the outside temperature is low enough that the heat pump cannot provide enough heat, the second thermostat contact will close and permit the electric heat strip to operate.

THE DIFFERENTIAL THERMOSTAT

The **differential thermostat** is used primarily with solar-powered heating systems. A differential thermostat is shown in Figure 29–16. This thermostat uses two separate temperature sensors and is activated by the difference of temperature between them. A solar hot-water system is shown in Figure 29–17. A solar collector is used to heat the water. A storage tank stores the heated water and acts as a heat exchanger for the domestic hot water for the home. The system is controlled by the differential thermostat. When the temperature of the collector becomes greater than the temperature of the water in the storage tank by so many degrees, the thermostat activates the pump motor. The pump motor circulates water from the storage tank to the collector, and from the collector back to the tank. When the temperature of the collector is within a certain amount of the water temperature, the thermostat turns the pump off. In this way, water is circulated through the collector only when the collector is at a higher temperature than the stored water.

A common setting for the differential thermostat is 20 and 5. This means that the thermostat will turn the pump on when the collector is 20 degrees hotter than the stored water, and turn the pump off when the collector is only 5 degrees hotter than the stored water.

Figure 29–16
Differential thermostat. (Courtesy of Independent Energy Corp.)

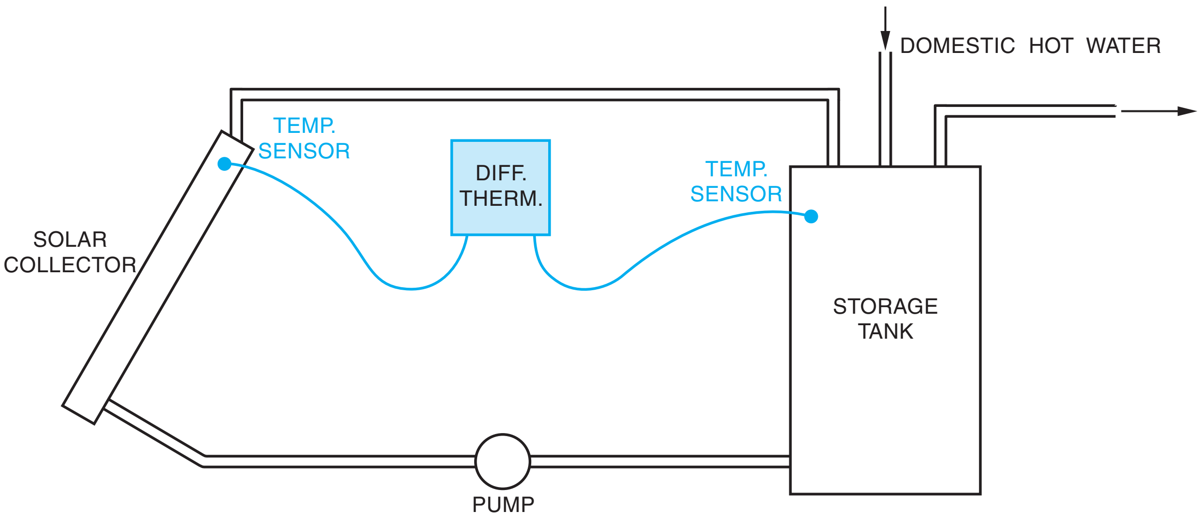


Figure 29–17
Solar hot-water system controlled by a differential thermostat. (Source: Delmar/Cengage Learning)

Some differential thermostats provide extra features, such as **antifreeze protection**. Antifreeze protection turns the pump on and circulates warm water through the collector when its temperature is near freezing. This does cool the warmed water, but cooling the water is generally preferred to damaging the collector. Some solar systems used a separate water supply for the collector. These systems use a mixture of antifreeze and water in the collector loop to avoid freezing problems.

THERMOSTAT TERMINAL IDENTIFICATION

Thermostats generally contain letters that are used to identify the terminal connections. The most common letters are R, G, Y, W, B, and O. The letters stand for common colors of thermostat wire.

R = Red
G = Green
Y = Yellow
W = White
B = Blue or Black
O = Orange

The B and O terminals are seldom used. The B terminal connects to a heating damper and the O terminal connects to a cooling damper. The other terminals connect as follows:

R – One side of the control transformer (generally 24 volts)
G – Fan relay
Y – Compressor relay
W – Heating relay

Some heating/cooling thermostats use R_C and R_H instead of R. When these thermostats are used for both heating and cooling, terminals R_C and R_H are connected with a jumper, Figure 29–18.

Heat pump thermostats generally contain terminals not found on common heating/cooling thermostats. Figure 29–19 illustrates the terminal connections for a common heat pump thermostat.

A listing of thermostat terminals and their meanings follows:

A General purpose (could be anything)
B Damper (heating) or Reversing solenoid on heat pumps (heating)
C Unswitched side, Class 2 power
DF Defrost
E Emergency heat relay on heat pumps
G Fan
K1 Switched side, Second source—Class 2 power
K2 Unswitched side, Second source—Class 2 power
L Indicator circuits or system monitors
O Damper (cooling) or reversing valve on heat pump (cooling)
R Switched side, Class 2 power (single source)
RC Switched side, Class 2 power, Cooling side
RH Switched side, Class 2 power, Heating side
T Outdoor thermostat
TT One side, Class 2 circuit-switch—Heat
TT Other side, Class 2 circuit-switch—Heat
W Heating
W1 1st Stage heating
W2 2nd Stage heating
W3 3rd Stage heating
X Lockout reset
Y Cooling
Y1 1st Stage cooling
Y2 2nd Stage cooling
Y3 3rd Stage cooling

NOTE: ***Class 2 power sources are generally low voltage and low power. They are not capable of supplying enough power to create a fire hazard or a shock hazard.***

Some manufacturers do not use the letters R, G, Y, and W, but use letters V, F, C, and H. The V terminal stands for voltage and is the same as the R terminal. The F terminal stands for "fan" and is the same as the G terminal. Terminal C stands for "compressor" and is the same as the Y terminal, and the H stands for "heat" and corresponds to the W terminal. A chart illustrating the thermostat terminal identification for different manufacturers is shown in Figure 29–20.

TESTING THE THERMOSTAT

It is possible to perform a simple test to determine if a problem exists in a thermostat. A jumper wire is used to bypass parts of the thermostat. A basic heating and cooling thermostat is shown in Figure 29–21. To perform the test, use a jumper

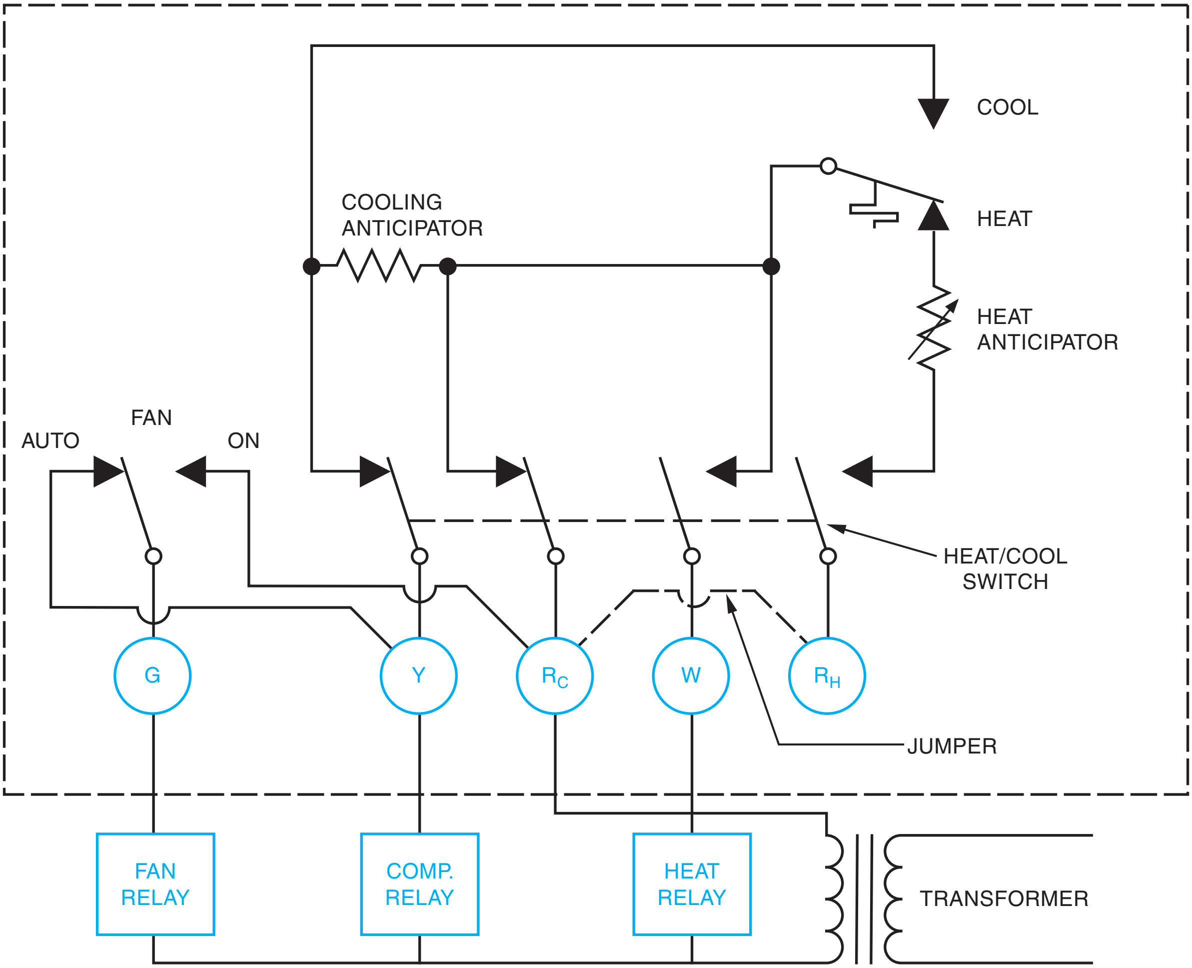


Figure 29–18
Thermostat terminal identification for a common heating/cooling thermostat. (Source: Delmar/Cengage Learning)

wire to make connection from the power input terminal, R_C or R_H to the G, Y, and W terminals one at a time, Figure 29–22. When connection is made from one of the R terminals and the W terminal, the heating relay should energize. When connection is made from one of the R terminals and the Y terminal, the compressor relay should energize, and when connection is made from one of the R terminals and the G terminal, the fan relay should energize.

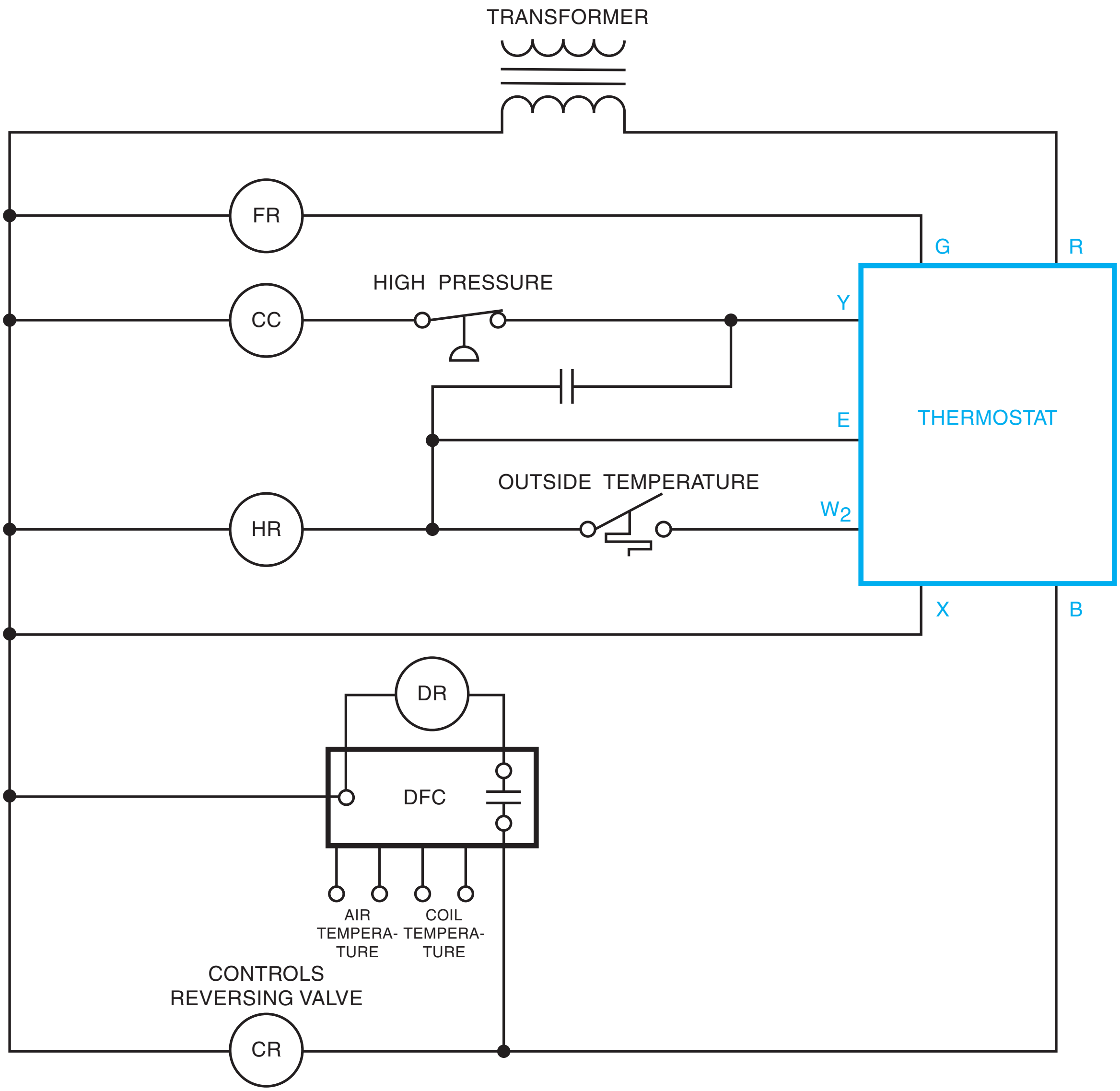


Figure 29–19
Typical thermostat connection for a heat pump. (Source: Delmar/Cengage Learning)

MANUFACTURER	TYPE	COMMON	COOLING	HEATING	FAN
Cam-Stat	T17	R	Y	W	G
Cont. Corp.	360	R	Y	W	G
General	T91	V	C	H	F&G
General	T199	R	Y	W	G
Honeywell	T834	R	Y	W	G
Honeywell	T87	R	Y	W	G
White-Rogers	IF56	R	Y	W	G

Figure 29–20
Typical thermostat markings. (Source: Delmar/Cengage Learning)

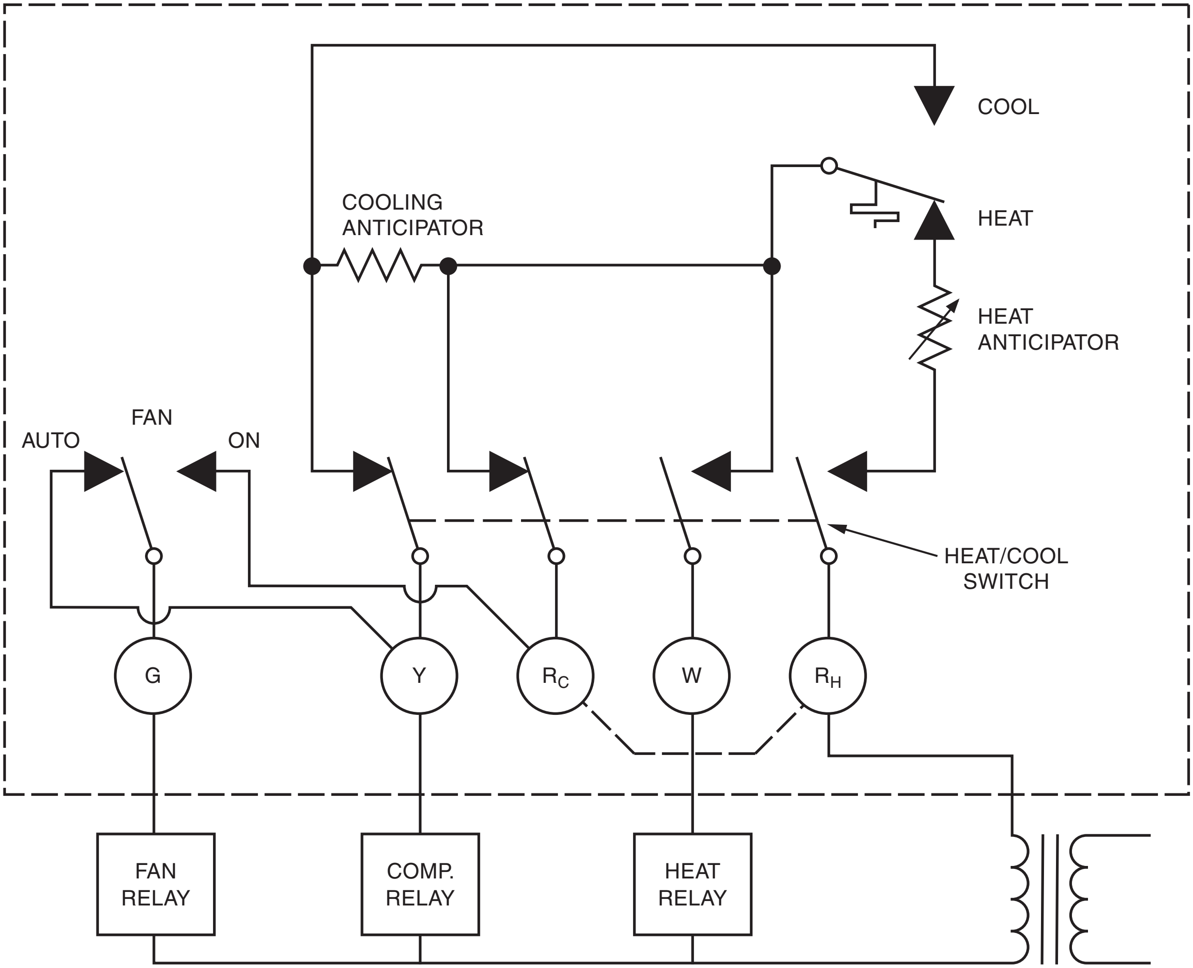


Figure 29–21
Basic heating and cooling thermostat. (Source: Delmar/Cengage Learning)

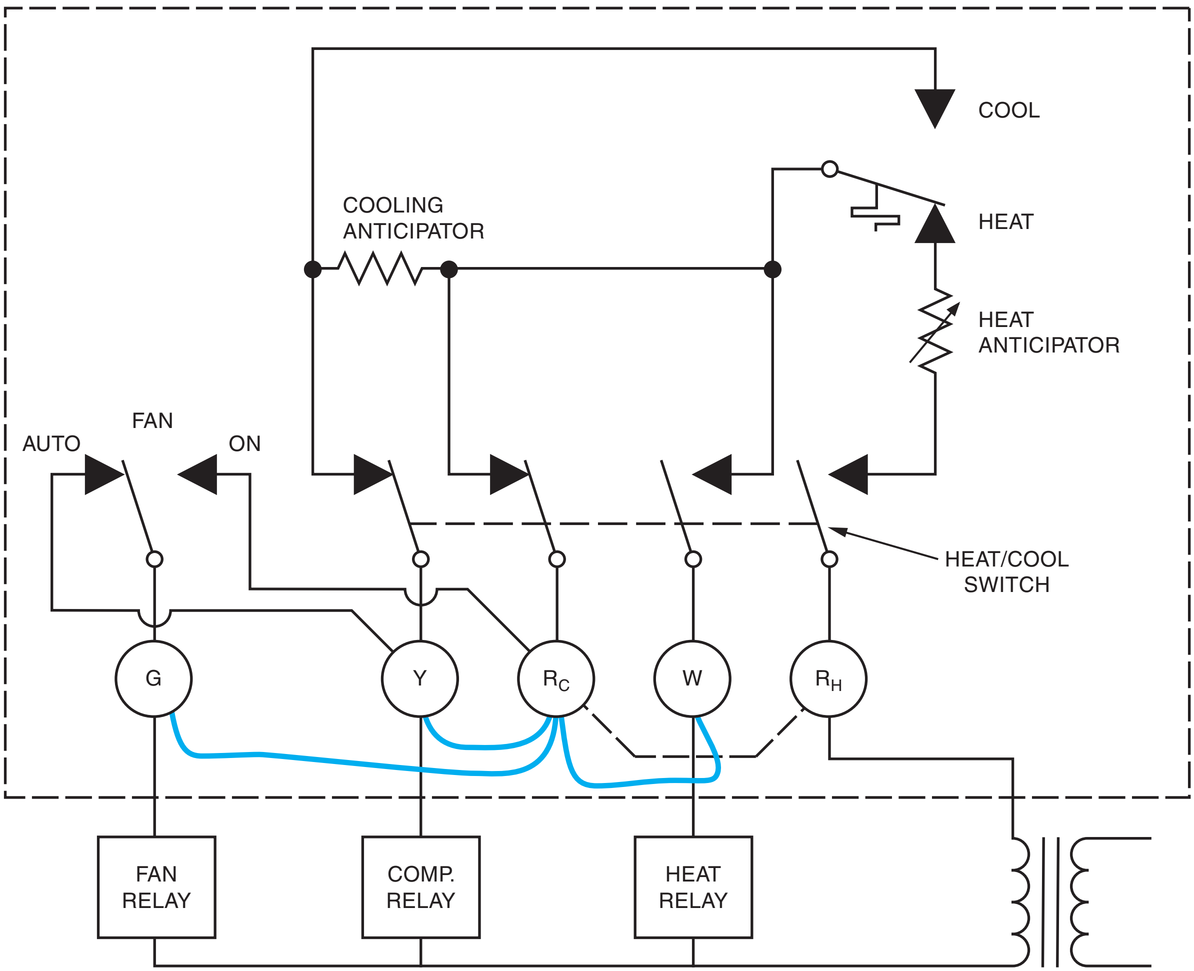


Figure 29–22
Testing a thermostat. (Source: Delmar/Cengage Learning)

SUMMARY

- Thermostats are temperature-sensitive switches.
- Most thermostats are intended to be used on low voltage control systems.
- A bimetal strip is often used to sense the temperature.
- Bimetal strips are generally bent in a spiral and resemble a clock spring. This is done to permit a longer length to fit into a small area.
- Contact thermostats have one stationary contact and one movable contact. The movable contact is attached to the bimetal strip.
- Contact-type thermostats use a small permanent magnet to provide a snap action when the contact opens or closes.

- Mercury-type thermostats operate by enclosing a pool of mercury inside a glass envelope. The glass envelope is attached to a bimetal strip.
- The weight of the mercury provides the snap action for the contacts when they open or close.
- Some thermostats are designed to be used as both a heating and cooling thermostat.
- The heat anticipator is a small resistive heater located near the bimetal strip. Its purpose is to open the contacts before the temperature actually reaches the thermostat setting.
- The cooling anticipator is a small resistive heater located near the bimetal strip of an air conditioning thermostat. It operates when the thermostat contacts are open and causes them to close before the ambient temperature becomes high enough to close the contacts.
- Some thermostats contain a fan switch, which permits the blower fan to be operated independently of the heating or cooling system.
- Line voltage thermostats are made with large contacts and can be used to connect a load to the line.
- Programmable thermostats contain more than one set of contacts and can be set to operate at different temperature settings at different times.
- Staging thermostats contain more than one set of contacts and are generally used with heat-pump systems. The first set of contacts is used to turn on the compressor and the second set of contacts is used to turn on the strip heaters.

KEY TERMS

antifreeze protection
cooling anticipator
contact
differential thermostat
fan switch
heat anticipator
line voltage thermostat
programmable thermostat
staging thermostat
thermostats

REVIEW QUESTIONS

1. What is a thermostat?
2. What is the advantage of an open-contact thermostat?
3. What is the disadvantage of an open-contact thermostat?
4. What is the advantage of a mercury thermostat?
5. What is used to provide a snap action for the contacts in an open-contact type of thermostat?
6. What is used to provide a snap action for the mercury thermostat?

