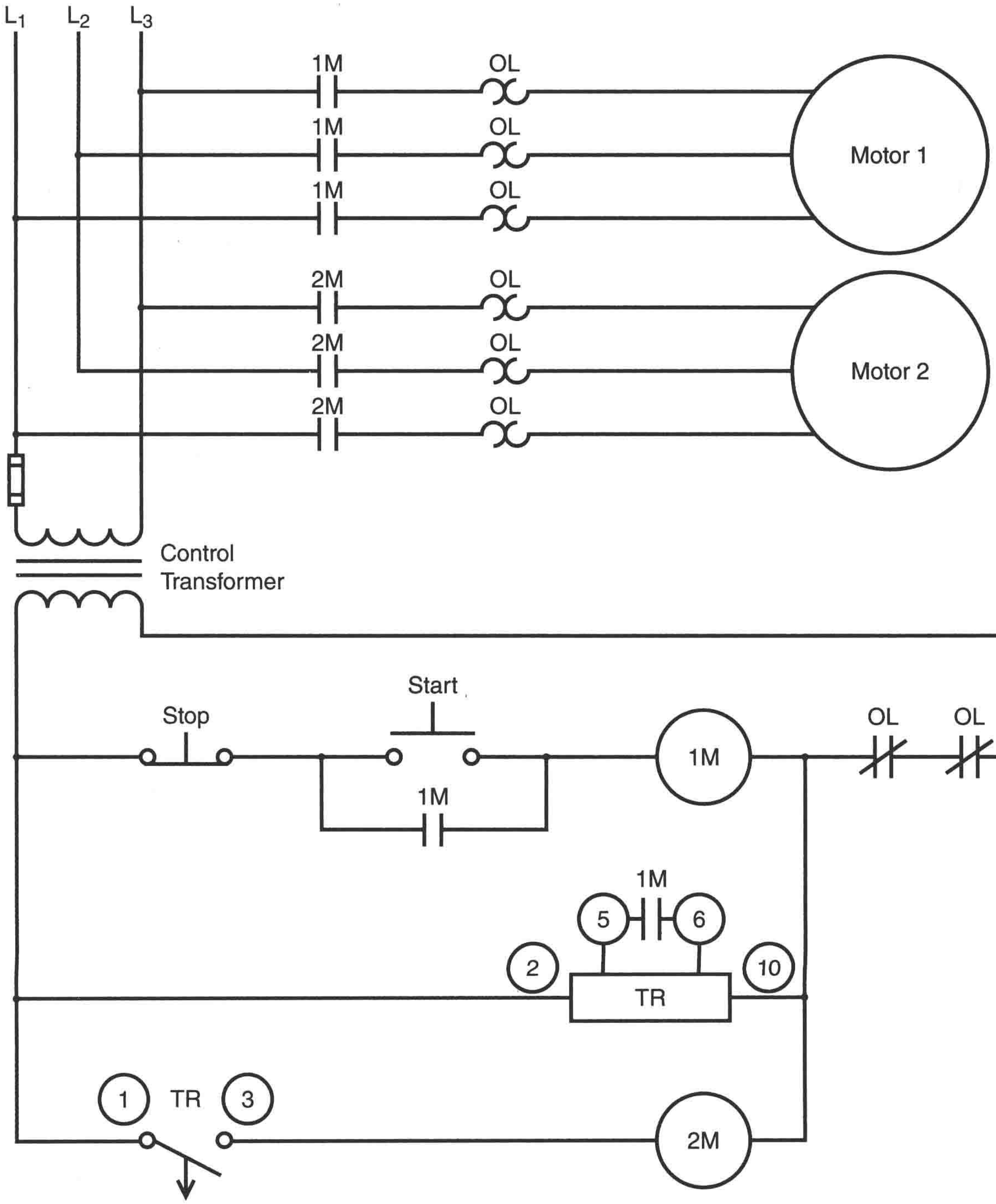

Figure 32-6 Amending the first circuit for an electronic timer.