7. What method of sensing temperature is often used with line voltage thermostats?
8. What is a programmable thermostat?
9. What is the advantage of the programmable thermostat?
10. What is a differential thermostat?
11. What are differential thermostats generally used to control?
12. What is antifreeze protection in reference to a differential thermostat?
13. What is the advantage of a low-voltage thermostat over a line voltage thermostat?
14. What is the purpose of the heat anticipator?
15. How is the setting of the heat anticipator generally determined?
16. To what does the G terminal on a typical heating/cooling thermostat connect?
17. Some thermostats contain terminals marked R_C and R_H. What must be done if this thermostat is used for both heating and cooling?
18. A thermostat has a terminal marked C. To what does this terminal connect?

UNIT 30

Pressure Switches

OBJECTIVES

After studying this unit the student should be able to:

- Describe the operation of high-pressure switches
- Describe the operation of low-pressure switches
- Make connection of a high-pressure switch
- Make connection of a low-pressure switch

High- and low-pressure switches are used to sense the amount of pressure in an air conditioning and refrigeration system. They are used to disconnect the compressor from the power line if the pressure should become too high or too low. Most of the pressure switches used for air conditioning are operated by a **bellows**. A tube is attached to one end of the bellows and the other end is connected to the discharge or suction side of the compressor, depending on which type of pressure switch is used.

THE HIGH-PRESSURE SWITCH

Figure 30–1 illustrates the operation of a **high-pressure switch**. The bellows is connected to the discharge side of the compressor via the tube. As the pressure of the system increases, the bellows

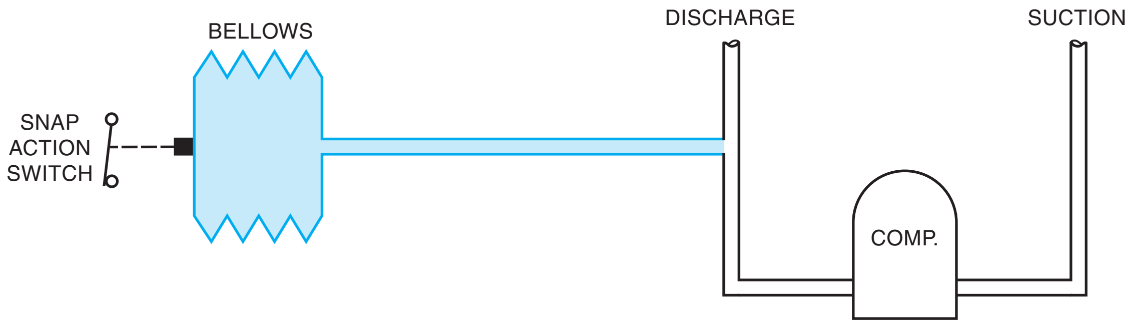


Figure 30–1
Pressure switch connected to sense high pressure. (Source: Delmar/Cengage Learning)

Figure 30–2
The pressure switch opens when the pressure becomes too high.
(Source: Delmar/Cengage Learning)

Figure 30–3
The pressure switch opens when the pressure becomes too low.
(Source: Delmar/Cengage Learning)

expands. The bellows is used to activate a spring-loaded normally closed switch. If the pressure should become too great, the bellows will expand far enough to open the switch. The normally closed pressure switch is connected in series with the compressor circuit shown in Figure 30–2. The pressure switch may be connected in series with the compressor, or in series with the compressor control relay, depending on the type of control circuit.

THE LOW-PRESSURE SWITCH

The **low-pressure switch** is very similar in construction to the high-pressure switch. The low-pressure switch, however, is connected to the low-pressure or suction side of the compressor. The low-pressure switch is used to disconnect the compressor from the circuit if the pressure on the suction side should become too low. Figure 30–3 illustrates this type of circuit. The low-pressure switch is a normally open held-closed switch. The switch is held in the closed position by the pressure of the system. If the pressure should drop low enough, the switch will open and disconnect the compressor from the circuit. As with the high-pressure switch, the low-pressure switch can be used to disconnect the compressor from the line or disconnect the compressor relay, depending on the type of control circuit. A low-pressure switch is shown in Figure 30–4.

Figure 30–4
Low-pressure switch. (Source: Delmar/Cengage Learning)

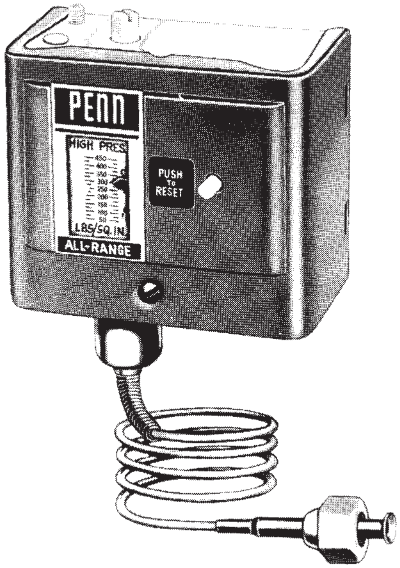


Figure 30–5
Adjustable pressure switch. (Courtesy of Johnson Controls Inc.)

PRESSURE SWITCH SETTINGS				
Type of Refrigerant	High Pressure Cut out	Cut in	Low Pressure Cut out	Cut in
12	275	145	15	35
22	380	300	38	68
500	280	200	22	46

Figure 30–6
Pressure switch settings. (Source: Delmar/Cengage Learning)

CONSTRUCTION

Most of the pressure switches used for commercial or industrial systems are **adjustable**, Figure 30–5. This feature allows the service technician to use the switch on different systems. For example, the pressure settings are different for different types of refrigerant. Figure 30–6 shows a table of common pressure settings for high- and low-pressure switches used with different types of refrigerant.

A **dual-pressure switch** is shown in Figure 30–7. This switch incorporates both high- and low-pressure switches in the same housing. Some manufacturers use a **nonadjustable** type of pressure switch. This switch is commonly found on central units designed for residential use. This type of switch is shown in Figure 30–8. The advantage of this type of switch is that it is inexpensive. When replacing this type of pressure switch, however, it must be matched to the refrigerant system. High- and low-pressure switches are shown in the schematic in Figure 30–9.

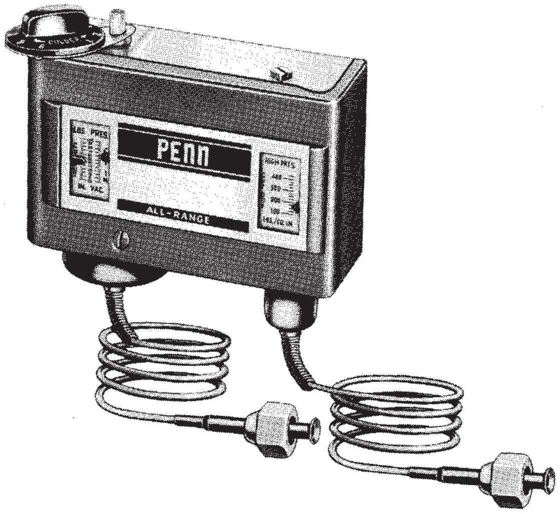


Figure 30–7
Dual pressure switch. (Courtesy of Johnson Controls Inc.)

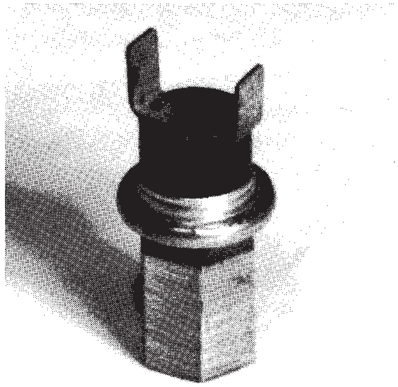


Figure 30–8
Nonadjustable pressure switch. (Source: Delmar/Cengage Learning)

LEGEND	
CMT	CONDENSER MOTOR THERMOSTAT
CAP	CAPACITOR
CC	COMPRESSOR CONTACTOR
CCH	CRANKCASE HEATER
CFM	CONDENSER FAN MOTOR
COMP	COMPRESSOR
EFC	EVAPORATOR FAN CONTACTOR
F	FUSE
RR	RESET RELAY
T	TRANSFORMER
TB	TERMINAL BLOCK
TOP	THERMAL OVERLOAD PROTECTOR
TS	TERMINAL STRIP
EFM	EVAPORATOR FAN MOTOR
LPC	LOW-PRESSURE CONTROL
HPC	HIGH-PRESSURE CONTROL
OL	OVERLOAD PROTECTOR

WARNING
DISCONNECT ELECTRICAL POWER SOURCE TO PREVENT INJURY OR DEATH FROM ELECTRICAL SHOCK

CAUTION
USE COPPER CONDUCTORS ONLY TO PREVENT EQUIPMENT DAMAGE

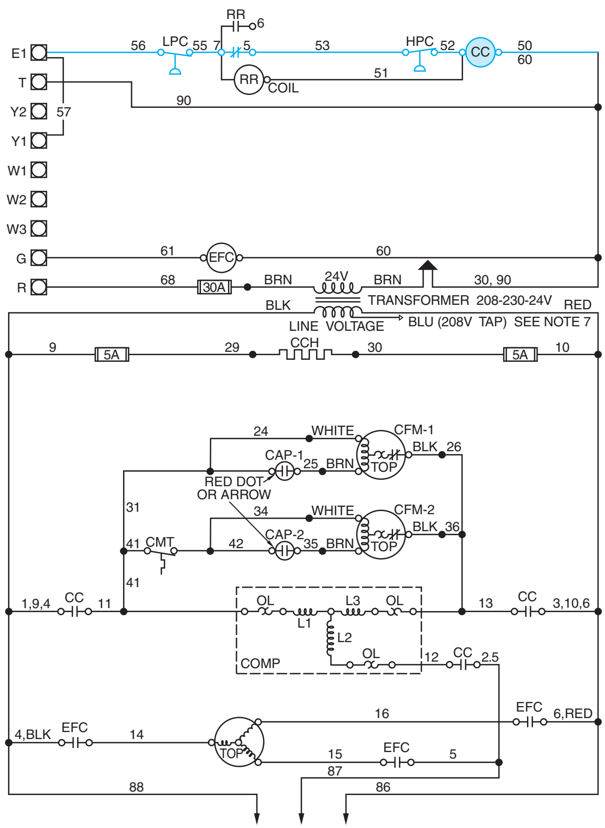


Figure 30–9
High- and low-pressure switches are used to disconnect the compressor contactor. (Courtesy of Trane Corp.)

SUMMARY

- High- and low-pressure switches are used to sense the pressure in an air conditioning and refrigeration system.
- High- and low-pressure switches generally use a bellows, which expands and contracts with a change of pressure. The bellows operates a set of contacts.
- High-pressure switches are normally closed switches that open when the pressure becomes too high. The switch is connected in series with the coil of the compressor relay.
- Low-pressure switches are normally open held-closed switches that open when the pressure drops below a certain level. Low-pressure switches are connected in series with the coil of the compressor relay also.
- Some pressure switches can be adjusted and some cannot.

KEY TERMS

adjustable
bellows
dual-pressure switch
high-pressure switch
low-pressure switch
nonadjustable

REVIEW QUESTIONS

1. What device is used to construct most of the pressure switches used in the air conditioning field?
2. What type of contact is used with a high-pressure switch?
3. What type of contact is used with a low-pressure switch?
4. Where in the refrigerant system is the high-pressure switch connected?
5. Where in the refrigerant system is the low-pressure switch connected?

TROUBLESHOOTING QUESTIONS

Refer to the schematic shown in Figure 30–9 to answer the following questions.

1. Is the compressor in this unit operated by a single-phase or a three-phase motor?
   A. Single-phase
   B. Three-phase
2. In order for the compressor contactor to energize, the thermostat (not shown) must make contact between which terminals?
   A. R and G
   B. R and T
   C. R and E1
   D. R and Y2
3. Are the condenser fan motors single-phase or three-phase?
   A. Single-phase
   B. Three-phase
4. In order to energize the EFC contactor coil, connection should be made between which terminals?
   A. E1 and G
   B. T and G
   C. Y1 and G
   D. R and G
5. Is the evaporator fan motor single-phase or three-phase?
   A. Single-phase
   B. Three-phase

UNIT 31

The Flow Switch

OBJECTIVES

After studying this unit the student should be able to:

- Describe the operation of a flow switch
- Draw the standard NEMA symbol for a flow switch
- Connect a flow switch in a circuit

The type of **flow switch** used in air conditioning systems senses the flow of air instead of the flow of liquid. The flow switch is often referred to as a **sail switch** because it operates on the principle of a sail. The flow switch is constructed from a snap-action microswitch. A metal arm is attached to the microswitch. A piece of thin metal or plastic is connected to the metal arm. The thin piece of metal or plastic has a large surface area and offers resistance to the flow of air. When a large amount of airflow passes across the sail, enough force is produced to cause the metal arm to operate the contacts of the switch. A flow switch is shown in Figure 31–1.

The flow switch is used to give a positive indication that the evaporator or condenser fan is operating before the compressor is permitted to operate. The airflow switch is the only positive method of indicating that the fan is actually in operation. For example, in the circuit shown in Figure 31–2, the thermostat controls the operation of a **control relay (CR)**. When the thermostat closes its contacts, CR coil energizes. This causes all CR contacts to close. When the first CR contact closes, **CFM (condenser fan motor) relay** energizes and starts the condenser fan motor. When the second CR contact closes, **EFM (evaporator fan motor) relay** coil energizes and starts the evaporator fan motor. The third CR contact cannot energize the **compressor relay coil**, however, because it is interlocked with CFM and EFM relays. The compressor relay coil can be energized only after the condenser fan and evaporator fan relay coils have energized.

The idea behind this type of control is to ensure that the compressor cannot be started until both the condenser and evaporator fans are operating. This control circuit, however, does not fulfill that requirement. This circuit does not sense if the fans are actually operating. It does sense if the relay coils, which control those fan motors, are energized. This circuit cannot detect if a fan motor is not operating, or if a belt is broken between the motor and the fan.

The circuit shown in Figure 31–3 has been modified from the circuit in Figure 31–2. Notice in this circuit that the normally open CFM and EFM contacts connected in series with the compressor relay have been replaced with airflow switches **CFS (condenser flow switch)** and **EFS (evaporator flow switch)**. These switches are operated by the force of air created by the condenser fan or the evaporator fan. In this circuit, the compressor can be started only after the condenser and evaporator fans are actually operating. If the circuit is in operation and one of the fans should stop, the compressor

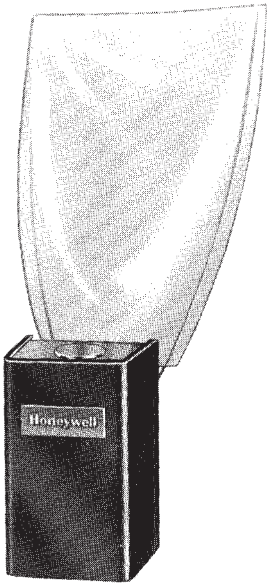


Figure 31–1
Airflow switch. (Courtesy of Honeywell Inc.).

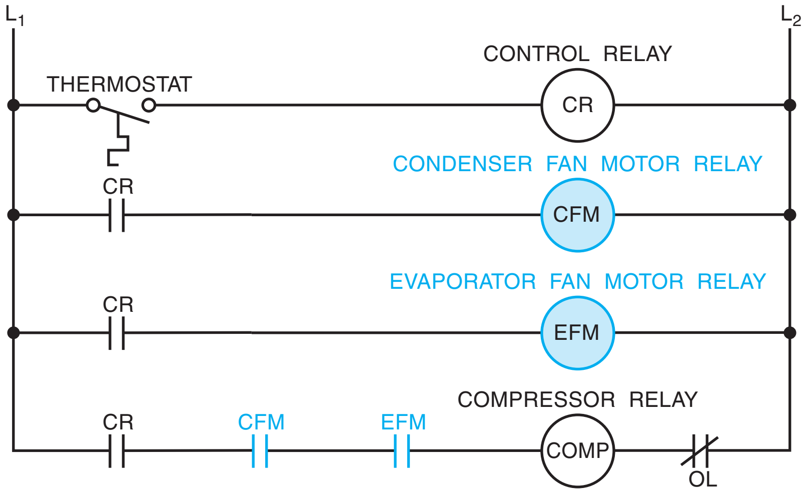


Figure 31–2
Compressor is interlocked with condenser and evaporator fan relays. (Source: Delmar/Cengage Learning)

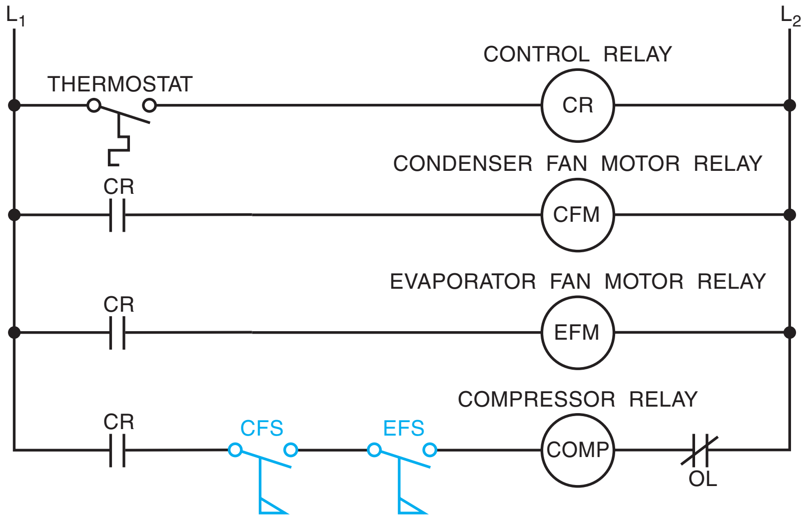


Figure 31–3
Compressor is interlocked with airflow switches. (Source: Delmar/ Cengage Learning)

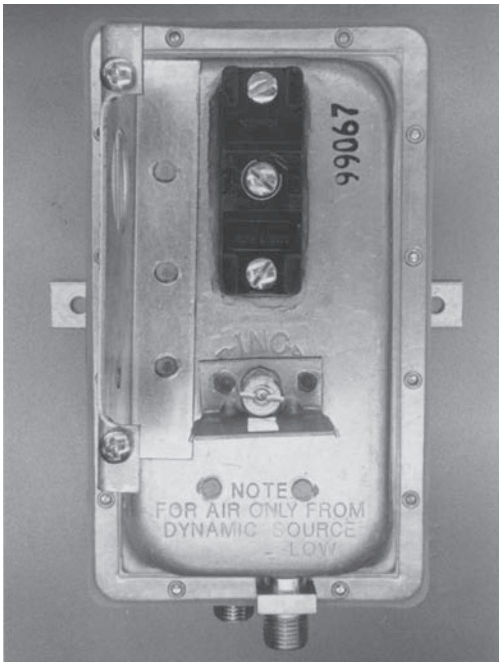


Figure 31–4
Flow switch senses the increase of air pressure inside the duct when the blower is in operation. (Source: Delmar/ Cengage Learning)

relay will be disconnected from the circuit. This will disconnect the compressor motor from the circuit.

Another type of flow switch is shown in Figure 31–4. This switch is actually a pressure switch that detects the increase in air pressure inside the duct when the blower is in operation. The switch can be adjusted for more or less sensitivity. The switch contacts connect in the same manner as shown in Figure 31–3.

SUMMARY

- Some flow switches sense the flow of liquid and some are made to sense the flow of air.
- Airflow switches are sometimes referred to as sail switches.
- Airflow switches are generally used to ensure that air is moving across the evaporator coil before the compressor is permitted to start.
- Flow switch contacts are generally normally open and are connected in series with the coil of the compressor relay.

KEY TERMS

CFM (condenser fan motor) relay
CFS (condenser flow switch)
compressor relay coil
CR (control relay)
EFM (evaporator fan motor) relay
EFS (evaporator flow switch)
flow switch
sail switch

REVIEW QUESTIONS

1. What is a common name for the airflow switch?
2. What function does the airflow switch perform in a circuit?
3. What is interlocking in a control circuit?

UNIT 32

The Humidistat

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of a humidistat
- Discuss how the humidistat is connected into the control circuit
- Connect a humidistat in a circuit

The control of humidity can be very important in some heating and air conditioning systems. Some industries, such as mills that knit polyester and nylon fibers, must maintain a constant humidity because these materials contract and expand with a change of humidity. The control of humidity is also important in heating systems. The amount of humidity in the air has a great effect on the comfort of the living area. If the humidity is to be maintained at a constant level, some device must be used to detect the amount of humidity and then operate some type of control.

The **humidistat** is a device that can sense the amount of humidity in the air and activate a set of contacts if the humidity should become too high or too low. The two most common materials used to sense humidity are **hair** and **nylon**. The materials contract and expand with a change in the amount of humidity in the air. A humidistat using hair as the sense element is shown in Figure 32–1.

If a humidifier is used in a central-heating or air conditioning system, it is generally operated only when the blower is in operation. For this reason, some means is used to interlock the humidifier with the blower. The circuit shown in Figure 32–2 uses a humidistat to control the operation of a solenoid coil. The solenoid coil operates a valve that supplies water to the humidifier. Notice that the solenoid coil is interlocked with an airflow switch. The coil can be energized only when the sail switch indicates there is airflow in the system. Some controls use a combination of a humidistat and a sail switch. Nylon strips are used to sense the amount of humidity in the air and a plastic sail is used to sense the flow of air in the duct.

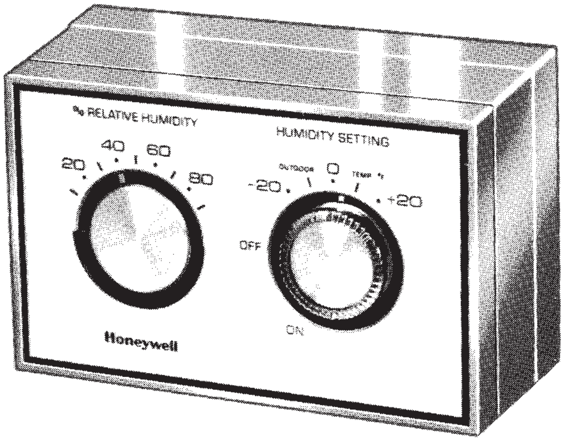
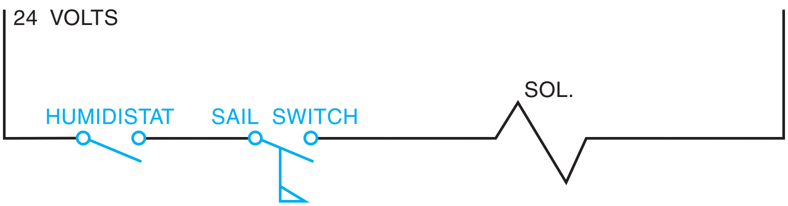


Figure 32–1
Humidistat. (Courtesy of Honeywell Inc.).

Figure 32–2
Humidifier is interlocked with an airflow switch.
(Source: Delmar/Cengage Learning)



SUMMARY

- A humidistat is used to control the amount of humidity in the air.
- The amount of humidity in the air greatly affects the comfort of the living area.
- The humidistat is a device that senses the amount of humidity in the surrounding air and controls a set of contacts.
- The two most common materials used to sense humidity are hair and nylon.
- A humidifier used in a central air conditioning system is generally permitted to operate only when the blower is in operation.

KEY TERMS

hair
humidistat
nylon

REVIEW QUESTIONS

1. What is a humidistat?
2. What are the two most common materials used to sense humidity?
3. What type of control is often used to interlock the humidifier with the blower?

UNIT 33

Fan-Limit Switches

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of a fan-limit switch
- Describe different types of fan and limit switches
- Draw the schematic symbol for a limit switch
- Test a fan or limit switch with an ohmmeter
- Connect a fan-limit switch in a circuit

The blower fan of a heating system is generally not permitted to operate until the heat exchanger reaches a high enough temperature to ensure that cold air will not be delivered into the living area. **Fan switches** are generally operated by a bimetal strip that closes a set of contacts when the temperature of the heat exchanger reaches a high enough level. A fan switch of this type is shown in Figure 33–1. The control shown on the face of the switch is used to determine the temperature at which the fan will turn off. The temperature at which the switch contacts will close is determined by the manufacturer. Longer operation time of the fan will generally increase the overall efficiency of the heating unit because more of the heat is delivered to the living area and less escapes to unheated areas. Some people, however, do not like the cooler air being delivered by the blower at the end of a heating cycle. For this reason, the switch can be set to turn off sooner and prevent this problem.

Some fan switches are designed with large enough contacts to permit them to control the operation of the blower motor without a fan relay. Other fan switches have small auxiliary contacts and are used to control the coil of a fan relay. The circuit in Figure 33–2 shows a fan switch being used to control a blower motor. Notice the schematic symbol is the same as a thermostat. This symbol is used because it is a thermally activated switch.

Another type of fan switch is shown in Figure 33–3. This type of switch does not sense the heat of a heat exchanger to close a set of contacts. This switch is basically a timer. It uses a small resistance heater that is controlled by the thermostat. The heater causes a bimetal strip to bend. When the strip has bent far enough, it closes a set of spring-loaded contacts and connects the motor to the line. A schematic of this relay is shown in Figure 33–4. Notice that this switch has two sections that are isolated from each other. The 24-volt section is connected to the heating element. The 120-volt section is connected to the switch contacts. When connecting this type of fan switch, care must be taken not to connect the terminals to the wrong voltage. The advantage of this type of switch is that it can be used to replace almost any type of thermally operated fan switch because it can be mounted almost anywhere.

Another type of fan switch is shown in Figure 33–5. This switch is used to control the speed of a fan motor as opposed to turning it on or off. This switch is more common to an air conditioning system than a heating system. It is used to control the speed of the condenser fan. Some systems decrease the speed of the condenser fan if the temperature of the condenser drops too low. A low condenser temperature will cause a low head pressure. This switch is basically a single-pole double-throw switch,

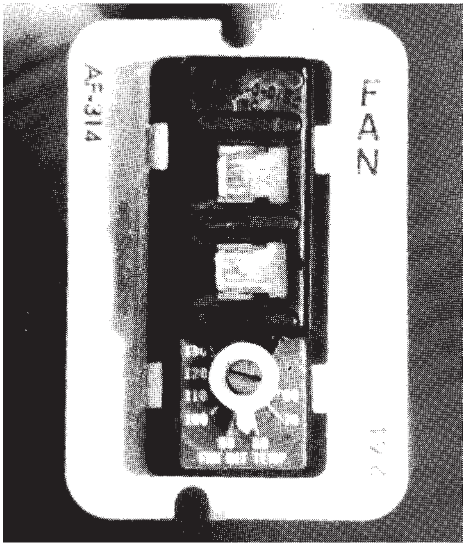


Figure 33–1
Fan switch. (Source: Delmar/Cengage Learning)

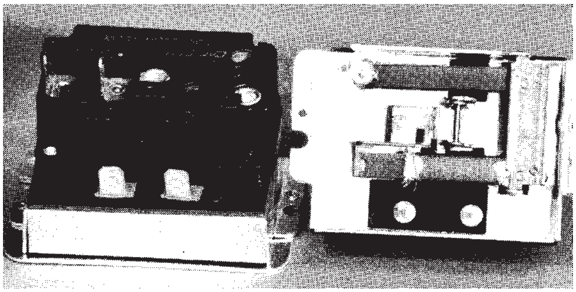


Figure 33–3
Time-delay fan switch. (Source: Delmar/Cengage Learning)

Figure 33–2
Fan switch controls the operation of the motor. (Source: Delmar/Cengage Learning)

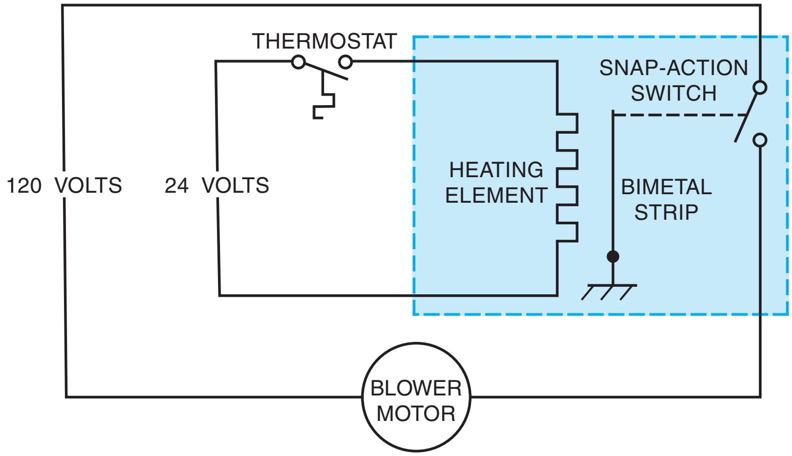


Figure 33–4
Timer used as a fan switch. (Source: Delmar/Cengage Learning)

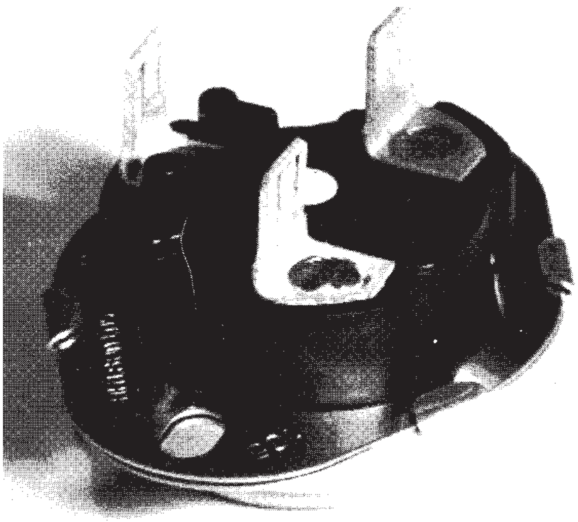


Figure 33–5
Bimetal fan-speed switch. (Source: Delmar/Cengage Learning)

Figure 33–6. When the condenser temperature is low, the motor is connected to low-speed operation. When the condenser temperature increases, the motor is connected for high-speed operation.

LIMIT SWITCHES

One type of **limit switch** is used as a safety cut-off switch for a heating system. Limit switches are generally a bimetal-operated switch. Two types of limit switches are shown in Figure 33–7. Limit switches contain a normally closed contact, which is connected in series with the system control. They are not, however, connected in series with the blower fan, Figure 33–8. Notice that the blower motor can operate independently of the burner control. This permits the blower to cool down the heating unit if the high-limit switch should open and turn the blower off.

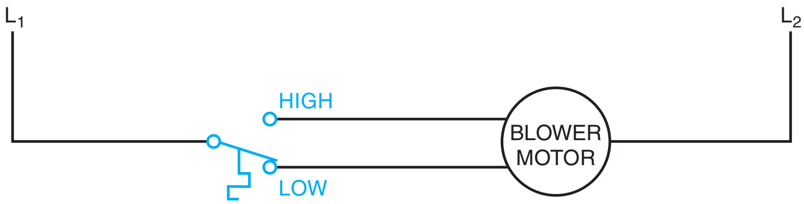


Figure 33–6
Condenser speed-control switch.
(Source: Delmar/Cengage Learning)

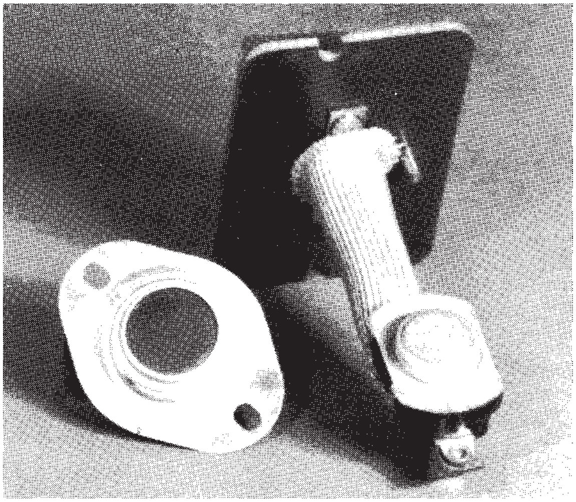


Figure 33–7
High-limit switches. (Source: Delmar/Cengage Learning)

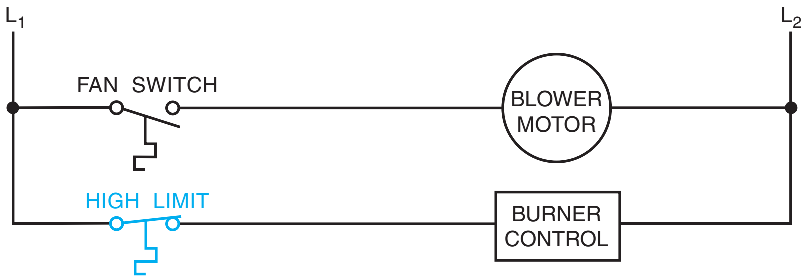


Figure 33–8
Limit switch is connected in series with the burner control. (Source: Delmar/Cengage Learning)

FAN-LIMIT SWITCH

The **fan-limit switch** contains both a fan switch and a high-limit switch in one housing, Figure 33–9. This type of switch uses a bimetal strip formed in the shape of a spiral. When the bimetal is heated, it causes a cam to rotate. When the cam has turned far enough, the normally open fan switch closes and connects the blower fan to the line, Figure 33–10. If the system is operating properly, the blower fan prevents the temperature of the heat exchanger from rising high enough to open the high-limit switch contacts. If the blower fan does not operate, however, the temperature of the heat exchanger will increase enough to open the normally closed limit switch. This will cause the burner to turn off and prevent damage to the heating system.

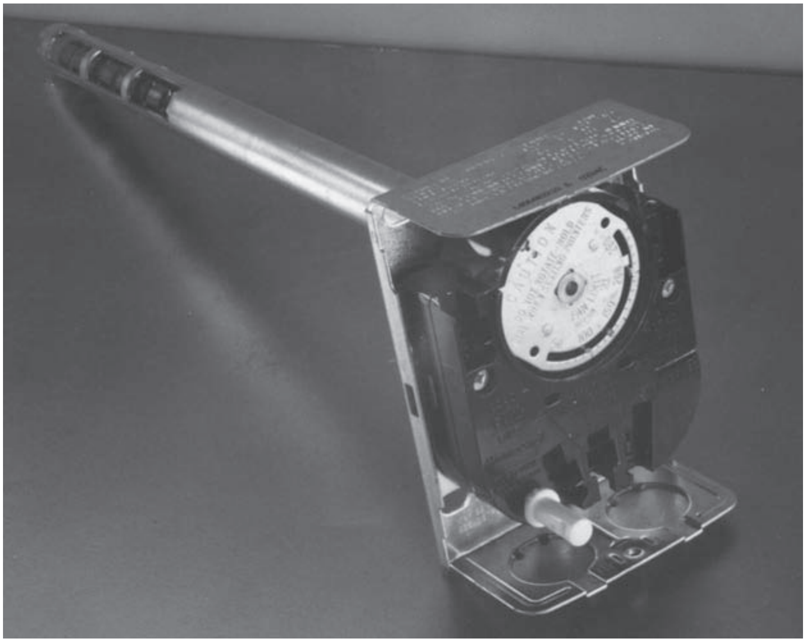


Figure 33–9
Fan-limit switch. (Source: Delmar/Cengage Learning)

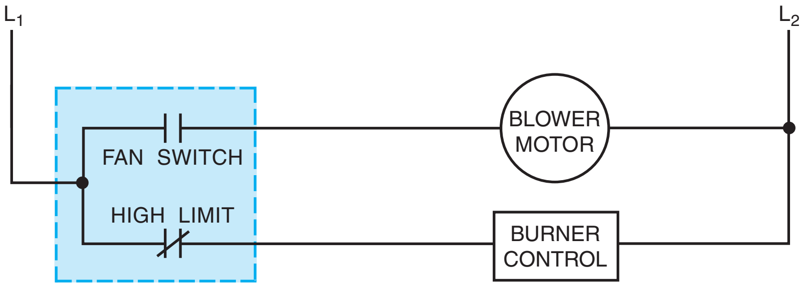


Figure 33–10
Schematic for fan-limit switch.
(Source: Delmar/Cengage Learning)

SUMMARY

- The blower fan of a heating system is generally not permitted to operate until the heat exchanger has reached a high enough temperature.
- Fan switches are generally operated by a bimetal strip that closes a set of contacts.
- Some fan switches can be adjusted to operate longer or turn off sooner.
- Some fan switches are designed with large enough contacts to control the operation of the blower motor without the use of a fan relay.
- Some fan and limit switches are constructed as one unit and others are constructed as separate units.
- Limit switches are generally used to stop the operation of the heating system if the temperature should become too high.

KEY TERMS

fan-limit switch
fan switches
limit switch

REVIEW QUESTIONS

1. Why do some fan switches permit the temperature at which the switch will turn on and off to be set?
2. What type of sensing device do most fan switches use to determine when the temperature is high enough to start the blower fan?
3. What type of contact arrangement is used for switches that control the speed of a condenser fan motor?
4. What is the most common use for a high-limit switch?
5. Why is the blower fan not connected in series with the limit switch?

UNIT 34

The Oil-Pressure Failure Switch

OBJECTIVES

After studying this unit the student should be able to:

- Discuss why the oil-pressure failure switch is necessary on large air conditioning systems
- Discuss differential pressure
- Describe the operation of the time-delay circuit
- Connect an oil-pressure failure switch for operation on a 120- or 240-volt system

Many of the larger air conditioning units use a forced-oil system for the compressor instead of a splash system. When a forced-oil system is used, an **oil-pressure failure switch** is often employed to protect the compressor from insufficient oil pressure. The oil-pressure failure switch actually contains several control functions in the same unit. These functions include a **differential pressure switch**, a timer, and a set of **control contacts**.

THE DIFFERENTIAL PRESSURE SWITCH

The actual oil pressure in a compressor is the difference in pressure between the suction pressure and the discharge pressure of the oil pump. For example, if the suction pressure is 35 psi, and the oil pump discharge pressure is 65 psi, the actual amount of oil pressure in the system is 30 psi (65 – 35 = 30). If the oil-pressure failure switch is to be used to measure the actual oil pressure in the system, it must be able to measure the difference between these two pressures. This is accomplished with a differential pressure switch. Figure 34–1 illustrates the operation of an oil-pressure failure switch. Notice in this illustration that two bellows are employed. One bellows is connected to the suction side of the compressor. The other bellows is connected to the oil pump discharge. If the oil pressure is low, the bellows connected to the suction side of the compressor forces the differential pressure switch to remain closed. If the oil pressure increases high enough above the pressure of the suction line, the oil pressure bellows will provide enough force to overcome the force of the suction line bellows and open the differential pressure switch. Notice that the differential pressure switch remains closed until there is enough oil pressure to open it.

THE TIME-DELAY CIRCUIT

The differential pressure switch is used to control the **time-delay circuit**. The time-delay circuit consists of a **current-limiting resistor**, a resistance heating element, and a bimetal strip. Most oil pressure failure switches are designed to be used on 120- or 240-volt connections. This selection is made possible by the value of the current-limiting resistor. Notice that this resistor is center tapped. If 240 volts is to be applied to the circuit, the full value of the current-limiting resistor is connected in series with the heater. If the circuit is 120 volts, the line is connected to the center tap position of the current-limiting resistor. Because the value of the resistor

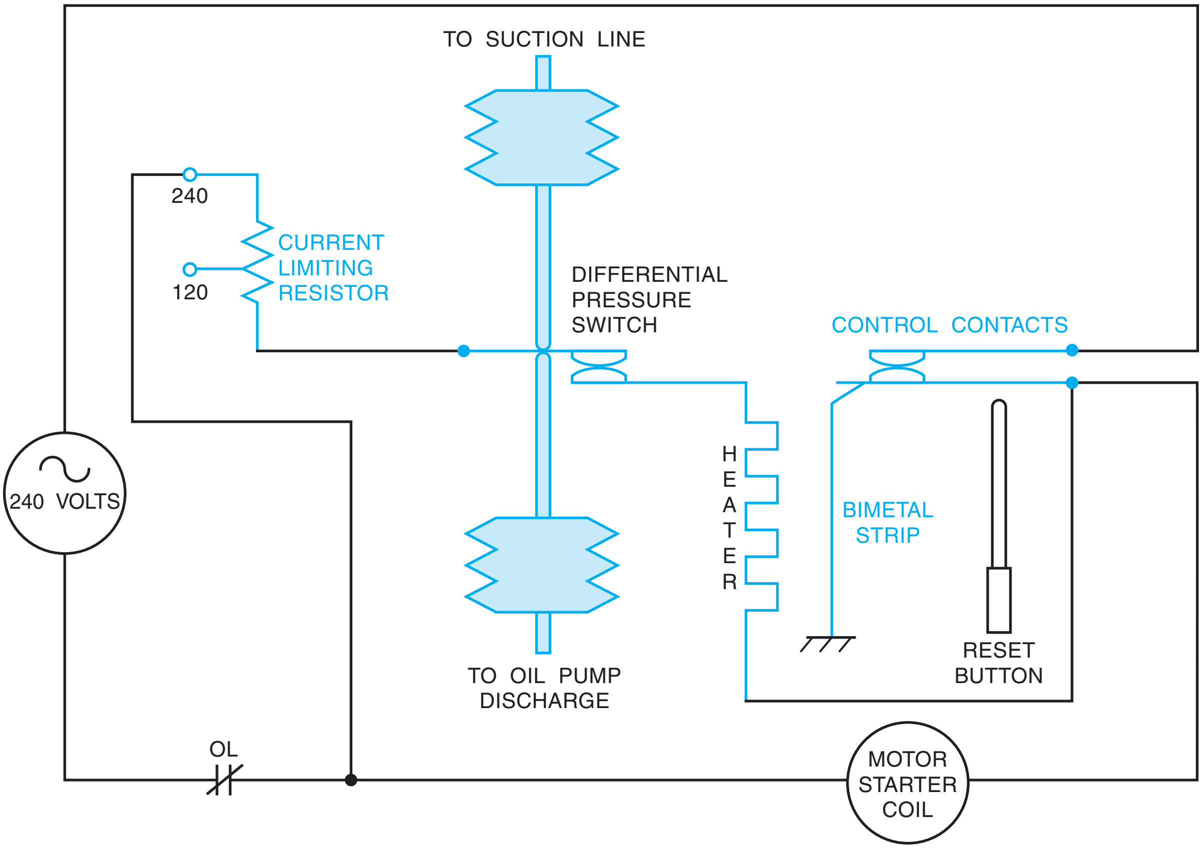


Figure 34–1
Schematic of oil-pressure failure switch. (Source: Delmar/Cengage Learning)

is cut in half for the 120-volt connection, the same amount of current will flow through the heater for either line voltage.

The resistance heater is used to heat the bimetal strip. If the heater is permitted to operate long enough, the bimetal strip will warp away, and the control contact will open. The time-delay circuit is necessary to permit the compressor to operate long enough for oil pressure to build up in the system. When the oil pressure reaches a high enough level, the differential pressure switch opens and disconnects the heater from the circuit. This stops the warping action of the bimetal strip and the control contacts do not open.

THE CONTROL CONTACTS

Notice that the control contacts are connected in series with the motor starter coil to the compressor. If the control contacts should open, the circuit to the motor starter will be broken and the compressor will be disconnected from the line. Notice that the control contacts provide power to the heater of the timer. If the control contacts should open, power cannot be applied to the heater circuit until the contacts are closed. Once the contacts have opened, they must be manually reset by the reset button.

SPECIFICATIONS

The normal usable oil pressure for most reciprocating compressors is generally between 35 and 45 psi. The differential pressure control permits the cut-in and cut-out points to be set. A common setting for this type of switch is cut in at 18 psi and cut out at 12 psi. This means that the differential pressure switch contacts will open when the oil pressure becomes 18 psi greater than the pressure of the suction line and will close when the oil pressure drops to a point that it is only 12 psi above the suction line pressure. The amount of time delay is set by the manufacturer and is generally about 2 minutes. An oil-pressure failure switch is shown in Figure 34–2.

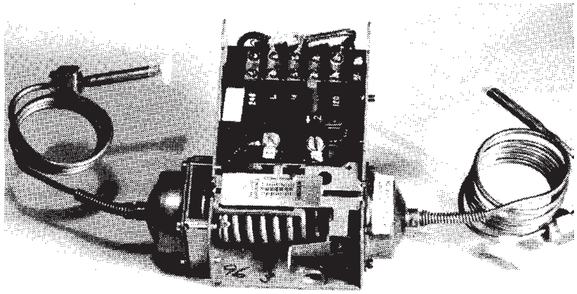


Figure 34–2
Oil-pressure failure switch. (Source: Delmar/Cengage Learning)

SUMMARY

- Many large air conditioning compressors use a forced-oil system instead of a splash system.
- The oil-pressure failure switch is used to protect the compressor from insufficient oil pressure.
- The oil-pressure failure switch senses the difference in pressure between the oil pump and suction pressure of the compressor.
- A time-delay circuit is used to stop the compressor if the oil pressure has not reached a sufficient level within a certain time.
- A current-limiting resistor permits the oil-pressure failure switch to be connected to 120 or 240 volts.
- The control contacts of the oil-pressure failure switch are connected in series with the coil of the compressor starter relay.
- Most reciprocating compressors operate with an oil pressure of 35 to 45 psi.
- Oil-pressure failure switches are generally set to cut in at about 18 psi and to cut out at about 12 psi.

KEY TERMS

control contacts
current-limiting resistor
differential pressure switch
oil-pressure failure switch
time-delay circuit

REVIEW QUESTIONS

1. How can the actual amount of useful oil pressure in a compressor be found?
2. What is the function of the current-limiting resistor?
3. Why is the current-limiting resistor center tapped?
4. Does a high enough oil pressure open the differential pressure switch contacts or close them?
5. What is the function of the heater?
6. Explain the sequence of events that take place if the oil pressure does not become great enough to disconnect the heater circuit.
7. What is the cut-in point?
8. What is the cut-out point?
9. Is the timer circuit connected in series with the motor starter coil?
10. Are the overload contacts connected in series with the motor starter coil?

UNIT 35

Solenoid Valves

OBJECTIVES

After studying this unit the student should be able to:

- Define a solenoid
- Properly connect the inlet and outlet of a solenoid valve
- Describe the operation of a 4-way, or reversing, valve
- Make the proper electrical connections for a solenoid valve

A **solenoid valve** is an electrically operated valve. These valves are used to control the flow of gases or liquids. They range in complexity from a simple on-off valve to 4-way reversing valves used on heat-pump systems. A simple plunger-type of solenoid valve is shown in Figure 35–1. This type of valve is often used to control the flow of gas or liquid in an air conditioning system. The plunger of the solenoid is used to lift the valve off its seat. The valve is held closed by a spring when it is in its normal or deenergized position. When the coil is energized, the plunger lifts the valve off the seat and liquid or gas is permitted to flow from the **inlet** to the **outlet**. When the coil is deenergized, the spring returns the valve to the seat and stops the flow of liquid or gas.

Notice that the valve is marked with an inlet and outlet side. The inlet is connected to the side of the system with the highest pressure. In this way, the

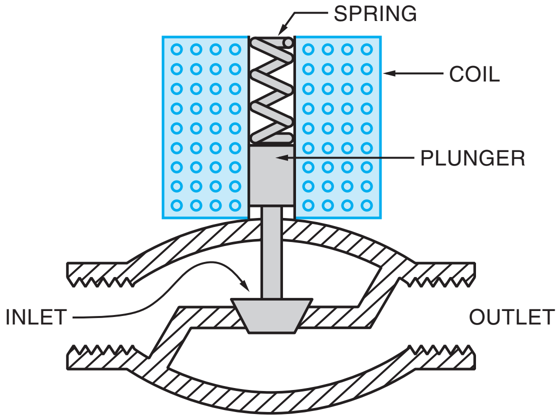


Figure 35–1
Solenoid valve. (Source: Delmar/Cengage Learning)

pressure of the system is used to help keep the valve closed. If the valve should be reversed and pressure applied to the outlet side, the pressure of the system could be enough to overcome the tension of the spring and lift the plunger off the seat. This would cause the valve to leak.

THE REVERSING VALVE

A very common solenoid valve used in the air conditioning field is the **4-way valve** or **reversing valve**. Reversing valves are used to change the direction of flow of refrigerant in a heat-pump system. Figure 35–2 shows the direction of refrigerant flow when the heat-pump unit is in the cooling cycle. Notice that the high-pressure gas leaving the compressor enters the reversing valve. It is then directed to the outside coil being used as the condenser during the cooling cycle. Liquid refrigerant flows from the outside coil to the **metering device** where it is changed to a low-pressure liquid. The low-pressure liquid then enters the inside coil where it attracts heat from the inside air and changes to a gas. It then flows to the reversing valve. The reversing valve directs the flow to the accumulator and back to the compressor.