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.

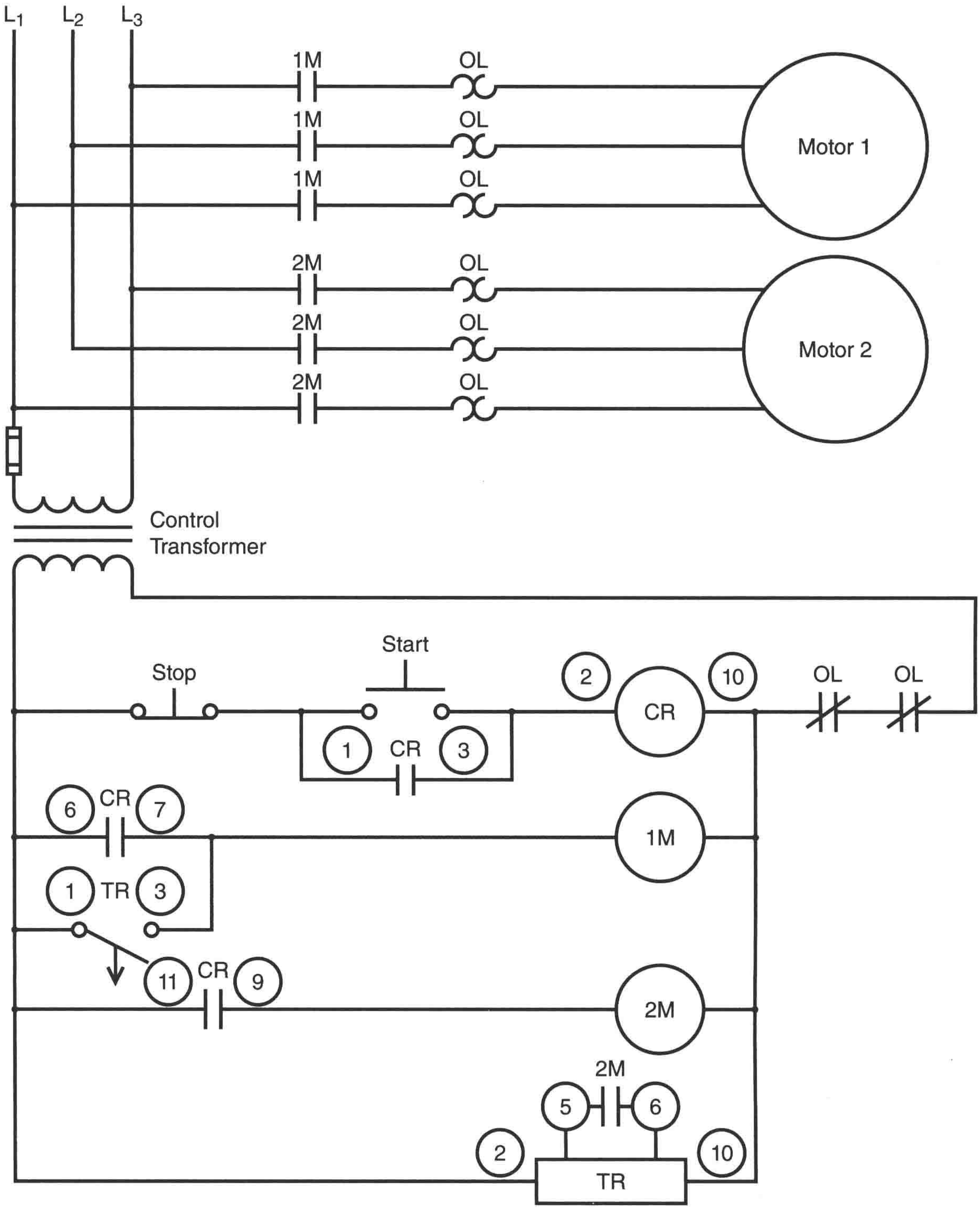

Figure 32-7 Amending circuit 2 for an electronic timer.