If the unit is now to be used for heating, the flow of refrigerant must be reversed through the system, Figure 35–3. Notice that the flow of hot, high-pressure gas is still from the discharge side of the compressor to the reversing valve. In this example, however, the flow of high-pressure gas is directed to the inside coil, which is now being used as the condenser. Liquid refrigerant leaves the inside coil and flows to the metering valve. The refrigerant is changed into a low-pressure liquid after going through the metering valve and flowing to the outside coil. Heat is then added to the liquid from the surrounding outside air. The gas then flows to the reversing valve, the accumulator, and back to the suction line of the compressor.

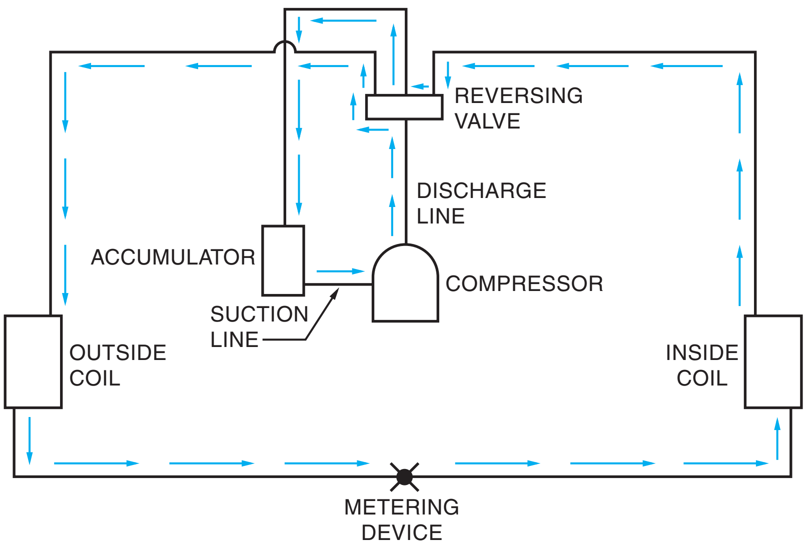


Figure 35–2
Refrigerant flow during the cooling cycle. (Source: Delmar/Cengage Learning)

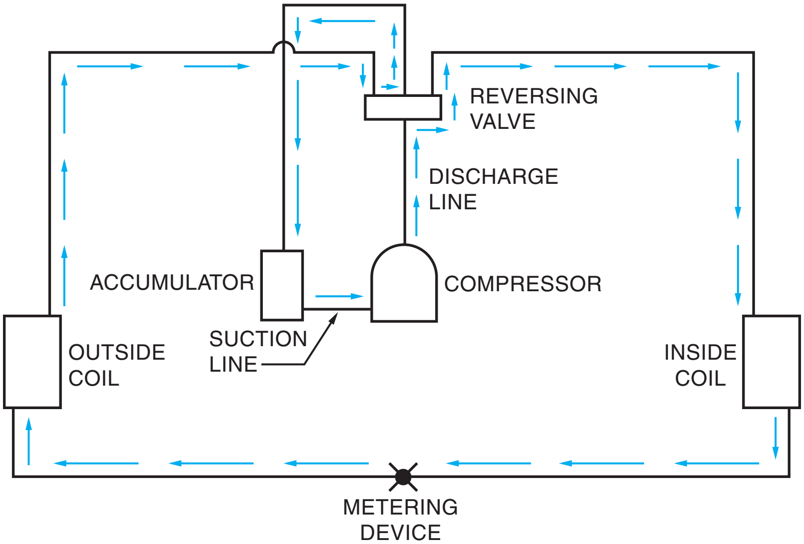


Figure 35–3 Refrigerant flow during the heating cycle. (Source: Delmar/Cengage Learning)

Notice in both examples that the direction of refrigerant flow from and to the compressor is the same. The reversing valve was used to change the direction of flow.

REVERSING VALVE OPERATION

The 4-way reversing valve is actually two valves that operate together. There is a main valve that actually controls the flow of refrigerant in the system, and a **pilot valve** that controls the operation of the main valve, Figure 35–4. The force needed to operate the main valve is provided by the compressor. The valve shown in Figure 35–4 has a sliding valve body that is used to control the flow of refrigerant through the system. In the illustration shown, the system is being used in the cooling cycle. Notice that on each side of the valve there is a small passage called an **orifice**. The orifice provides a path for a very small amount of refrigerant to flow. Notice also that there is a small capillary tube connected from each end of the valve body to the pilot valve and a third capillary tube connected from the pilot valve to the suction line of the compressor. In the position shown, the plunger of the pilot valve is blocking the capillary from the left side of the main valve body. The capillary tube connected to the right side of the main valve is connected to the suction side of the compressor through the pilot valve. With the plunger of the pilot valve in this position, a high pressure is formed on the left side of the main valve and a low pressure is formed on the right side. The high pressure created on the left side of the main valve forces the main valve to slide to the right. With the main valve in this position, the discharge line of the compressor is connected to the outside coil and the inside coil is connected to the suction side of the compressor.

If the **solenoid coil** is energized, the plunger of the pilot valve will change to the position shown in Figure 35–5. The plunger now blocks the capillary tube connected to the right side of the main valve body. The capillary tube connected on the left side of the main valve is now connected to the suction line of the compressor through the pilot valve. This causes a high pressure to be created on the right side of the main valve and a low pressure on the left side. The high pressure forces the main valve to slide to the left. When the reversing valve is in this position, the discharge side of the compressor is connected to the inside coil and the suction line is connected to the outside coil. The unit is now in the heating cycle.

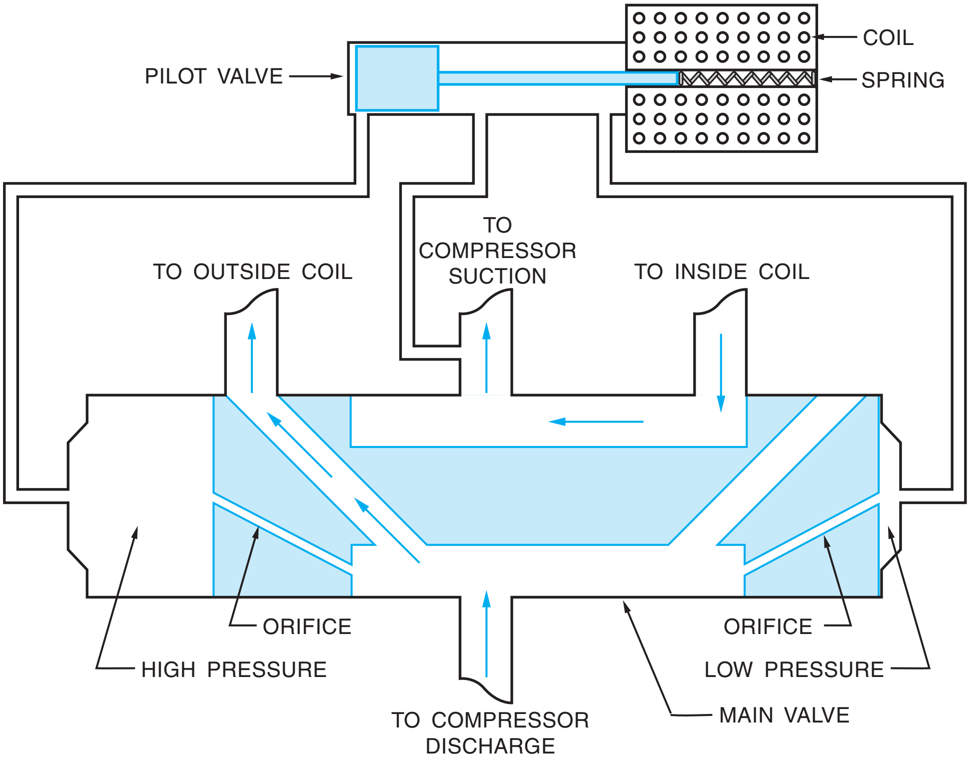


Figure 35–4 Reversing valve set for the cooling cycle. (Source: Delmar/Cengage Learning)

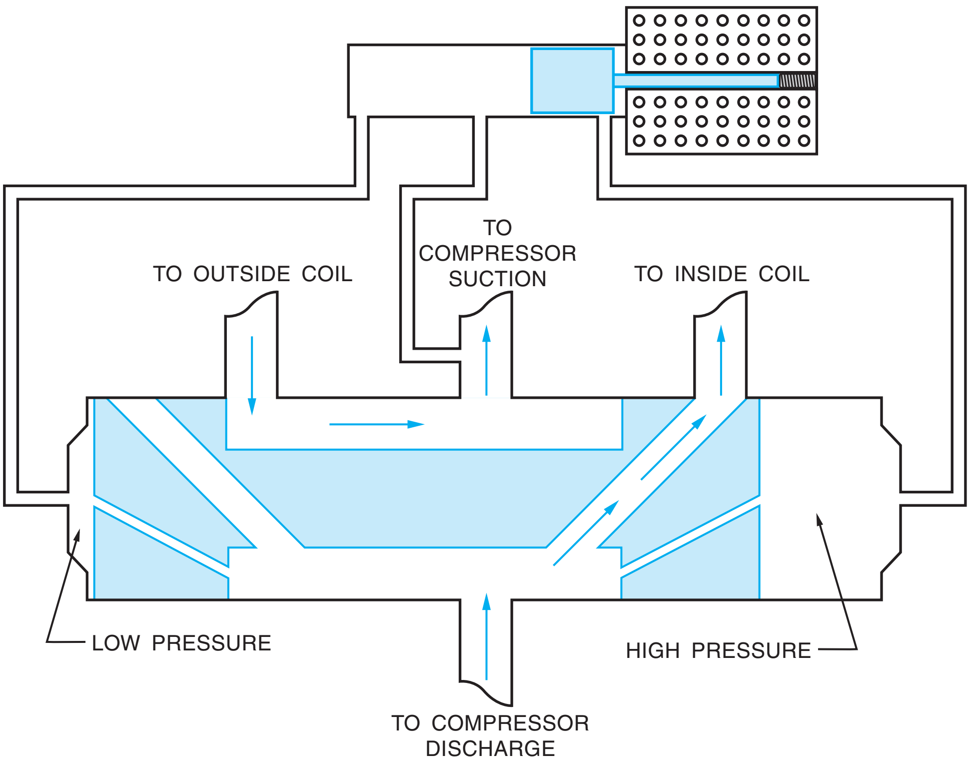


Figure 35–5 Reversing valve set for the heating cycle. (Source: Delmar/Cengage Learning)

The valve illustrated in this example shows the valve is in the cooling cycle when the solenoid is deenergized and in the heating cycle when energized. This has been standard for many years for heat-pump systems. Now, however, some manufacturers are reversing this procedure. Some reversing valves are made in such a manner that when the valve is deenergized the unit is in the heating cycle. This was done so that valve failure would result in the unit being in the heating cycle. It is felt that heat is necessary to life while air conditioning is not. A 4-way reversing valve is shown in Figure 35–6.

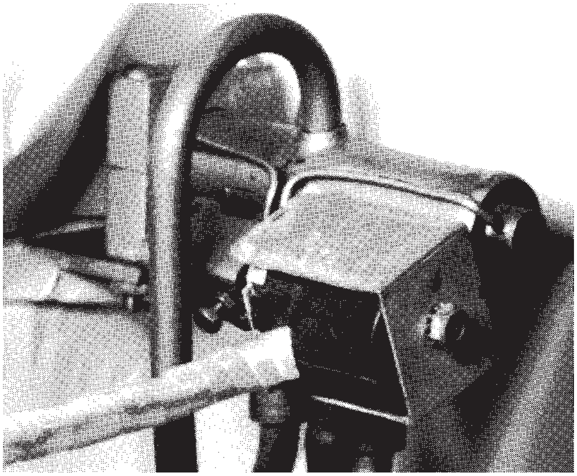


Figure 35–6
Reversing valve. (Source: Delmar/Cengage Learning)

SUMMARY

- A solenoid valve is an electrically operated valve.
- The inlet and outlet side of a valve should never be reversed.
- Four-way valves are used to reverse the flow of refrigerant in a heat pump system.
- Reversing valves are actually two valves that operate together.
- The solenoid coil of a 4-way valve actually operates a pilot valve that is used to operate the main valve.
- The force needed to operate the main valve is provided by the compressor.

KEY TERMS

4-way valve
inlet
metering device
orifice
outlet
pilot valve
reversing valve
solenoid coil
solenoid valve

REVIEW QUESTIONS

1. What is a solenoid valve?
2. Why is it important not to reverse the connection of the inlet and outlet side of a solenoid valve?
3. What is used to cause the plunger to close when the solenoid coil is deenergized?
4. What is the function of a 4-way reversing valve?
5. What is the function of the pilot valve?
6. What is the function of the main valve?
7. What is actually used to change the position of the main valve from one setting to another?

UNIT 36

The Short-Cycle Timer

OBJECTIVES

After studying this unit the student should be able to:

- Define the condition known as short cycling
- List reasons that short cycling occurs
- Describe the construction of a short-cycle timer
- Describe the circuit operation of a short-cycle timer
- Connect a short-cycle timer in the circuit

Short cycling is a condition that occurs when the compressor is restarted immediately after it has been turned off. This causes the compressor to restart against a high head pressure. Trying to restart a compressor in this manner can cause damage to the compressor, motor winding, or at the very least, open a circuit breaker or overload relay. After a compressor has been turned off, enough time should be permitted to pass to allow the pressure in the system to equalize before it is restarted.

CAUSES OF SHORT CYCLING

Short cycling can be caused by several situations. For example, a loose thermostat wire can cause a bad connection that will cause the compressor to alternately start and stop. A momentary interruption of the power line can cause the compressor to stop and then restart when power is restored. People can also cause short cycling. Assume, for example, that the air conditioning system is in operation. Now assume that someone changes the thermostat setting and causes the thermostat contact to open and stop the compressor. Now assume that the person changes his mind and again changes the thermostat so that the compressor tries to restart. Regardless of the reason or causes of short cycling, it should be avoided whenever possible.

THE SHORT-CYCLING TIMER

The **short-cycling timer** is a cam-operated, motor driven, on-delay timer. A photograph of a short-cycling timer is shown in Figure 36–1. This timer is used in conjunction with a relay generally referred to as a holding relay. The timer contains a set of double-pole double-throw contacts (DPDT). A basic schematic of a short-cycling timer circuit is shown in Figure 36–2. Notice the two sets of double-throw contacts labeled A and B. The dashed line

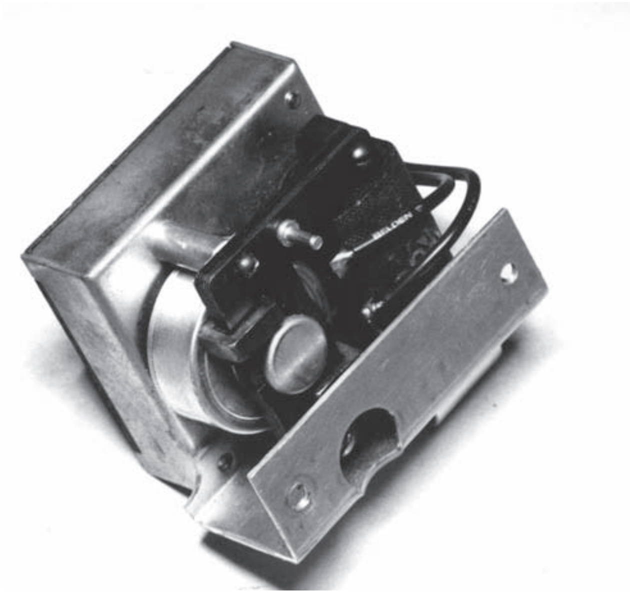


Figure 36–1
Short-cycling timer. (Source: Delmar/Cengage Learning)

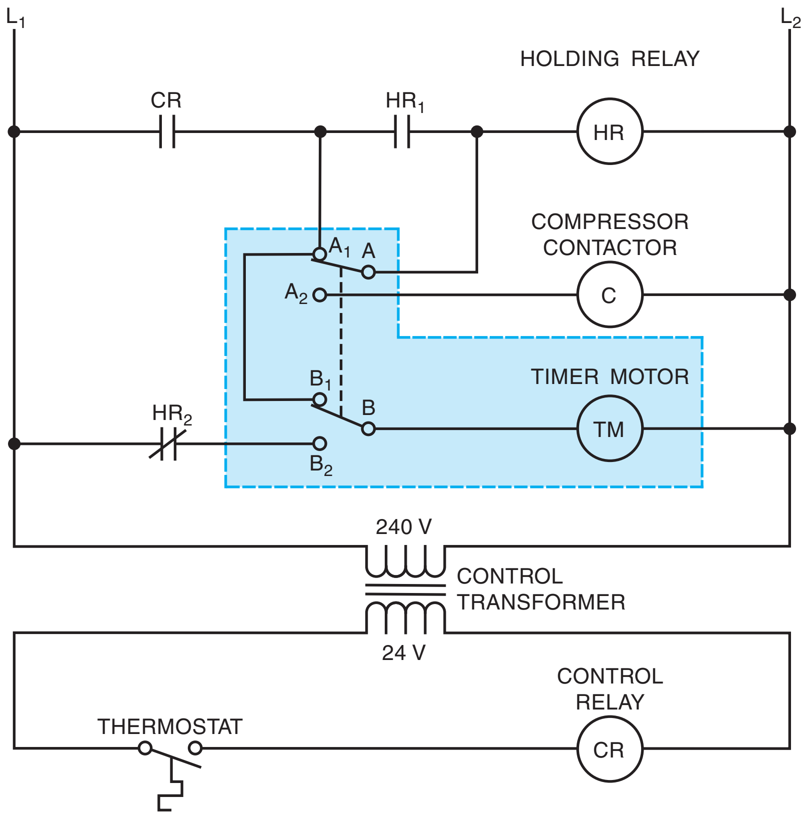


Figure 36–2
Basic schematic of a short-cycle timer circuit. (Source: Delmar/Cengage Learning)

between the contacts indicates mechanical connection so that they operate together. Notice also the holding relay labeled HR. The circuit is controlled by the operation of the thermostat.

CIRCUIT OPERATION

To understand the operation of this circuit, refer to the schematic shown in Figure 36–3. The arrows indicate the paths for current flow. Notice there is a path from line L1 through the primary of the control transformer and back to L2. This provides 24 volts for the operation of the control circuit. When the thermostat contacts close, a circuit is provided through the coil of the control relay (CR). This causes contact CR to close and provides a current flow path to the short-cycle timer. Notice there are two paths of current flow at the timer. The current enters the A1 terminal and flows to the B1 contact terminal. The current can then flow through the contact to terminal B and then to the **timer motor**. There is also a current path from terminal A1 to A. The current can then flow from A to the **holding relay (HR)**.

The holding relay energizes and changes both HR contacts as shown in Figure 36–4. The now closed HR 1 contact is used as a holding contact. Notice that current is also flowing through the timer motor. The timer motor is geared to permit a delay of about 3 minutes before the contacts change position.

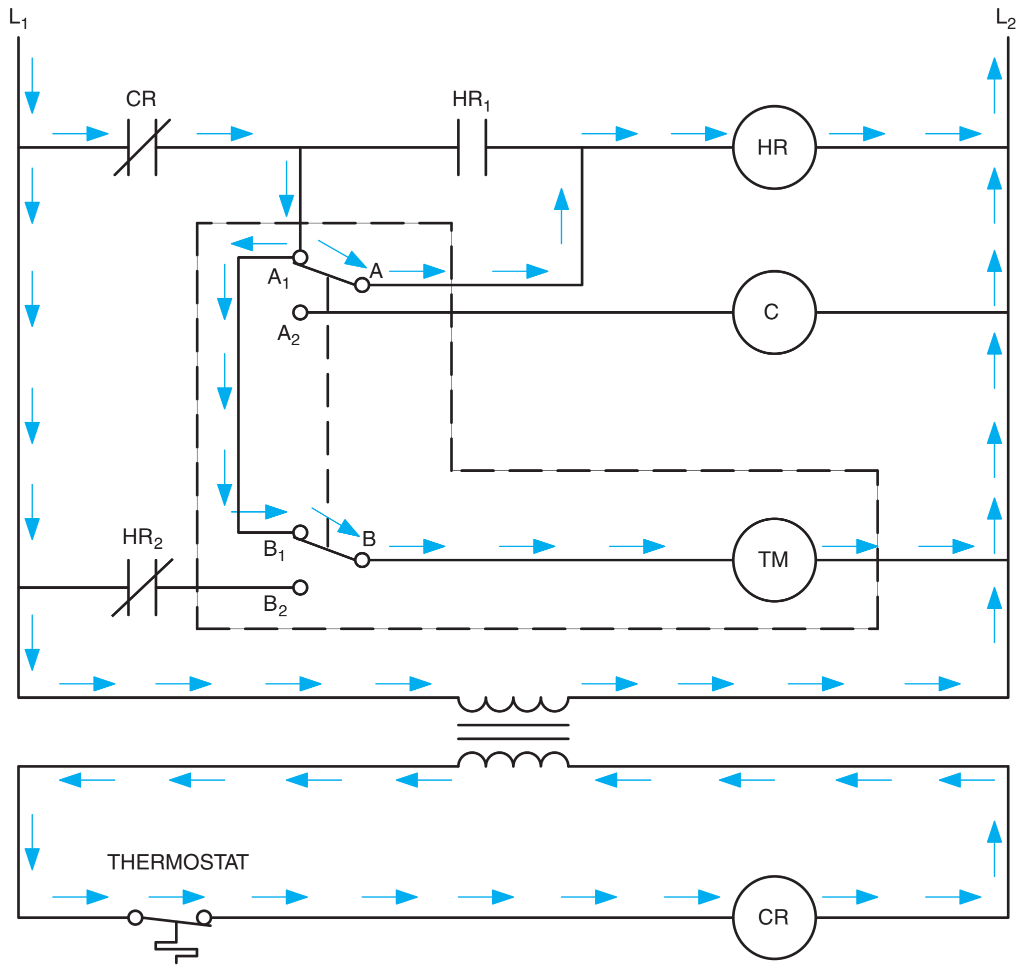


Figure 36–3
The thermostat energizes the control relay. (Source: Delmar/Cengage Learning)

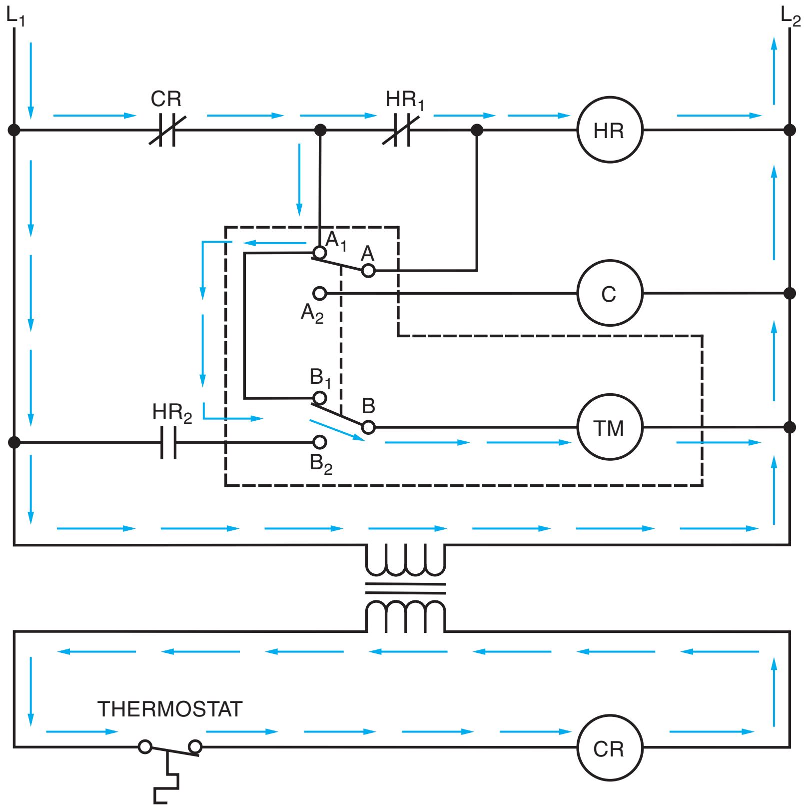


Figure 36–4 The holding relay and the timer motor are energized. (Source: Delmar/Cengage Learning)

Figure 36–5 illustrates the operation of the circuit when the timer contacts change position. Notice that current now flows through the closed CR contact and the closed HR contact to contact A. Current can now flow to contact A2 and then to the compressor contactor. When the compressor contactor energizes, it connects the compressor to the line. Notice that contact B2 is connected to the now open HR2 contact. Because there is no current flow to the timer motor, the timing operation is stopped for as long as the thermostat maintains a circuit to CR relay.

After the thermostat has been satisfied, it will reopen and deenergize CR relay coil. This causes CR contact to open and deenergize HR relay coil. When HR relay deenergizes, HR2 contacts will again close and current flow is provided through the B2 and B contact to the timer motor, Figure 36–6. The timer motor now operates and resets the contacts to their original position as shown in Figure 36–2. The circuit is now ready for another operation sequence. If the thermostat momentarily opens and then recloses, or if there is a momentary loss of power, the holding relay will deenergize and the timer will have to time out before the compressor can be reconnected to the line. About 1 minute is required for the timer to reset.

ELECTRONIC SHORT-CYCLE TIMERS

Many short-cycle timers use electronic components to affect a time delay. These units are relatively simple to install and set. All logic functions are contained within the timer, eliminating the need for a holding relay. Electronic short-cycle timers can be obtained that operate as **delay-on-make** or as **delay-on-break**.

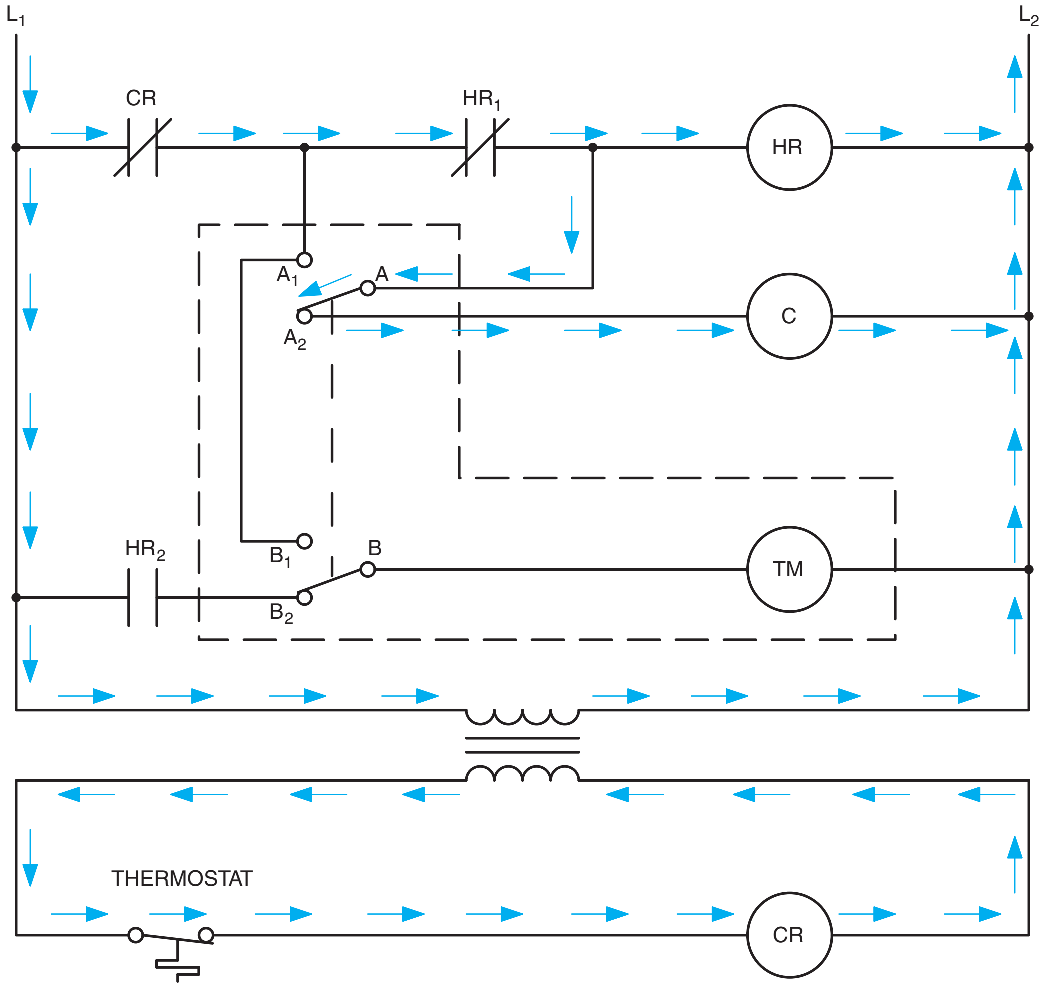


Figure 36–5
The compressor contactor energizes when the timer contacts change position. (Source: Delmar/Cengage Learning)

The Delay-on-Make Short-Cycle Timer

Delay-on-make timers are basically on-delay timers. They connect in series with the coil of the compressor contactor, Figure 36–7. When the thermostat contacts close and apply power to the timer, the timer starts timing for the period of time set on the timer. After the time delay period, power is applied to the coil of the compressor contactor and the compressor starts. The delay-on-make timer is not as popular as the delay-on-break timer because the delay-on-make timer will not permit the compressor to start when the thermostat contacts are first closed. A delay-on-make short-cycle timer is shown in Figure 36–8.

The Delay-on-Break Short-Cycle Timer

The delay-on-break short-cycle timer begins its timing sequence when the thermostat contacts open instead of close. This permits the delay-on-break timer to start the compressor instantly when the

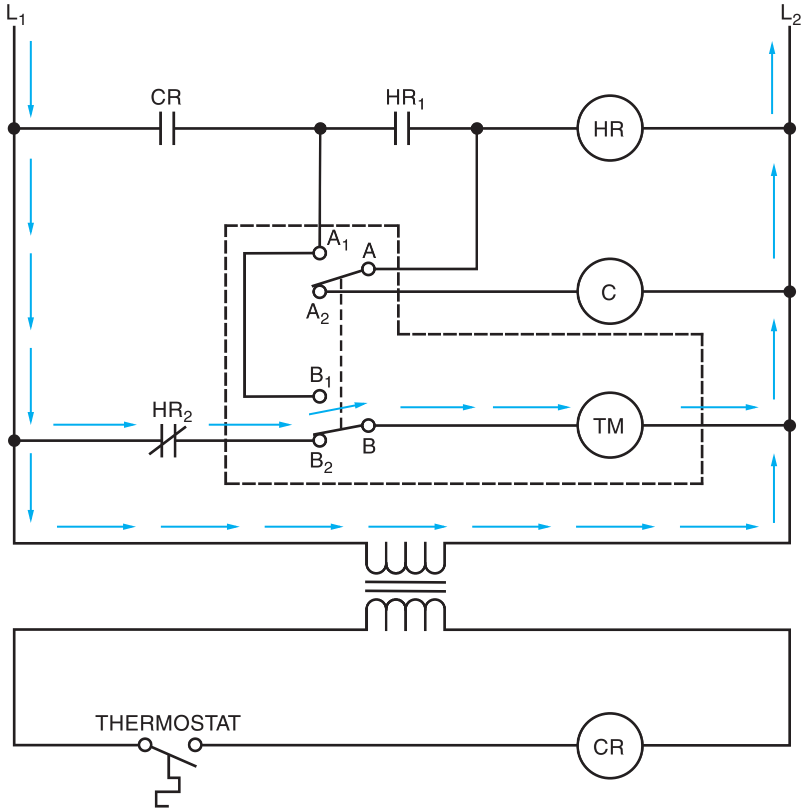


Figure 36–6
When the thermostat deenergizes, current is provided to the timer motor to reset the contacts.
(Source: Delmar/Cengage Learning)

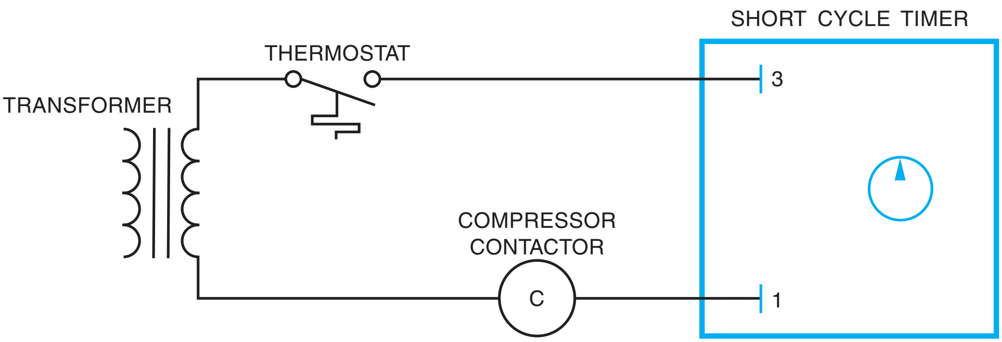


Figure 36–7
Delay-on-make short-cycle timer connection. (Source: Delmar/Cengage Learning)

thermostat contacts close. If the power is interrupted, the timer must time out before power can be reapplied to the compressor contactor. The delay-on-brake short cycle time has three connection terminals instead of two, Figure 36–9. A delay-on-break short-cycle timer is shown in Figure 36–10.

Line Monitors and Short-Cycle Timers

Some electronic controls combine more than one function in a single unit. The control shown in Figure 36–11 is a combination line monitor and

Figure 36–8
Delay-on-make short-cycle timer. (Source: Delmar/Cengage Learning)

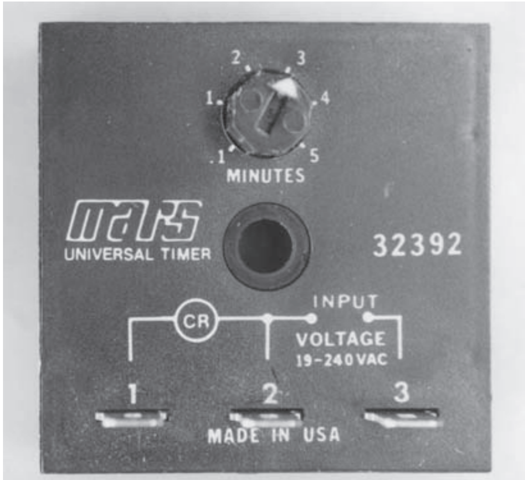


Figure 36–10
Delay-on-break short cycle timer. (Source: Delmar/Cengage Learning)

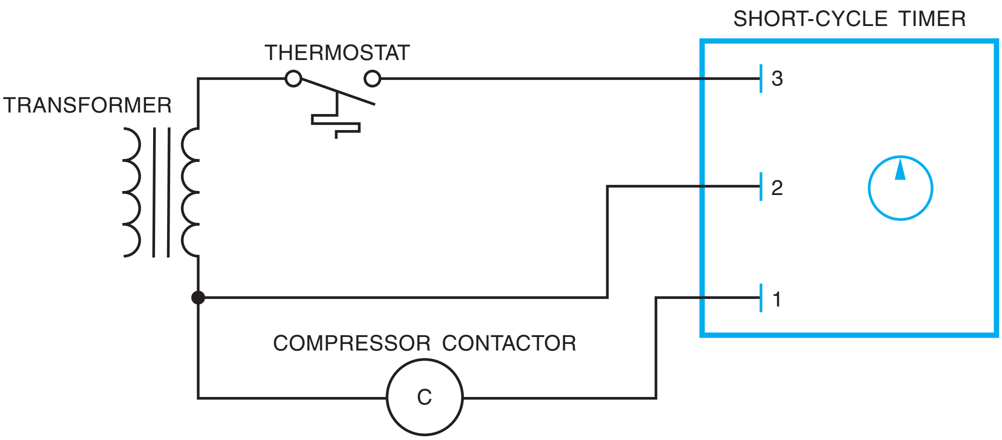


Figure 36–9
Delay-on-break short-cycle timer connection. (Source: Delmar/Cengage Learning)

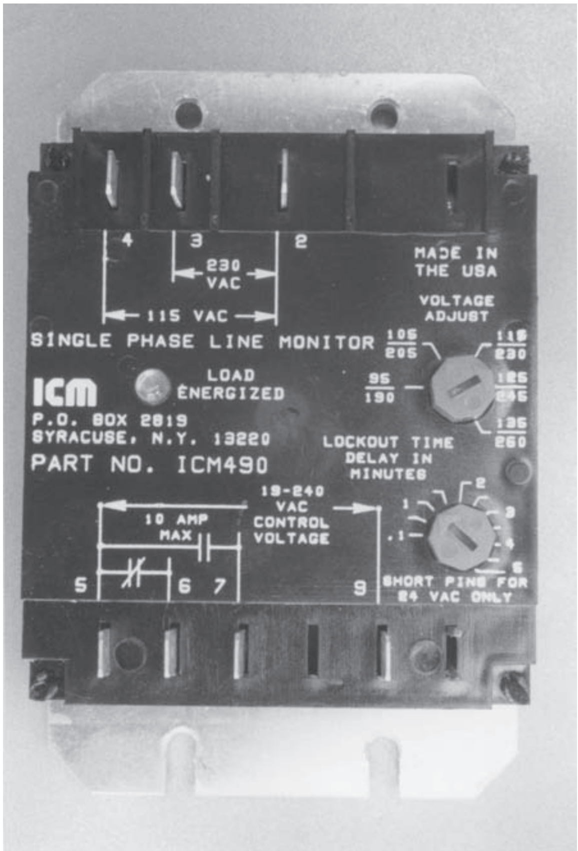


Figure 36–11
Single-phase line monitor and short-cycle timer.
(Source: Delmar/Cengage Learning)

short-cycle timer for a single-phase unit. The control monitors the line voltage for a high or low condition. A 5-second time delay is built into the unit in the event a voltage fault is encountered. This prevents the control from opening the circuit to the coil of the compressor contactor in the event of a momentary line fluctuation that can occur as a result of a heavy load being connected to the power line. The voltage drop due to the starting of a large motor is a good example of a momentary voltage fluctuation.

This control also acts as a short-cycle timer. There are two control knobs on the control unit. One is set to the line voltage value the control is connected to and the other sets the delay time of the short-cycle timer. Voltage values of 95 to 135 volts AC or 190 to 260 volts AC can be selected. Control voltage can range from 18 to 240 volts AC. A schematic connection diagram for this control is shown in Figure 36–12.

A three-phase line monitor and short-cycle timer control is shown in Figure 36–13. This unit performs the same basic function as the single-phase unit except that it monitors three line voltages. Like the single-phase control, the three-phase control has settings for different voltage ranges and delay times for the short-cycle timer.

Another three-phase line monitor is shown in Figures 36–14A and 36–14B. This monitor does not provide short-cycle protection. Its function is

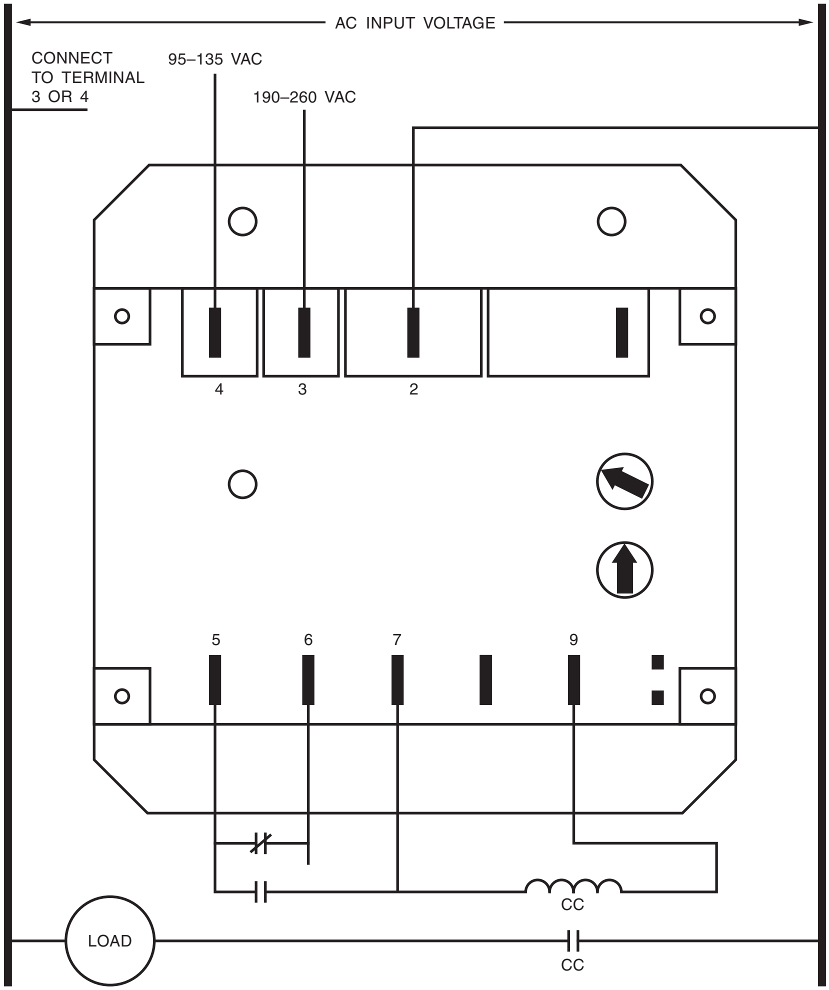


Figure 36–12
Connection for a single-phase line monitor and short-cycle timer.
(Source: Delmar/Cengage Learning)

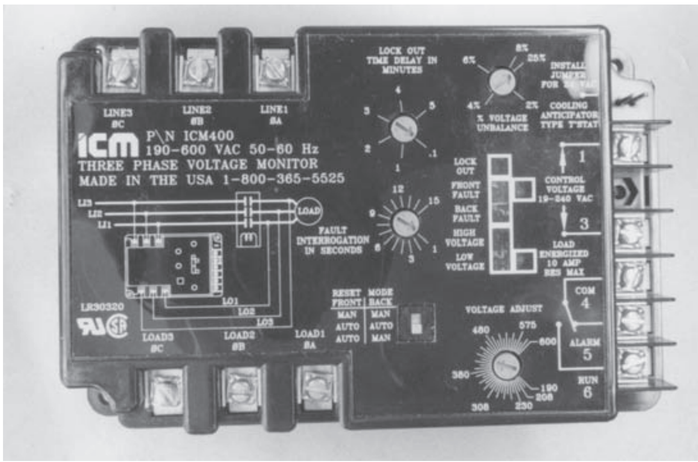


Figure 36–13
Three-phase line monitor and short-cycle timer. (Source: Delmar/Cengage Learning)

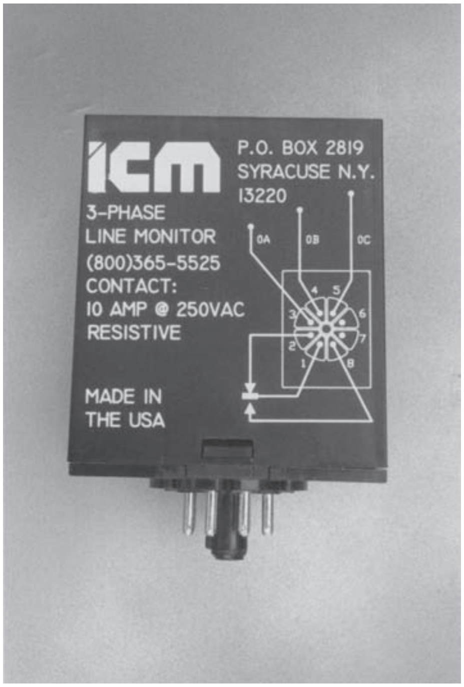


Figure 36–14A
The monitor is designed to plug into an eight-pin tube socket. (Source: Delmar/Cengage Learning)

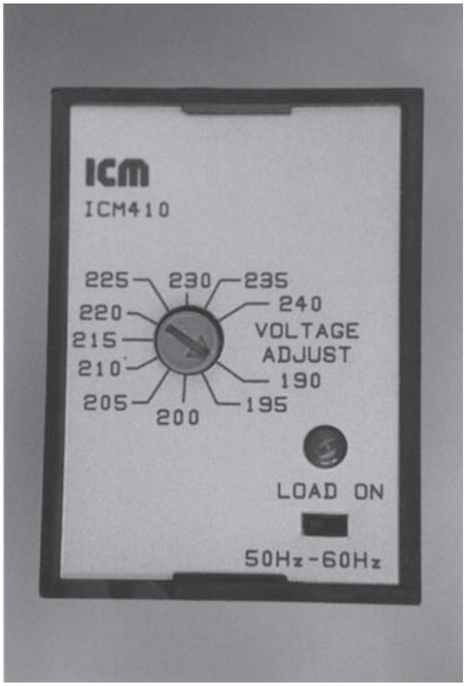


Figure 36–14B
Voltage adjustment for the three-phase line monitor. (Source: Delmar/Cengage Learning)

to monitor the line voltages and disconnect the compressor from the line if a problem should exist. The monitor is designed to plug into an eight-pin tube socket. A set of contacts are connected in series with the coil of the compressor contactor. In the event of a line problem, the contacts open and the contactor disconnects the compressor from the line.

SUMMARY

- Short cycling is a condition that occurs when a compressor is restarted immediately after it has been stopped.
- Short cycling can cause the compressor to try to restart against a high head pressure and damage the compressor motor.
- A short-cycling timer can be installed to prevent short cycling.
- The short-cycling timer is a cam-operated, motor driven, on-delay timer.
- The short-cycling timer is controlled by the thermostat.

KEY TERMS

delay-on-break
delay-on-make
holding relay (HR)
short cycling
short-cycling timer
timer motor

REVIEW QUESTIONS

1. What is short cycling?
2. What is used to provide the timing operation for the short-cycle timer?
3. What type of contacts are used in the short-cycle timer?
4. How many and what type of contacts must the holding relay have?
5. What does the dashed line drawn between the two sets of timer contacts represent?

UNIT 37

Methods of Sensing Temperature

OBJECTIVES

After studying this unit the student should be able to:

- List two factors that determine the amount of expansion that occurs when metal is heated
- Describe the construction and use of a bimetal strip
- Describe how a bimetal strip can be used to construct a thermometer and to operate a set of contacts
- Describe the operation of a thermocouple
- List two factors that determine the amount of voltage produced by a thermocouple
- Discuss the operation of a resistance temperature detector (RTD)
- Discuss the operation of thermistors
- Describe methods to measure temperature

In the air conditioning and refrigeration field, the ability to sense and measure temperature is of great importance. There are numerous methods used to sense the temperature. In fact, there has probably been more emphasis on the ability to measure temperature than any other quantity. This unit will deal with some of these methods.

EXPANSION OF METAL

A very common and reliable method for sensing temperature is by the **expansion** of metal. It has been known for many years that metal expands when heated. The amount of expansion is proportional to two things:

1. The type of metal used.
2. The amount of heat.

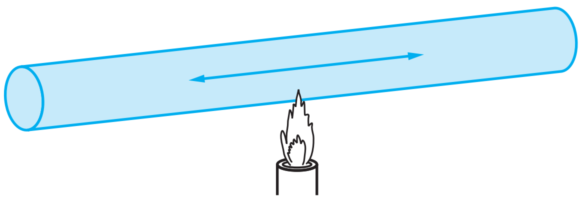


Figure 37–1
Metal expands when heated. (Source: Delmar/Cengage Learning)

Consider the metal bar shown in Figure 37–1. When the bar is heated, its length expands. When the metal is permitted to cool, it will contract. Although the amount of the movement due to contraction and expansion is small, a simple mechanical principle can be used to increase the amount of movement, Figure 37–2.

The metal bar is mechanically held at one end. This permits the amount of expansion to be in only one direction. When the metal is heated and the bar expands, it pushes against the mechanical arm. A small movement of the bar causes a great amount of movement in the mechanical arm. This increased movement of the arm can be used to indicate the temperature of the bar, or it can be used to operate a switch as shown. It should be understood that illustrations are used to convey a principle. In actual practice, the switch shown in Figure 37–2 would be spring loaded to provide a "snap" action for the contacts. Electrical contacts must never be permitted to open or close slowly. This produces poor contact pressure and will cause the contacts to burn, or cause erratic operation of the equipment they are intended to control. A device that uses this principle is one type of starting relay known as the hot-wire relay. This starting relay was covered in an earlier chapter.