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.

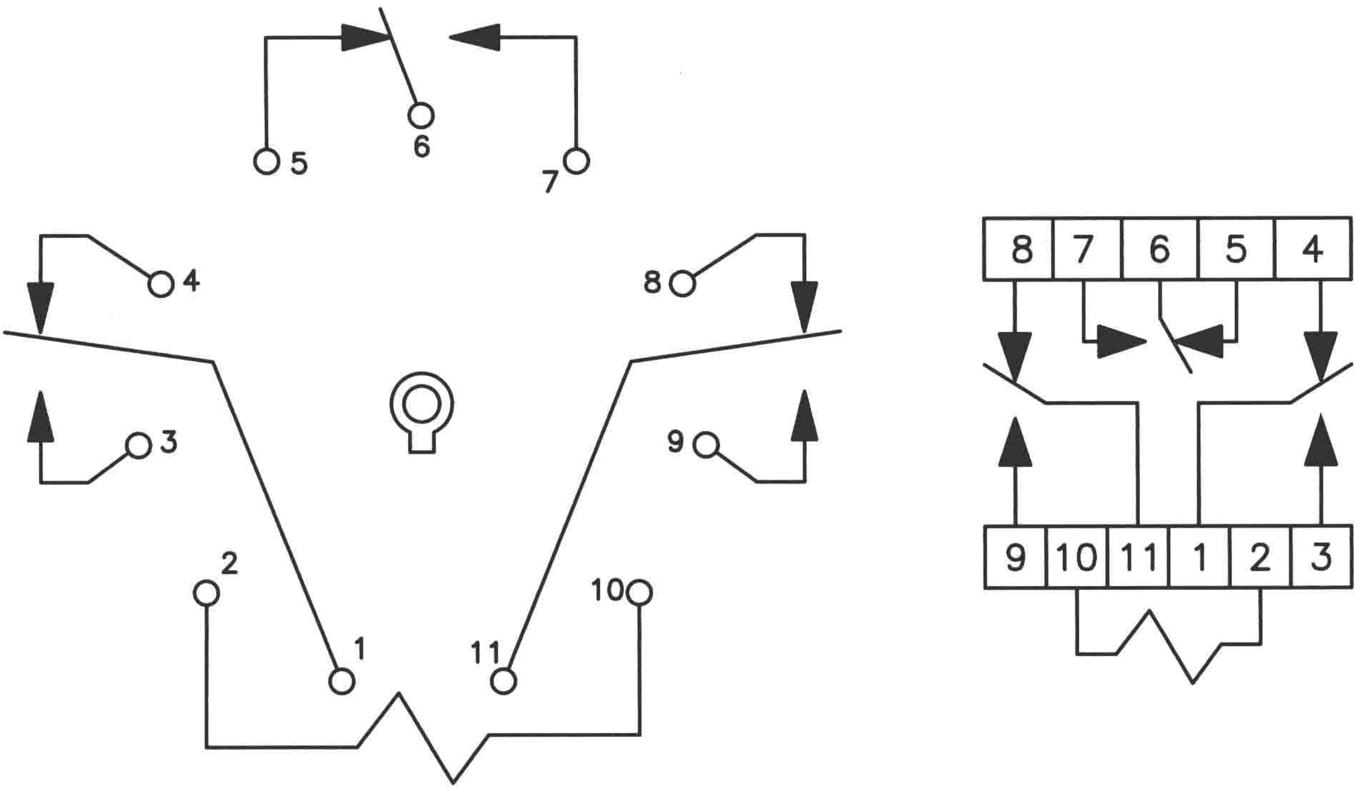

Figure 32-8 Connection diagram for an 11-pin control relay.

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.

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

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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.

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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.

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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.