Another very common device that operates on the principle of expansion and contraction of metal is the mercury thermometer. Mercury is a metal that remains in a liquid state at room temperature. If the mercury is confined in a narrow glass tube as shown in Figure 37–3, it will rise up the tube as it expands due to heat. If the tube is calibrated correctly, it provides an accurate measurement for temperature.

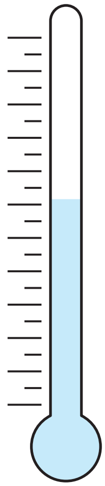


Figure 37–3
A mercury thermometer operates by the expansion of metal. (Source: Delmar/Cengage Learning)

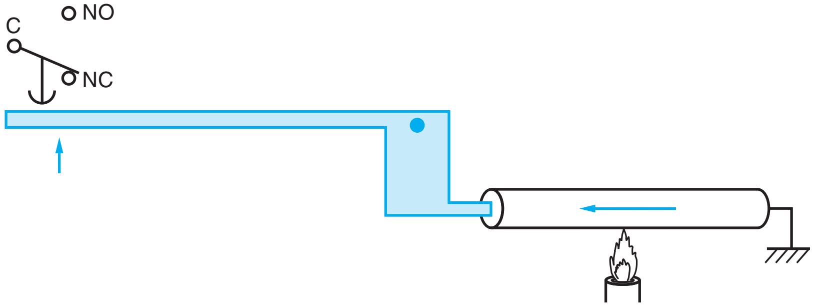


Figure 37–2
Expanding metal operates a set of contacts. (Source: Delmar/Cengage Learning)

THE BIMETAL STRIP

The bimetal strip is another device that operates by the expansion of metal. It is probably the most common heat-sensing device used in the production of thermometers and thermostats. The bimetal strip is made by bonding two dissimilar types of metal together, Figure 37–4. Because these metals are not alike, they have different expansion rates. This difference causes the strip to bend or wrap when heated, Figure 37–5.

The bimetal strip is often formed into a spiral shape as shown in Figure 37–6. The spiral permits a longer bimetal strip to be used in a small space. The longer the strip is, the more movement that will be produced by a change of temperature. If one end of the strip is mechanically held, and a pointer is attached to the center of the spiral, a change in temperature will cause the pointer to rotate. If a calibrated scale is placed behind the pointer, it becomes a thermometer. If the center of the spiral is held, and a contact is attached to the end of the bimetal strip, it becomes a thermostat. As stated previously, electrical contacts cannot be permitted to open or close slowly. This type of thermostat uses a small permanent magnet to provide a snap action for the contact, Figure 37–7. When the moving contact reaches a point that is close to the stationary contact, the magnet attracts the metal strip and causes a sudden closing of the contacts. When the bimetal strip cools, it attempts to pull itself away from the magnet. When the force of the bimetal strip becomes strong enough, it overcomes the force of the magnet and the contacts snap open. This type of thermostat is inexpensive and has been used in homes for many years.

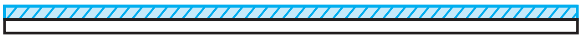


Figure 37–4
A bimetal strip. (Source: Delmar/Cengage Learning)

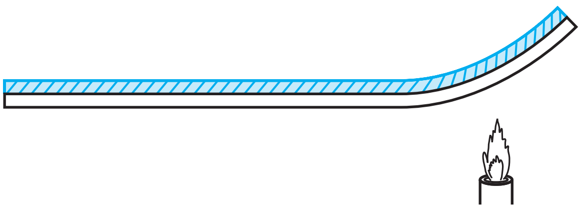


Figure 37–5
A bimetal strip warps with a change of temperature. (Source: Delmar/Cengage Learning)

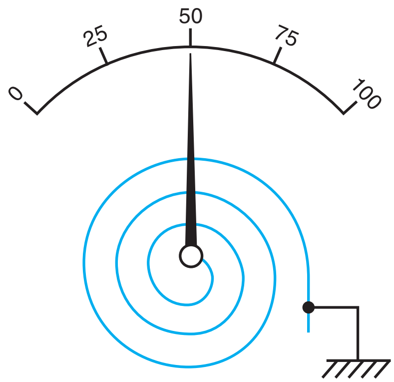


Figure 37–6
A bimetal strip used as a thermometer. (Source: Delmar/Cengage Learning)

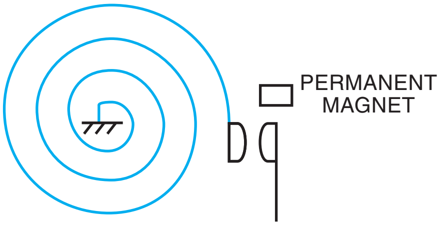


Figure 37–7
A bimetal strip used to operate a set of contacts. (Source: Delmar/Cengage Learning)

THE THERMOCOUPLE

The **thermocouple** is made by joining two dissimilar metals together at one end. When the joined end of the thermocouple is heated, a voltage is produced at the opposite end, Figure 37–8. The amount of voltage produced is proportional to:

1. The types of metals used to produce the thermocouple.
2. The difference in temperature of the two junctions.

The chart in Figure 37–9 shows common types of thermocouples. The metals the thermocouples are constructed from are shown as well as their normal temperature range.

The amount of voltage produced by a thermocouple is small, generally on the order of millivolts (1 millivolt = .001 volt). The polarity of the voltage of a thermocouple is determined by the temperature. For example, a type "J" thermocouple produces zero volts at about 32 degrees Fahrenheit. At temperatures above 32 degrees, the iron wire is positive and the constantan wire is negative. At a temperature of 300 degrees, this thermocouple will produce a voltage of about 7.9 millivolts. At a temperature of −300 degrees, it produces a voltage of about −7.5 millivolts. This indicates that at temperatures below 32 degrees Fahrenheit the iron wire becomes the negative lead and the constantan wire becomes the positive-voltage lead.

Because thermocouples produce such low voltages, they are often connected in series as shown in Figure 37–10. This series connection permits the voltages to add and produce a higher output voltage. This connection is known as a **thermopile**.

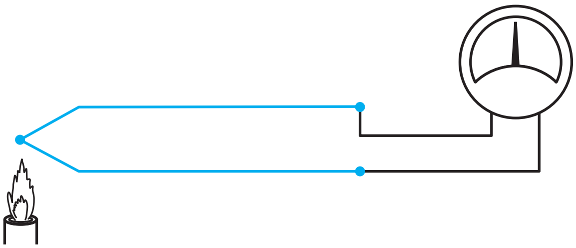


Figure 37–8
A thermocouple produces a voltage when the two ends are at different temperatures. (Source: Delmar/Cengage Learning)

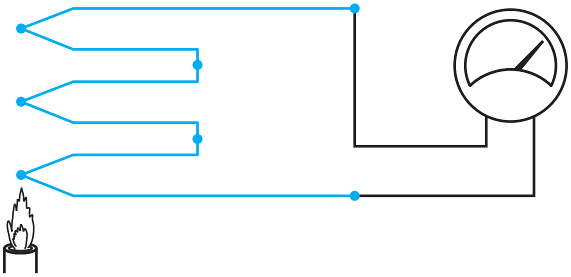


Figure 37–10
Thermocouple. (Source: Delmar/Cengage Learning)

TYPE	MATERIAL		DEGREES F	DEGREES C
J	Iron	Constantan	−328 to +32 +32 to +1432	−200 to 0 0 to 778
K	Chromel	Alumel	−328 to +32 +32 to +2472	−200 to 0 0 to 1356
T	Copper	Constantan	−328 to +32 +32 to +752	−200 to 0 0 to 400
E	Chromal	Constantan	−328 to +32 +32 to +1832	−200 to 0 0 to 1000
R	Platinum 13% Rhodium	Platinum	+32 to +3232	0 to 1778
S	Platinum 10% Rhodium	Platinum	+32 to +3232	0 to 1778
B	Platinum 30% Rhodium	Platinum 6% Rhodium	+992 to +3352	533 to 1800

Figure 37–9
Thermocouple chart. (Source: Delmar/Cengage Learning)

RESISTANCE TEMPERATURE DETECTORS

The **resistance temperature detector (RTD)** is made of platinum wire. The resistance of platinum changes greatly with temperature. When platinum is heated, its resistance increases at a very predictable rate. This makes the RTD an ideal device for measuring temperature very accurately. RTDs are used to measure temperatures that range from –328 to +1166 degrees Fahrenheit (–200 to +630 degrees Celsius). RTDs are made in different styles to perform different functions. Figure 37–11 illustrates a typical RTD used as a probe. A very small coil of platinum wire is encased inside a copper tip. Copper is used to provide good thermal contact. This permits the probe to be very fast-acting. The chart in Figure 37–12 shows resistance versus temperature for a typical RTD probe. The temperature is given in degrees Celsius and resistance is given in ohms.

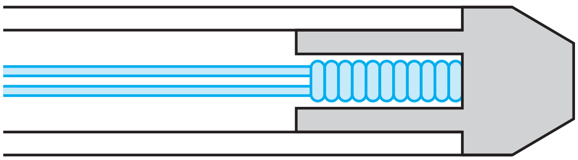


Figure 37–11
Resistance temperature detector. (Source: Delmar/Cengage Learning)

DEGREES C	RESISTANCE
0	100
50	119.39
100	138.5
150	157.32
200	175.84
250	194.08
300	212.03
350	229.69
400	247.06
450	264.16
500	280.93
550	297.44
600	313.65

Figure 37–12
Temperature and resistance for a typical RTD.
(Source: Delmar/Cengage Learning)

THERMISTORS

The term *thermistor* is derived from the words *thermal* and *resistor*. Thermistors are actually thermally sensitive semiconductor devices. There are two basic types of thermistors. One type has a **negative temperature coefficient (NTC)** and the other has a **positive temperature coefficient (PTC)**. A thermistor that has a negative temperature coefficient will decrease its resistance as the temperature increases. A thermistor that has a positive temperature coefficient will increase its resistance as temperature increases. The NTC thermistor is the most widely used.

Thermistors are highly nonlinear devices. For this reason, they are difficult to use for measuring temperature. Devices that measure temperature with a thermistor must be calibrated for the particular type of thermistor being used. If the thermistor is ever replaced, it has to be an exact replacement or the circuit will no longer operate correctly. Because of their nonlinear characteristic, thermistors are often used as set point detectors as opposed to actual temperature measurement. A set point detector is a device that activates some process or circuit when the temperature reaches a certain level. For example, assume a thermistor has been placed inside the stator of a motor used to operate a compressor. If the motor should become overheated, the windings of the motor could be severely damaged or destroyed. The thermistor can be used to detect the temperature of the windings. When the resistance of the thermistor falls to a certain level, NTC type, a set of contacts connected in series with the motor starter coil of the compressor, opens. When the compressor motor starter deenergizes, the compressor is disconnected from the power line. Thermistors can be operated in temperatures that range from about –100 to +300 degrees Fahrenheit.

THE PN JUNCTION

Another device that has the ability to measure temperature is the **PN junction** or diode. The diode is becoming a very popular device for measuring temperature because it is accurate and linear.

When a silicon diode is used as a temperature sensor, a constant current is passed through the diode. Figure 37–13 shows this type of circuit. In this circuit, resistor R1 limits the current flow through the transistor and the sensor diode. The value of R1 also determines the amount of current that will flow through the diode. Diode D1 is a 5.1-volt zener diode used to produce a constant voltage between the base and emitter of the PNP transistor. Resistor R2 limits the amount of current flow through the zener diode and the base of the transistor. Diode D2 is a common silicon diode. It is being used as the temperature sensor for the circuit. If a digital voltmeter is connected across the diode, a voltage drop between .8 and 0 volts can be seen. The amount of the voltage drop is determined by the temperature of the diode.

If the diode is subjected to a lower temperature, say by touching it with a piece of ice, it will be seen that the voltage drop of the diode will increase. If the temperature of the diode is increased by holding it between two fingers or bringing a hot soldering iron near it, its voltage drop will decrease. Notice that the diode has a negative temperature coefficient. As its temperature increases, its voltage drop becomes less. The circuit shown in Figure 37–14

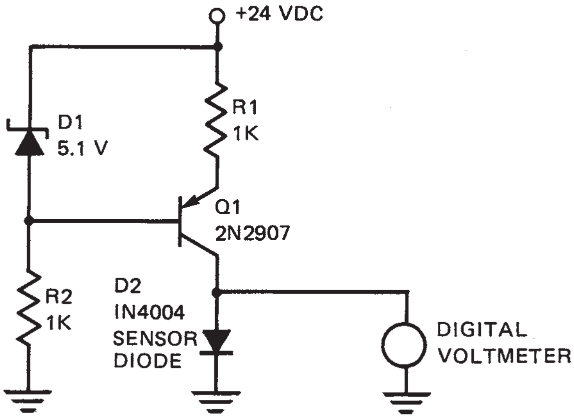


Figure 37–13
Constant current generator. (Source: Delmar/Cengage Learning)

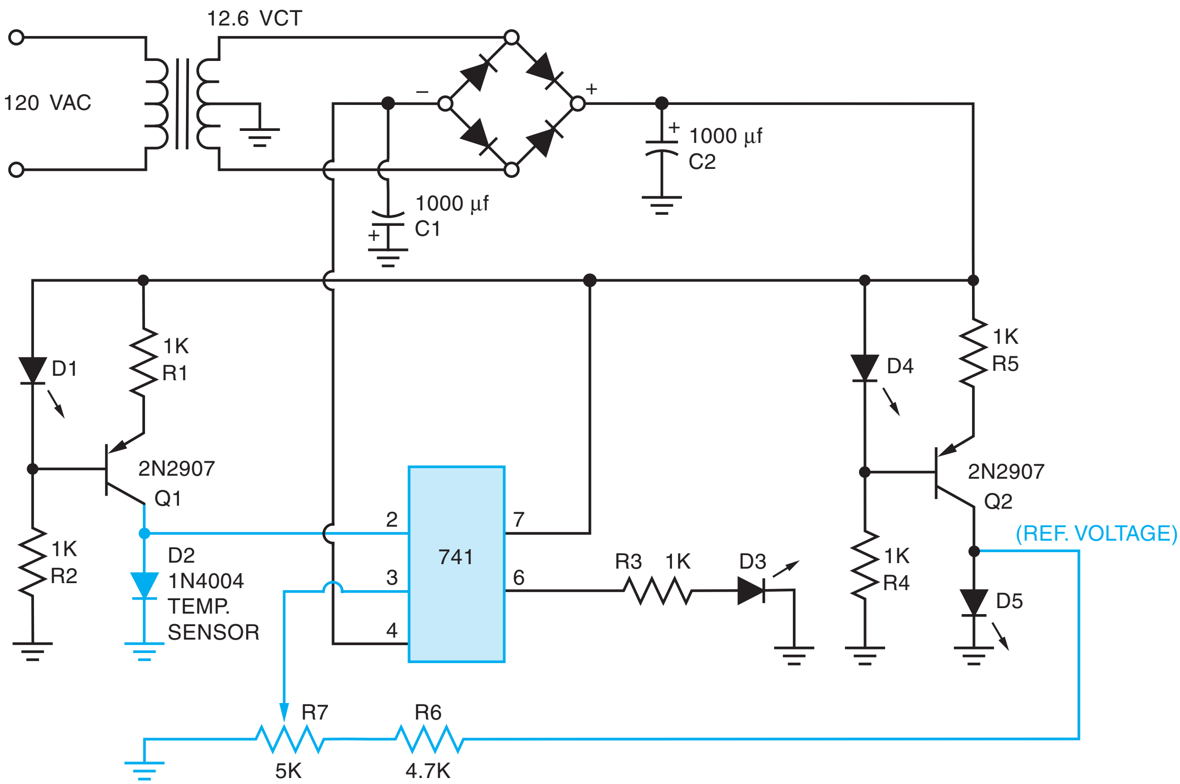


Figure 37–14
Set level detector for temperature. (Source: Delmar/Cengage Learning)

can be used as a set point detector. The operation of the circuit is as follows.

A bridge rectifier and a center-tapped transformer are used to produce an above- and below-ground power supply. If ground is considered as zero volts, the positive output of the bridge will be positive with respect to ground and the negative output of the bridge will be negative with respect to ground. Capacitors C1 and C2 are used to filter the DC output voltage of the rectifier. Notice that capacitor C1 has its positive lead connected to ground and C2 has its negative lead connected to ground. The positive output of the rectifier will produce a voltage that is about +9 volts compared to ground, and the negative output will produce a voltage that is about −9 volts compared to ground.

Diode D1 is a light-emitting diode connected in the forward direction. In this circuit, the LED is used as a low-voltage zener diode. Because the LED has a constant voltage drop of about 1.7 volts, it can be used to provide a constant voltage. Resistor R1 limits the current flow through the diode and the sensor resistor. Resistor R2 limits current flow through the LED and the base of the transistor. Notice this is the same constant current generator circuit shown in Figure 37–13 with the exception of the LED's being used as the zener diode.

Transistor Q2, resistors R5 and R4, and LED D4 form another constant current generator circuit. Notice this generator is connected to an LED, D5. In this circuit, D5 is used to provide a low-voltage reference source for the operational amplifier. When a light-emitting diode is connected to a constant current source, its voltage drop is very stable. This makes it an ideal choice when a steady reference voltage is needed. Resistors R6 and R7 are used to form a voltage divider. Resistor R5 is a 5000-ohm variable resistor that has a voltage drop across its entire resistance of about 1 volt. The wiper tap of this resistor is connected to the noninverting input of the 741. Because resistor R5 has a voltage drop of only 1 volt across its resistance, the full range of the wiper will adjust the voltage applied to the noninverting input between 1 volt and 0. This is done to make adjustment of the detector circuit easy. Because the voltage drop of diode D2 will never be greater than .8 volts, resistor R7 can adjust the entire range over which the detector can operate.

Diode D3 is used as an output indicator. When the output is low, D3 will be turned off. When the output of the op amp goes high, D3 will be turned on. Diode D3 is used only as an indicator in this circuit. The output of the op amp could be used to operate the input of a transistor or a solid-state relay. The transistor or relay could be used to operate almost anything desired. Resistor R3 limits the current flow through D3.

To understand the operation of this circuit, assume that resistor R7 has been adjusted to a point that the output of the op amp is off or low. This means that the voltage applied to the inverting input, pin 2, is more positive than the voltage set at pin 3. If the temperature of diode D2 is increased, its voltage drop will decrease. When the temperature of the sensor diode becomes high enough, its voltage drop will be less than the voltage set at the noninverting input. When the voltage applied to pin 3 becomes more positive than the voltage applied to pin 2, the output of the op amp will go high or turn on. Adjustment of resistor R7 permits the detector to be used over a wide range of temperatures.

EXPANSION DUE TO PRESSURE

Another common method of measuring temperature is by the increase of pressure of some chemicals. Refrigerant, for example, increases pressure as temperature increases. If a simple bellows is connected to a line containing refrigerant, Figure 37–15, the bellows will expand as the pressure inside the sealed system increases. When the surrounding temperature decreases, the pressure inside the system decreases, and the bellows contracts. When the bellows is made to operate a set of contacts, it is generally referred to as a **bellows-type thermostat**.

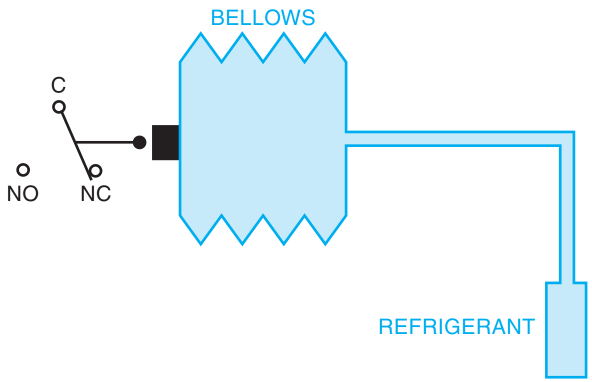


Figure 37–15
Bellows contracts and expands with a change of refrigerant pressure. (Source: Delmar/Cengage Learning)

SUMMARY

- A common method of sensing temperature is by the expansion of metal.
- Two factors that determine the amount of expansion that will occur when metal is heated are:
  A. The type of metal used.
  B. The temperature of the metal.
- A common device that operates on the principle of expansion of metal is the mercury thermometer.
- A bimetal strip is constructed by bonding two types of metal together that expand at a different rate.
- The sensitivity of a bimetal strip is proportional to its length.
- Bimetal strips are often wound into a spiral to permit a longer strip to be used in a small space.
- Thermocouples produce a voltage when heated at one end.
- Thermocouples are made by joining two dissimilar metals together at one end.
- The amount of voltage produced by a thermocouple is determined by:
  A. The types of metals used.
  B. The difference in temperature of the two junctions.
- Resistance temperature detectors (RTDs) are made of platinum wire.
- The resistance of platinum changes at a very predictable rate as the temperature changes.
- Thermistors are devices that rapidly change their resistance with a change of temperature.
- The resistance of a thermistor with a positive temperature coefficient will increase with an increase of temperature.

- The resistance of a thermistor with a negative temperature coefficient will decrease with an increase of temperature.
- Because of thermistors' ability to rapidly change resistance with a change of temperature, they are generally used as temperature-sensitive switches.
- A PN junction can be used to sense temperature by passing a constant current through it and detecting the voltage drop across the junction.
- When a constant current is passed through a PN junction, its voltage drop is proportional to the temperature.
- A metal bellows connected to a sealed refrigerant line can be used to sense temperature because the pressure in the sealed system will be proportional to the temperature.

KEY TERMS

bellows-type thermostat
expansion
negative temperature coefficient (NTC)
PN junction
positive temperature coefficient (PTC)
resistance temperature detector (RTD)
thermocouple
thermopile

REVIEW QUESTIONS

1. Should a metal bar be heated or cooled to make it expand?
2. What type of metal remains in a liquid state at room temperature?
3. How is a bimetal metal strip made?
4. Why are bimetal strips often formed into a spiral shape?
5. Why should electrical contacts never be permitted to open or close slowly?
6. What two factors determine the amount of voltage produced by a thermocouple?
7. What is a thermopile?
8. What do the letters RTD stand for?
9. What type of wire are RTDs made of?
10. What material is a thermistor made of?
11. Why is it difficult to measure temperature with a thermistor?
12. If the temperature of a NTC thermistor increases, will its resistance increase or decrease?
13. How can a silicon diode be made to measure temperature?
14. Assume that a silicon diode is being used as a temperature detector. If its temperature increases, will its voltage drop increase or decrease?
15. What is an above- and below-ground power supply?

UNIT 38

Gas Burner Controls

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the functions of a gas burner control
- Discuss the pilot light method of igniting a gas burner
- Discuss high-voltage spark ignition
- Describe the operation of a thermocouple
- Describe the operation of a "fire eye" and "flame rod" flame sensor
- Discuss the operation of the main control valve

The primary function of a gas burner control is to ensure that gas is not permitted to enter the system if it cannot be ignited in a safe manner. An accumulation of gas is extremely explosive and must be avoided. Several methods of igniting the main burner can be employed. The two most common in use today are the pilot light and high-voltage spark ignition.

PILOT LIGHT

Probably the oldest method of automatically igniting the main burner is with a **pilot light**. A pilot light is a small gas flame that burns continuously near the main burner. When gas is permitted to flow to the main burner, the pilot light ignites the fuel. If the pilot light should not be in operation when the gas is permitted to flow to the main burner, an accumulation of gas could result in an explosion. Therefore, the control system must have some means of sensing the presence of the pilot flame. If the pilot flame is not present, the main gas valve goes into safety shutdown and does not permit gas to be supplied to the main burner.

HIGH-VOLTAGE SPARK IGNITION

Many of the newer gas-operated appliances and heating systems use an **electric arc** to ignite the gas flame. This system uses less energy than a pilot light because it does not depend on a gas flame being present at all times. The electric arc is used only during the actual ignition sequence. When electric arc ignition is used, the gas-control system must be different also. Instead of sensing the presence of a pilot flame, the control system turns on the electric ignitor and permits gas to flow. If a flame is not detected in a short period of time, the control system turns off the flow of gas.