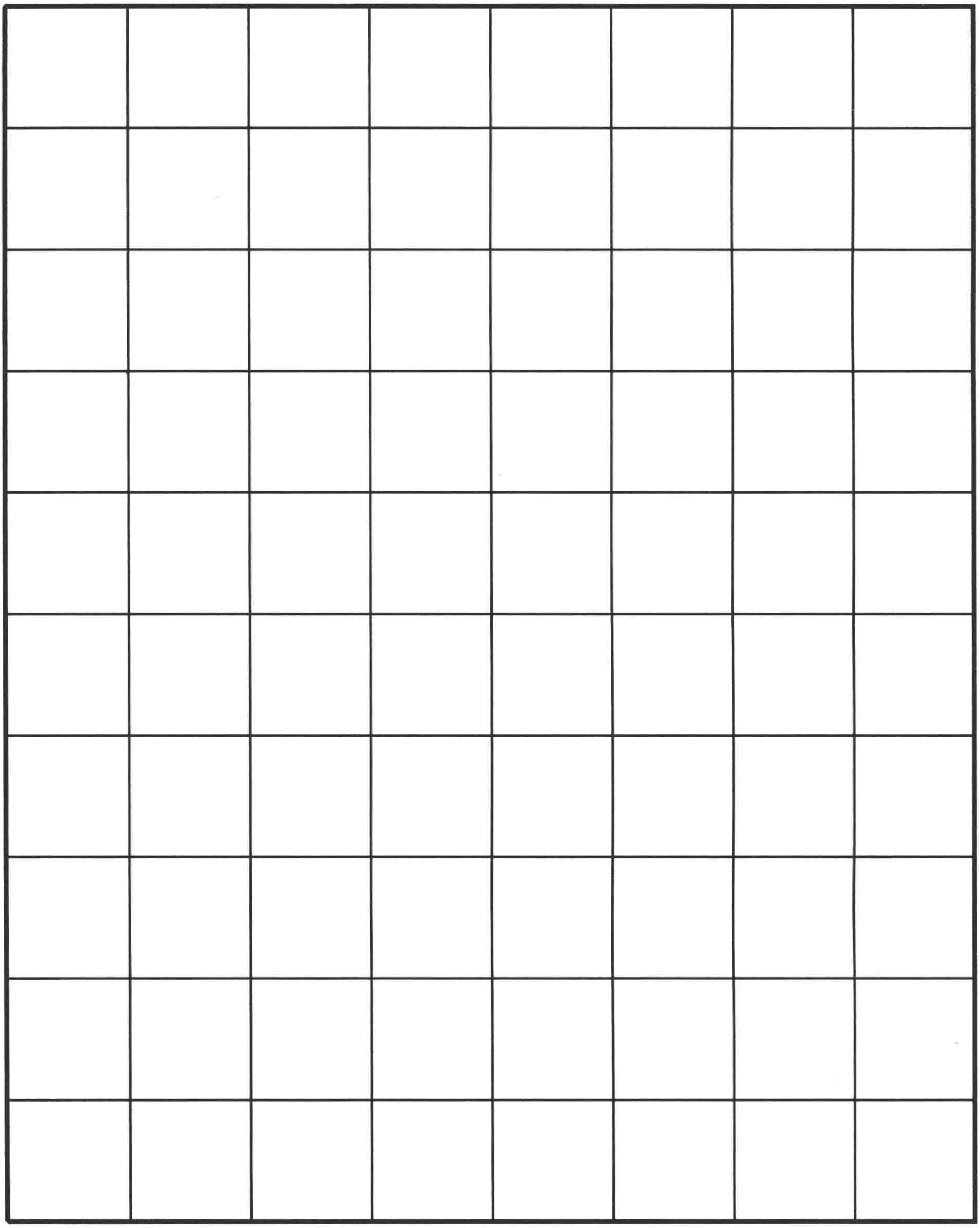

Figure 32-9 Amending the circuit design.