FLAME SENSORS

There are several methods used to sense the presence of a gas flame. One of the most common is with the use of a thermocouple. The thermocouple is a device that produces a voltage when heated. If the thermocouple is inserted in the gas flame as shown in Figure 38–1, a voltage will be produced. The voltage produced by the thermocouple is used to create a current flow through the coil of a solenoid. The current produces a magnetic field that holds the valve open. As long as the solenoid receives enough current, a valve is held open and gas is permitted to flow to the main burner. If the pilot light should go out, no voltage will be produced and the pilot valve will stop the flow of gas. It should be noted that the thermocouple has the ability to produce enough current to hold the valve open, but it cannot produce enough current to reopen the valve if it is closed. The pilot valve must be opened manually by pushing the pilot button located on the main valve. It should also be noted that some controls of this type are actually thermopiles and not thermocouples. Recall that a thermopile is a series connection of several thermocouples used to produce a higher voltage. When replacing a thermocouple, care must be taken to use the proper type. A thermocouple is shown in Figure 38–2.

Another type of flame sensor uses pressure. This control is similar to the pressure type of thermostat. A refrigerant-filled bulb is located in the pilot flame. When the refrigerant is heated, a pressure is produced that holds the pilot safety valve open.

Another type of gas flame sensor is the **"fire eye"** or **"flame eye"**. The fire eye is a gas-filled tube that has a very high resistance in its normal state and will not conduct electricity. A gas flame contains ultraviolet (UV) radiation. The ultraviolet radiation of the gas flame causes the gas in the fire eye to ionize and conduct electricity. Notice that this type of sensor detects the light of a flame and not the heat. This type of control is generally used to sense

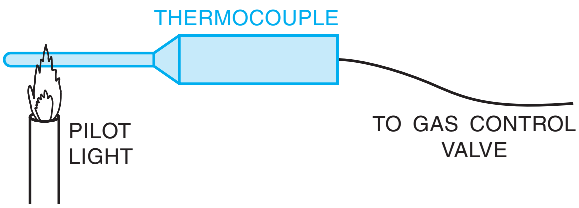


Figure 38–1
Thermocouple senses pilot flame. (Source: Delmar/Cengage Learning)

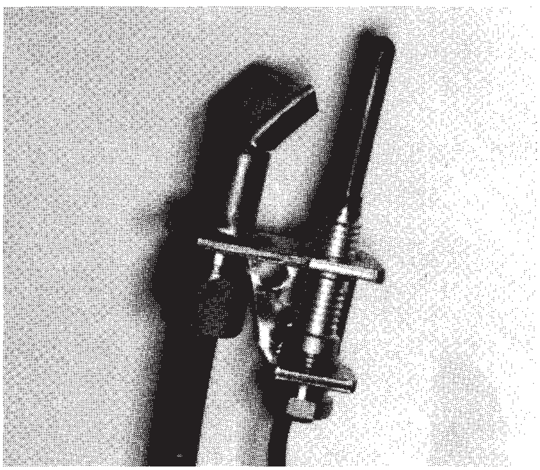


Figure 38–2
Thermocouple and pilot burner. (Source: Delmar/Cengage Learning)

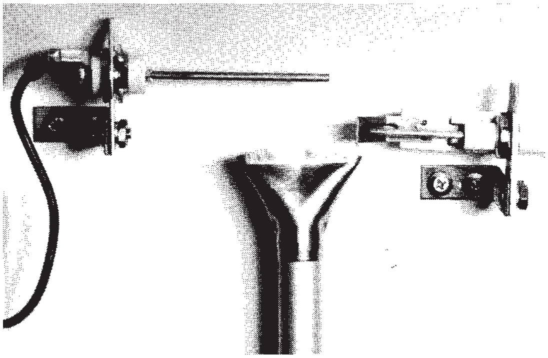


Figure 38–3
Flame rod, burner head, and high-voltage ignition electrode. (Source: Delmar/Cengage Learning)

the presence of the main burner flame instead of the pilot flame. Fire eye detectors are generally used with timers that turn the gas supply off if a flame is not detected within a certain time after a call for heat.

The **"flame rod"** is another sensor that is generally used to detect the presence of flame at the main burner. The flame rod operates by using the gas flame as a conductor of electricity. A gas flame contains many ionized particles that will conduct electricity in a similar manner to some types of vacuum tubes. When the flame rod is inserted in a flame, a current path exists between the rod and the metal of the burner head itself. As long as there is a flame, there can be a flow of electricity between the rod and the burner head. If the flame should be extinguished, the flow of electricity will stop. Figure 38–3 shows a photograph of a flame rod, a small burner head and an electric spark ignitor.

CONTROL VALVES

The gas **control valve** is the real heart of the gas heating system. Control valves control the flow of gas to the main burner and the pilot light, if used. Many of them contain an internal **pressure regulator**, which maintains a constant pressure to the main burner. A simple gas control valve is shown in Figure 38–4. This illustration is used to show the basic principle of operation. This type of valve uses a thermocouple to detect the presence of a pilot flame. Notice that a spring is used to close the valve if the thermocouple should stop producing current for the solenoid coil. Also notice that a solenoid coil is used to open the main valve when the thermostat calls for heat. Different valves use different methods of opening the main valve. Some valves use a small electric heater to heat a bimetal strip that opens the main valve. Others use a small heater to cause a metal rod to expand and open the main valve. Regardless of the method used, all control valves perform the same basic function.

The schematic in Figure 38–5 shows a basic control circuit for a gas heating system. Notice that the fan and high-limit switch are connected in the 120-volt line ahead of the control transformer. When the thermostat closes, 24 volts AC is applied to the control valve. This permits the valve to open and supply gas to the main burner. Notice that this control valve uses a thermocouple to sense the presence of a pilot light. If the pilot light should go out, the pilot valve will close and gas flow to the burner will stop.

The schematic in Figure 38–6 shows a control circuit that uses a high-voltage spark ignitor. Notice that a fan-limit switch is connected ahead of the 24 volts control transformer. This is the same as the other type of control. In this circuit, however, when the thermostat calls for heat, 24 volts AC is applied to a direct spark ignition control module. When the control module receives a call for heat, it turns on the main control valve and provides about 15,000 volts to the ignition electrode. The module also starts an electronic timer at the same time. When the gas is ignited at the burner head, a current flows from the flame rod to the base of the burner. This completes a circuit through the ground wire back to the control module. This flow of current is used to turn off the timer and electric ignitor. As long as a flame is present, and the thermostat calls for heat, the main valve is permitted to remain open. If the flame should go out, however, current flow between the flame rod and burner ground will be broken and the timer and electric ignitor will be started. If a flame is not established in a predetermined time, the main valve will be turned off and the flow of gas stopped. Some systems are equipped with an alarm relay that is turned on by a solid-state relay when the control module senses an unsafe condition.

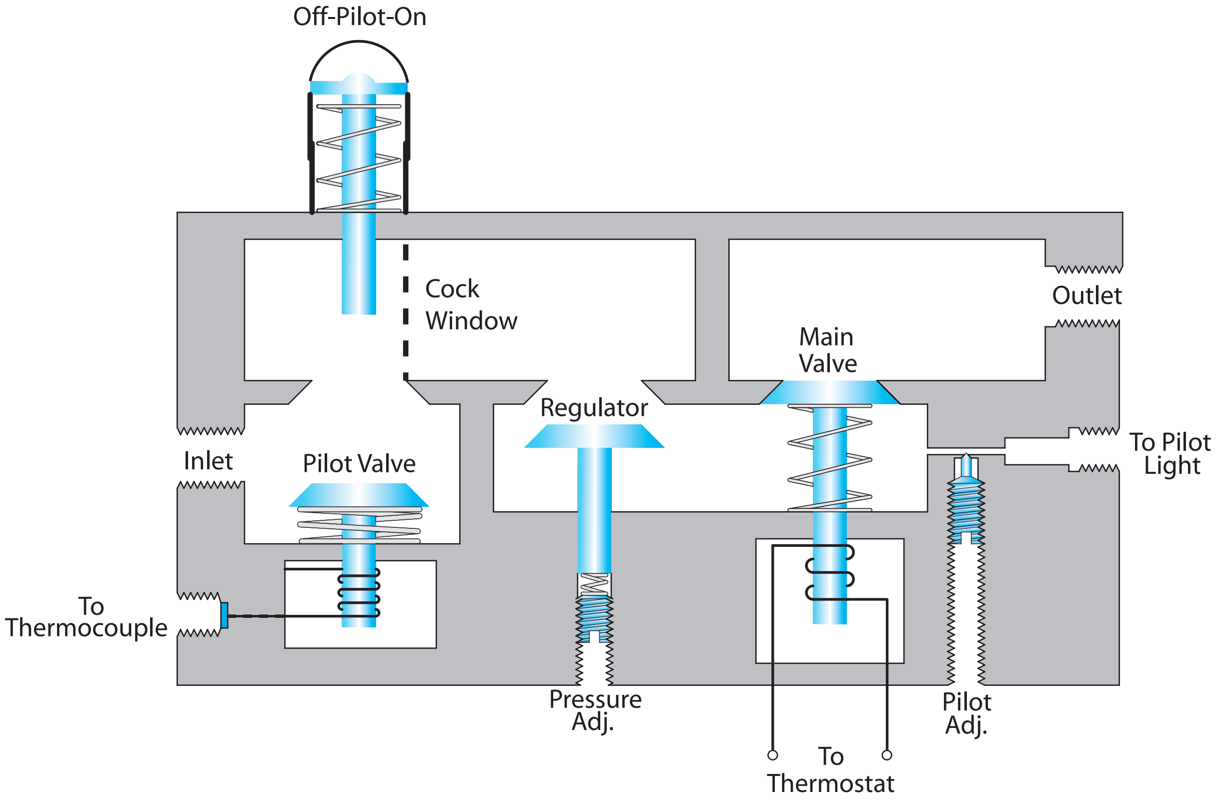


Figure 38–4
Basic gas control valve. (Source: Delmar/Cengage Learning)

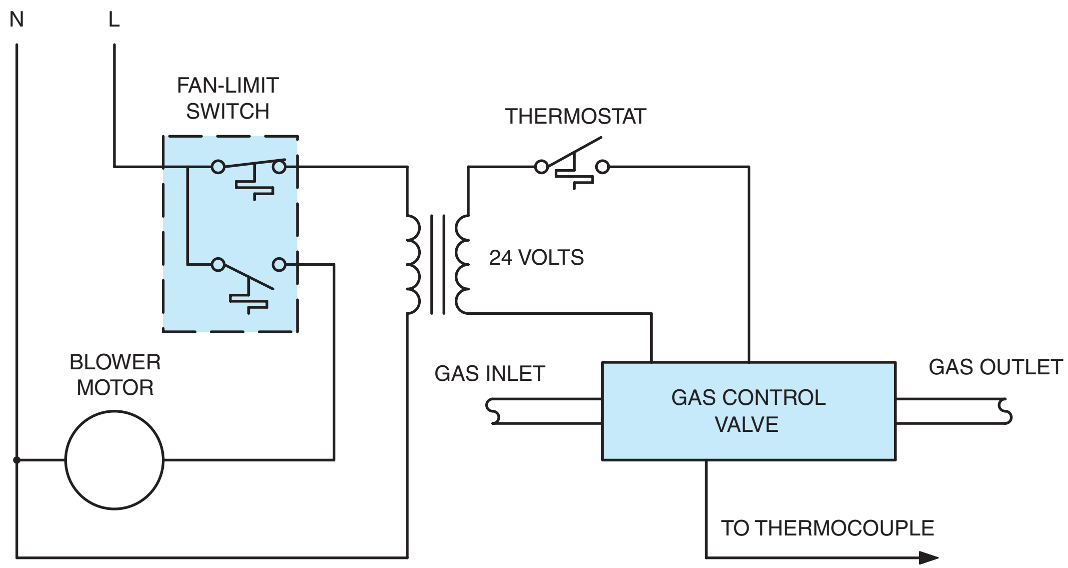


Figure 38–5
Basic gas control system. (Source: Delmar/Cengage Learning)

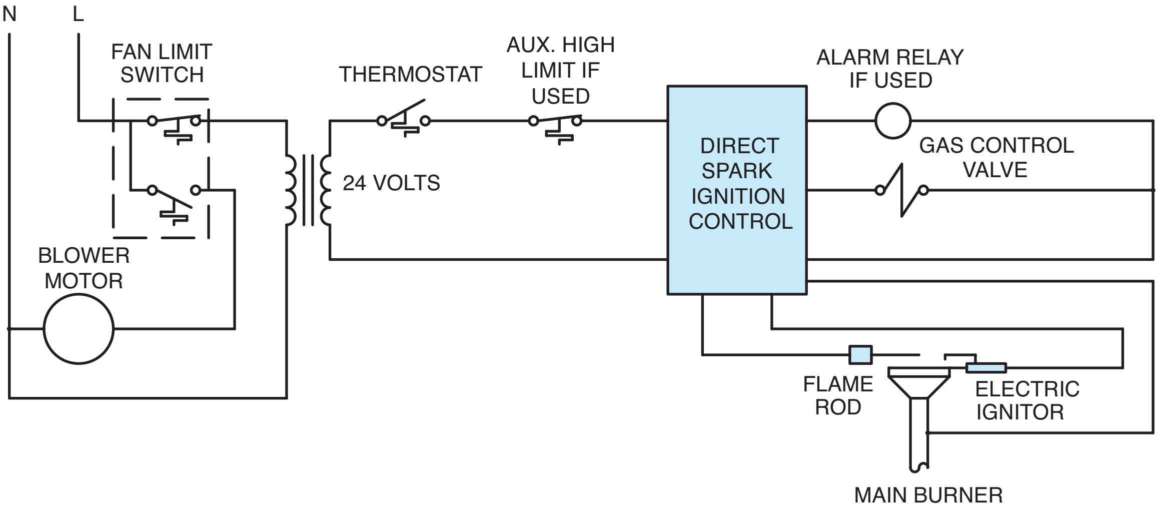


Figure 38–6
Electric spark-ignition control. (Source: Delmar/Cengage Learning)

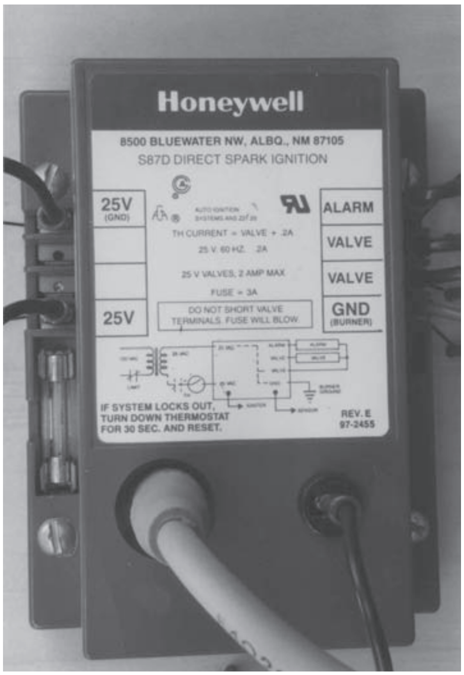


Figure 38–7
Direct spark-ignition control module. (Courtesy of Honeywell Inc.).

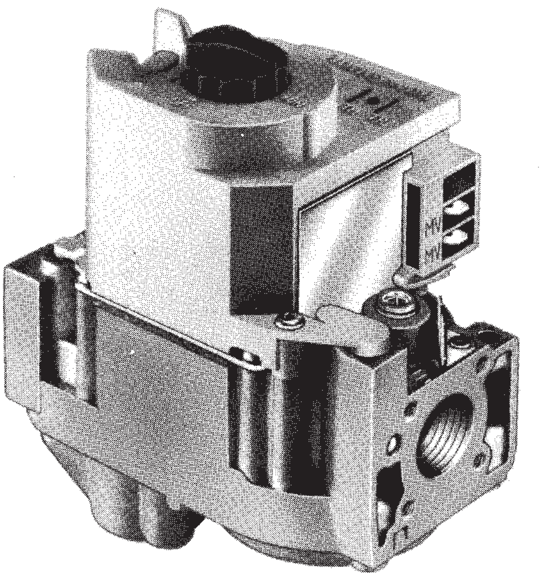


Figure 38–8
Main gas valve used with electric ignition. (Courtesy of Honeywell Inc.).

If a flame is not established when the thermostat calls for heat, the timer will shut down the system in the same manner. A direct ignition control module is shown in Figure 38–7, and a gas control valve used with an electric spark-ignition system is shown in Figure 38–8.

SUMMARY

- The primary function of a gas burner control is to ensure that gas is not permitted to enter the system if it cannot be ignited in a safe manner.
- The oldest method of automatically igniting a gas burner is with a pilot light.
- A thermocouple is used to sense the presence of a pilot light before gas is permitted to flow to the main burner.
- The pilot light heats the thermocouple, which supplies an electric current to hold a solenoid valve open in the main control valve.
- High-voltage spark ignition is used on some gas appliances to ignite the main burner.
- The "fire-eye" type of flame sensor changes resistance in the presence of the light of the flame of the main burner.
- A "flame rod" senses the presence of a gas flame by using ionized particles in the flame as a conductor.
- The gas control valve controls the flow of gas to the main burner.

KEY TERMS

control valve
electric arc
"fire eye" or **"flame eye"**
"flame rod"
pilot light
pressure regulator

REVIEW QUESTIONS

1. What is the purpose of a pilot light?
2. Why is it necessary to be certain that the gas is ignited at the main burner on a call for heat by the thermostat?
3. What is a thermocouple?
4. What is a thermopile?
5. Why must the pilot control valve be reset manually if it should open?
6. Explain how a "fire eye" works.
7. Explain the operation of a "flame rod."
8. What is of common amount of voltage applied to an electric spark ignitor?
9. Why must a ground wire be connected between the direct spark-ignition control module and the burner head?
10. What is the advantage of electric-spark ignition over pilot-light ignition?

UNIT 39

Oil Burner Controls

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of an oil-fired heating system
- Describe electric ignition of a gun-type oil heating system
- Discuss the operation of the primary control
- Describe the operation of the CAD cell

Some of the controls on an oil-fired heating system are basically the same as the controls on a gas-fired system. The fan and limit controls are very similar and in some cases the same. The major part of an oil-fired control system is the **primary control**. The primary control's function is to ensure that when the thermostat calls for heat, the flame will be established within a predetermined amount of time. This is to prevent an accumulation of oil vapor in the combustion chamber. If a large amount of oil is formed in the combustion chamber and ignited, an explosion could occur.

IGNITION

A **gun-type** oil furnace is ignited by an electric arc. Two electrodes are located near the nozzle. When the thermostat calls for heat, the primary control connects the ignition transformer to the 120-volt AC power line. The transformer steps the 120 volts up to 10,000 volts. The 10,000 volts is connected to two electrodes. This causes an arc to be produced between the two electrodes. The air produced by the combustion fan motor causes the arc to be blown in a horseshoe shape as shown in Figure 39–1. This arc is used to ignite the oil. The electrodes are adjusted in such a manner that they do not enter into the oil spray produced by the nozzle. Only the horseshoe-shaped arc is permitted to contact the oil spray. If the electrodes are adjusted too far in front of the nozzle, they may touch the spray, which will cause them to burn and soot. If they are adjusted too far behind the nozzle, the arc will not contact the oil spray. This will cause the furnace to start hard and have delayed ignition.

PRIMARY CONTROL

The schematic of a typical primary control is shown in Figure 39–2. Notice that this control employs several solid-state components in its operation. These components are:

1. The **silicon bilateral switch (SBS)**.
2. The triac.
3. The **cadmium sulfide cell (CAD cell)**.

In this circuit, the gate lead of the SBS has been left disconnected. This permits the SBS to operate very similar to a diac. When the voltage applied to the SBS reaches a high enough level, assume 5 volts for this example, it will turn on and conduct current to the gate of the triac. This will permit the triac to turn on.

CAD CELL

The CAD cell is a device that changes its resistance in accordance with the amount of light it is exposed to. When the CAD cell is in darkness, it will have a very high resistance of several hundred thousand ohms. When it is in light, its resistance will decrease to about 50 ohms.

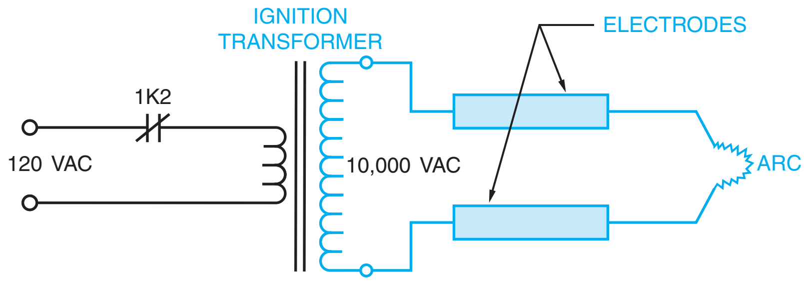


Figure 39–1
Electric-arc ignites oil-fired furnace.
(Source: Delmar/Cengage Learning)

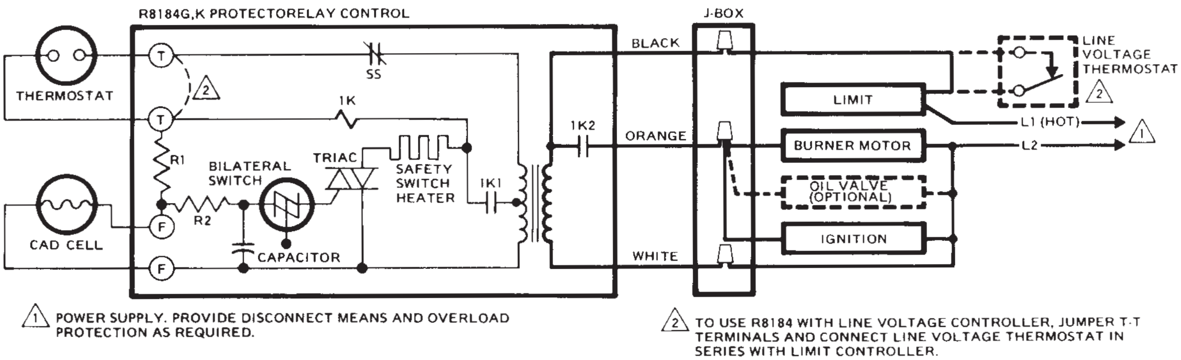


Figure 39–2
Internal schematic and typical hookup for R8184G. (Courtesy of Honeywell Inc.).

CIRCUIT OPERATION

To help in understanding how this circuit works, it will be shown in different stages of operation. In the circuit shown in Figure 39–3, the thermostat has just called for heat. The arrows are used to show the path of current flow through the circuit. The current leaves one side of the step-down transformer and flows through the thermostat contacts. The current then flows through resistor R1. Because the CAD cell is in darkness, it has a very high resistance. This causes most of the voltage to be dropped at the junction point of R1 and R2. Because the voltage at this point is greater than 5 volts, the SBS will turn on and conduct current to the gate of the triac. When the triac turns on, current is permitted to flow through relay coil 1K, the safety switch heater, the triac, and back to the transformer. Notice that coil 1K is connected in series with the safety switch heater at this time.

Figure 39–4 illustrates the operation of the circuit when relay coil 1K energizes. Notice that both contacts 1K1 and 1K2 are shown closed. When contact 1K2 closes, 120 volts is connected to the burner motor and the ignition transformer. When contact 1K1 closes, a different current path for the relay coil and safety heater is provided to the center tap of the transformer. Relay coil 1K and the safety switch heater are no longer connected in series. Notice that one current path is through the thermostat, and 1K relay coil. The current path through the SBS and triac gate is still provided because the oil flame has not been ignited as yet and the CAD cell is still in darkness.

A second current path is provided through the triac and safety switch heater. If, for some reason, ignition

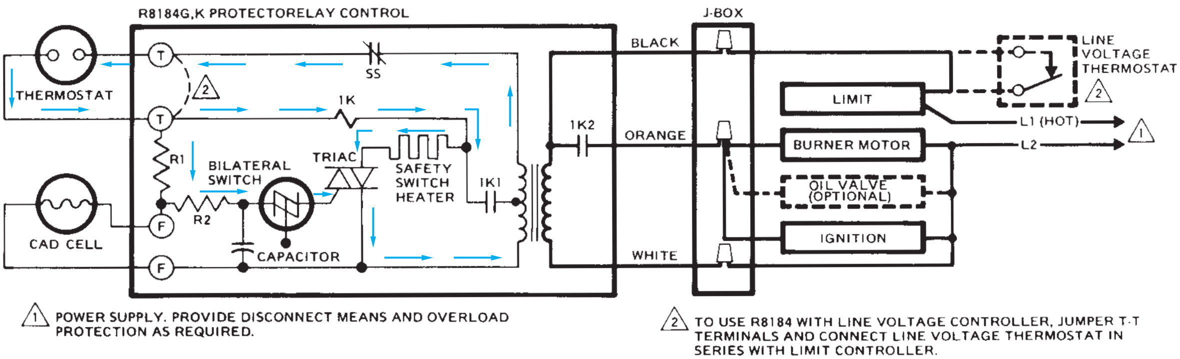


Figure 39–3
Internal schematic and typical hookup for R8184G after thermostat has called for heat. (Courtesy of Honeywell Inc.).