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 re-opens, a current path is maintained though the now closed 1M auxiliary contact connected

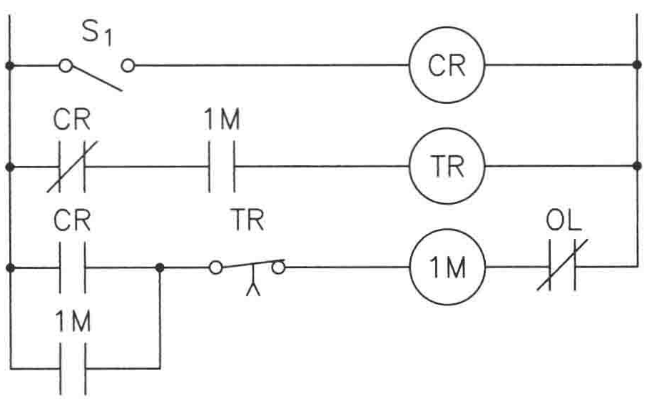

Figure 33-1 Basic circuit to change the logic of an on-delay timer into an off-delay timer.

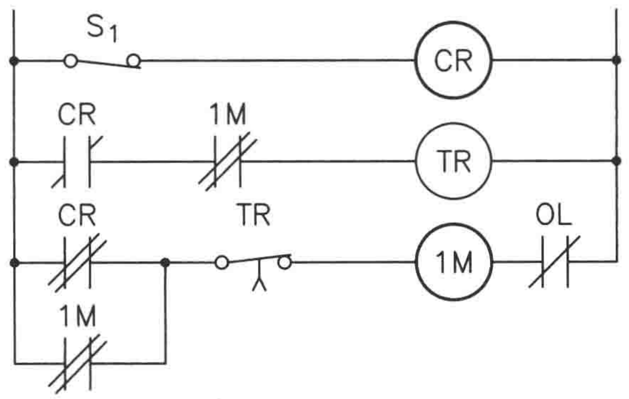

Figure 33-2 Starter 1M energizes immediately, but the timer does not start timing.

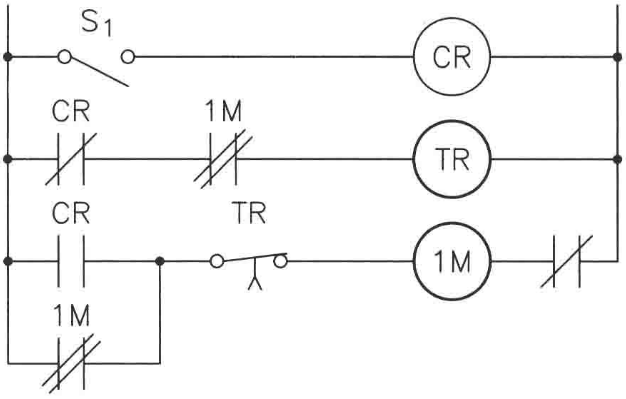

Figure 33-3 Switch S_1 opens and starts the timer.

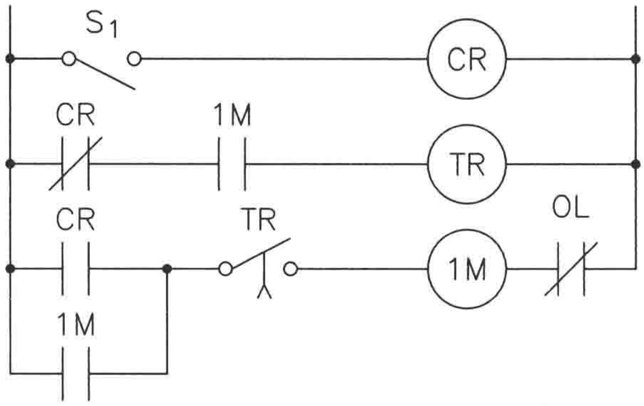

Figure 33-4 Starter 1M de-energizes when timer contact TR opens.

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, as 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.