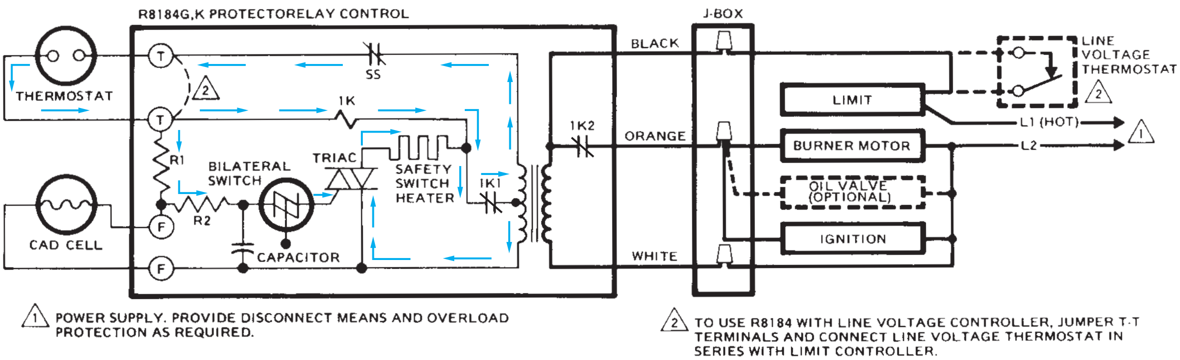


Figure 39–4
Internal schematic and typical hookup for R8184G when relay coil 1K energizes. (Courtesy of Honeywell Inc.).

should not occur, current will continue to flow through the triac and safety switch heater. This will eventually cause the bimetal contact SS to open and disconnect the thermostat circuit. If this should happen, it is necessary to manually reset the primary control with the reset button located on the control unit.

In Figure 39–5, the circuit is shown in its normal operating condition after ignition. Notice that current is still permitted to flow through the 1K relay coil to keep it energized. The triac, however, has been turned off. When ignition occurs, the CAD cell "sees" the light of the flame. This causes its resistance to drop to a low value. When this happens, the voltage drop at the junction of resistors R1 and R2 becomes very low. Because there is now less than 5 volts, the SBS is turned off and no current is conducted to the gate of the triac. This stops the current flow through the safety switch heater and the circuit continues to operate until the thermostat is satisfied.

A photograph of a CAD cell used as the flame detector in an oil furnace is shown in Figure 39–6. A primary control unit for an oil furnace is shown in Figure 39–7. A burner assembly with pump, burner motor, primary control, and ignition transformer is shown in Figure 39–8.

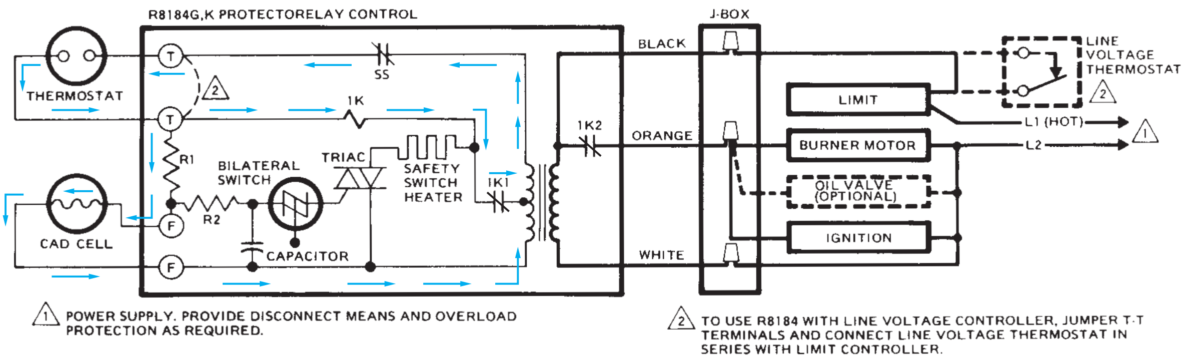


Figure 39–5
Internal schematic and typical hookup for R8184G in normal operating condition after ignition. (Courtesy of Honeywell Inc.).

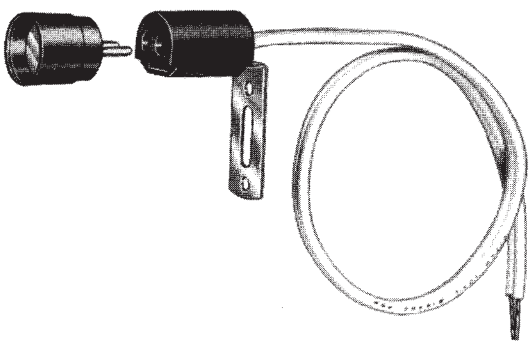


Figure 39–6
CAD cell flame detector. (Courtesy of Honeywell Inc.).

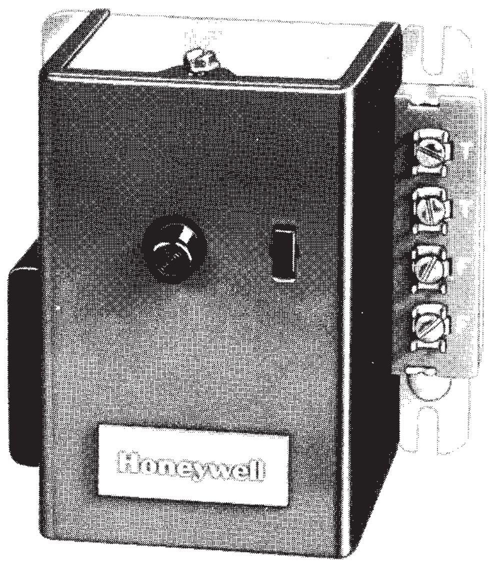


Figure 39–7
Primary control. (Courtesy of Honeywell Inc.).

Figure 39–8 Oil burner assembly with pump, burner motor, primary control, and ignition transformer. (Source: Delmar/Cengage Learning)

SUMMARY

- The primary control controls the major operation of an oil-fired heating system.
- The primary control must ensure that ignition is established in the combustion chamber to prevent an accumulation of oil vapor.
- Oil-fired systems are generally ignited by a high-voltage transformer producing an arc across two electrodes located near the nozzle.
- Most primary controls contain solid-state components.
- A CAD cell located in a position close to the flame is used to sense burner igniting by detecting the light of the flame.
- A CAD cell is a solid-state device that lowers its resistance in the presence of light.

KEY TERMS

cadmium sulfide cell (CAD cell)
gun-type
primary control
silicon bilateral switch (SBS)

REVIEW QUESTIONS

1. What is the function of the ignition transformer?
2. How much voltage is supplied to the electrodes?
3. Are the electrodes permitted to enter into the oil spray?
4. What does enter into the oil spray to cause ignition?
5. What device is controlled by the operation of the triac?
6. What solid-state device controls the flow of gate current to the triac?
7. Does the CAD cell have a high resistance or low resistance when in the presence of light?
8. How would the circuit operate if the CAD cell were in the presence of light when the thermostat called for heat?

SECTION 6

Troubleshooting Using Control Schematics

UNIT 40

Introduction to Troubleshooting

OBJECTIVES

After studying this unit the student should be able to:

- Use a voltmeter to measure voltage across circuit components
- Use an ohmmeter to measure continuity and component resistance
- Use an ammeter to measure circuit current
- Explain the hopscotch method of troubleshooting
- Discuss the use of current transformers
- Discuss safety considerations when using CTs

Troubleshooting is probably the most important part of a service technician's job. Good troubleshooting ability will save hours of valuable time and money. Unfortunately, troubleshooting can be one of the most confusing aspects of the job if the technician does not know the basics. Different technicians use different methods. Most adopt a procedure they are comfortable with and understand. Some basic questions that should be considered when troubleshooting any type of system are:

- What is the system supposed to do?
- How does it do it?
- What is it doing that it should not be doing, or what is it not doing that it should be doing?

Knowing the answer to these basic questions will generally point you in the right direction for determining the problem.

Troubleshooting electric circuits generally involves the use of electric **measuring instruments**. The most common are the **voltmeter**, **ammeter**, and **ohmmeter**. Understanding how each of these instruments functions and how to employ them is one of the keys to developing good troubleshooting skills. The general use of each will be discussed in this unit.

THE VOLTMETER

Recall that one definition of voltage is **electrical pressure**. The voltmeter indicates the amount of potential between two points, in much the same way a pressure gauge indicates the pressure difference between two points. In the circuit shown in Figure 40–1, assume that a voltage of 120 volts exists between L1 and N. If the leads of a voltmeter were to be connected between L1 and N, the meter would indicate 120 volts. Now assume that the leads of the voltmeter are connected across the lamp, Figure 40–2.

QUESTION 1: Assuming the lamp filament is good, would the voltmeter shown in Figure 40–2 indicate 0 volts, 120 volts, or some voltage value between 0 and 120?

ANSWER: The voltmeter would indicate 0 volts. In the circuit shown in Figure 40–2 the switch and lamp are connected in series. One of the basic rules for a series circuit is that the voltage drop across all components equals the applied voltage. The voltage drop across each component is proportional to the amount of resistance of the component and the amount of current flow. In the circuit shown in Figure 40-2, there is no current flow because the switch is open. Because no current can flow through the lamp there can be no voltage drop.

QUESTION 2: If the voltmeter probes were to be moved across the switch as shown in Figure 40–3 would the meter indicate 0 volts, 120 volts, or some value between 0 and 120 volts?

Figure 40–1
A voltage of 120 volts exists between L1 and N. (Source: Delmar/Cengage Learning)

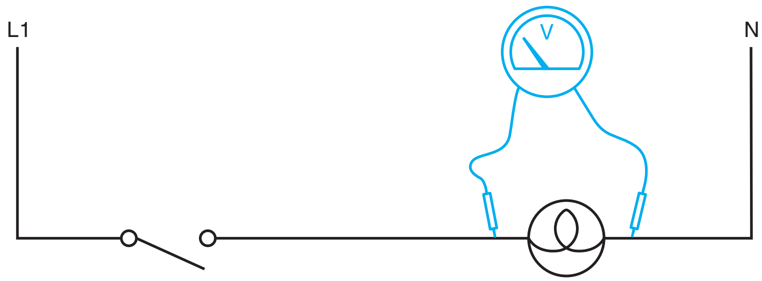


Figure 40–2
The voltmeter is connected across the lamp. (Source: Delmar/Cengage Learning)

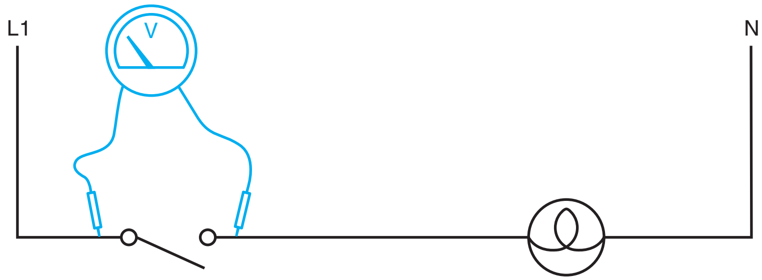


Figure 40–3
The voltmeter is connected across the switch. (Source: Delmar/Cengage Learning)

ANSWER: The voltmeter would indicate 120 volts. Because the switch is an open circuit, the resistance is infinite at this point, which is millions of times greater than the resistance of the lamp filament. Remember that voltage is electrical pressure. The only current flow necessary to measure voltage is the current flow through the meter itself. In this circuit, the only current path is through the resistance of the voltmeter and the lamp filament, Figure 40–4. If the probes of the voltmeter were to be connected to a wall outlet the meter would indicate 120 volts, but there would be no current flow except through the meter itself.

QUESTION 3: If the total or applied voltage in a series circuit equals the voltage drop across each component, why is all the voltage drop across the voltmeter resistor and none across the lamp filament?

ANSWER: There is some voltage drop across the lamp filament because the current of the voltmeter is flowing through it. The voltage drop across the lamp filament, however, is so small as compared with the voltage drop across the voltmeter resistance it is generally considered to be zero. Assume the lamp filament to have a resistance of 50 ohms. Now assume the voltmeter is a digital voltmeter with a resistance of 10 million ohms. The total circuit resistance is 10,000,050 Ω. The total circuit current is 0.000011999 amps (120/10,000,050) or about 12 microamperes. The voltage drop across the lamp filament is 0.0006 volts or 0.6 millivolts ($50 \times 12\ \mu A$).

QUESTION 4: Assume that the filament of the lamp is open or burned out. Would the voltmeter in Figure 40–3 indicate 0 volts, 120 volts, or some value between 0 and 120 volts?

ANSWER: The voltmeter would indicate 0 volts. If the lamp filament is open or burned out, a current path for the voltmeter does not exist and the voltmeter would indicate zero, Figure 40–5. In order for the voltmeter to indicate voltage, it would have to be connected across L1 and N so that a complete circuit through the meter would exist, Figure 40–6.

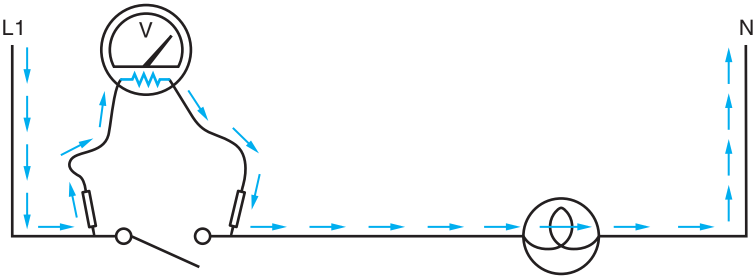


Figure 40–4 Current flows through the meter and lamp filament. (Source: Delmar/Cengage Learning)

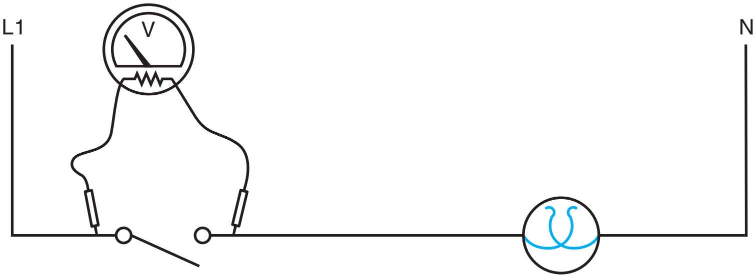


Figure 40–5 If the lamp filament is open, no current can flow. (Source: Delmar/Cengage Learning)

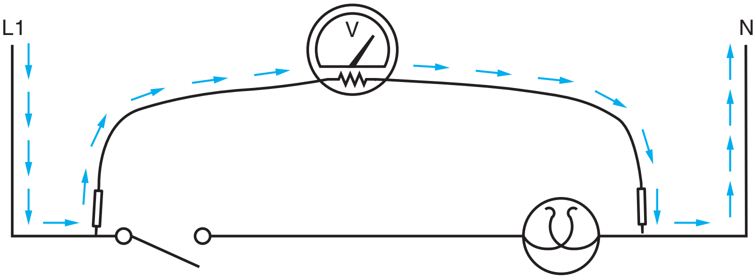


Figure 40–6 A complete circuit must exist through the meter to measure voltage. (Source: Delmar/Cengage Learning)

TROUBLESHOOTING WITH THE VOLTMETER

Before it is possible to troubleshoot a circuit, the technician must have an understanding of how the circuit operates normally. The circuit shown in Figure 40–7 is a basic control circuit for a compressor. The circuit operates as follows:

1. When the thermostat contacts close, power is provided to the FR (fan relay) coil.
2. This causes both FR load contacts to close and connect the fan motor to the 240-volt line.
3. The moving air of the fan causes flow switch FL to close.
4. When switch FL closes, power is provided to the compressor contactor (CC).
5. Both CC load contacts close and supply power to the compressor motor.

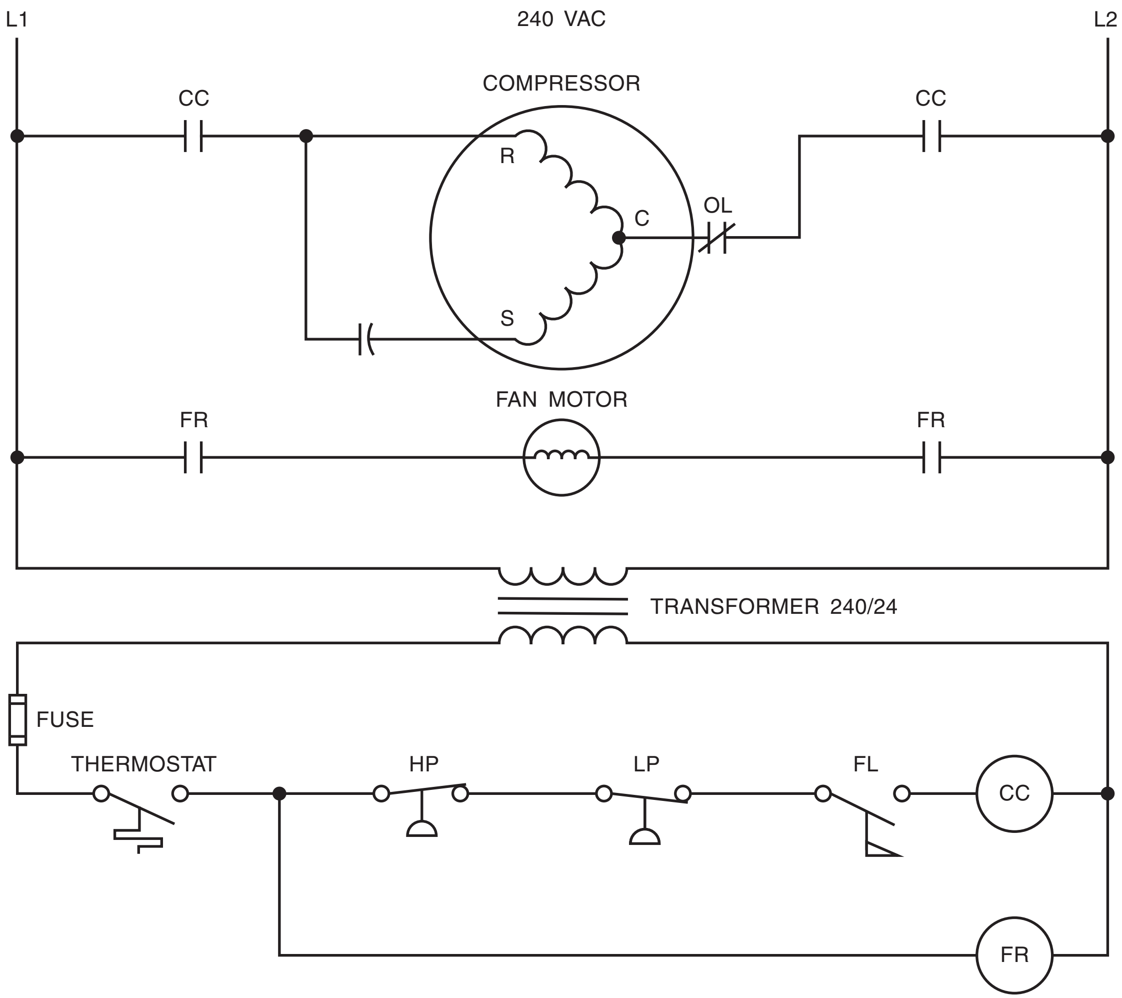


Figure 40–7
Basic compressor circuit. (Source: Delmar/Cengage Learning)

6. High-pressure and low-pressure switches connected in series with the compressor contactor provide protection for the compressor.
7. When the thermostat opens, the circuit to both the compressor contactor and fan relay is broken disconnecting the compressor and fan from the line.

Assume that a problem has developed with the unit. The service technician is told that the air conditioner will not work. The first test to be made is to determine if control voltage is available from the secondary of the transformer. This can be done by checking for 24 volts from the thermostat to CC, Figure 40–8. For the purpose of this example, it will be assumed that the voltmeter indicated 24 volts.

The next step is to attempt to operate the unit. Many service technicians use a jumper to short the thermostat contacts. When a jumper is used to short components in a control circuit, a **fused jumper**

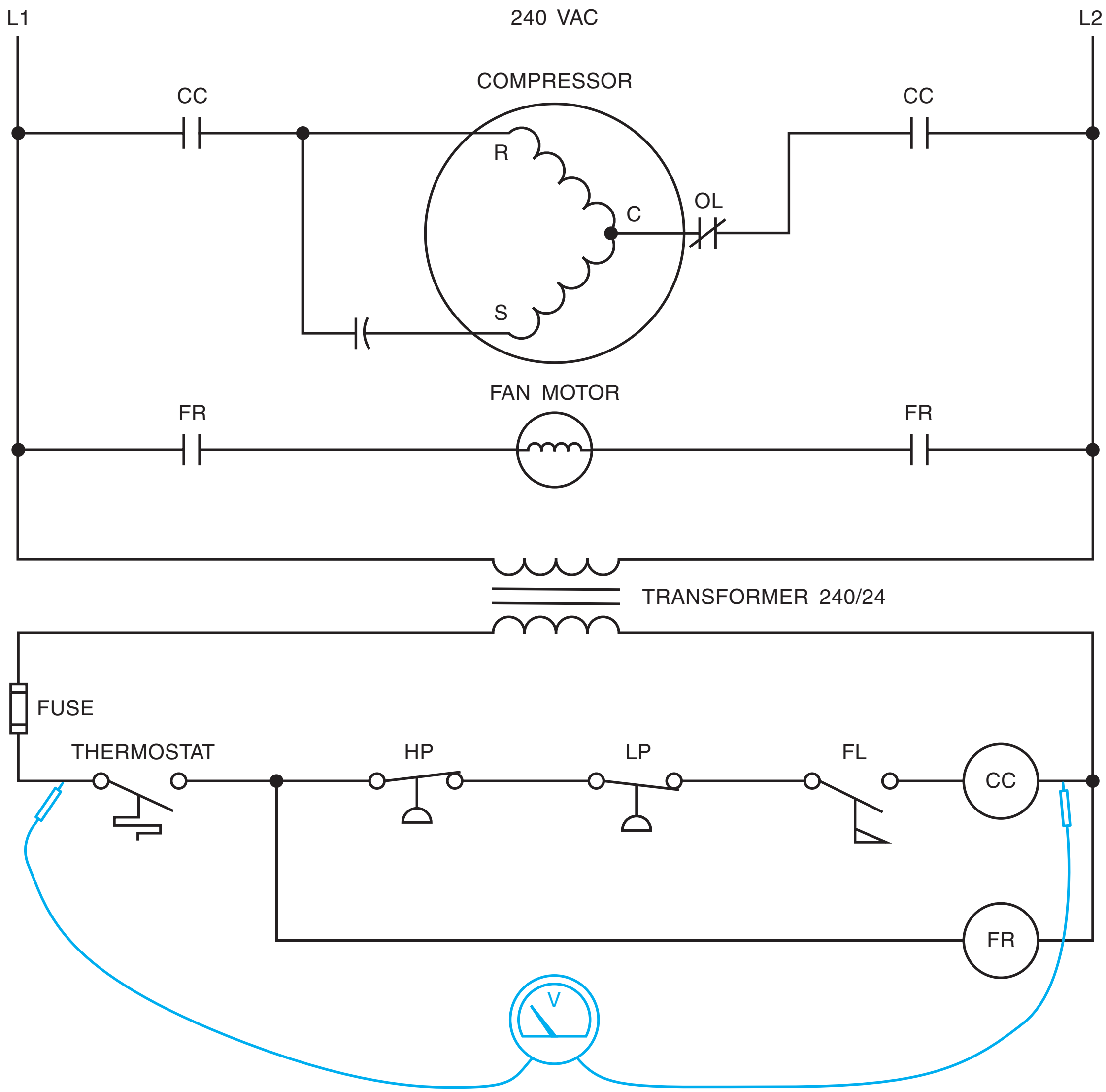


Figure 40–8
Testing the transformer voltage. (Source: Delmar/Cengage Learning)

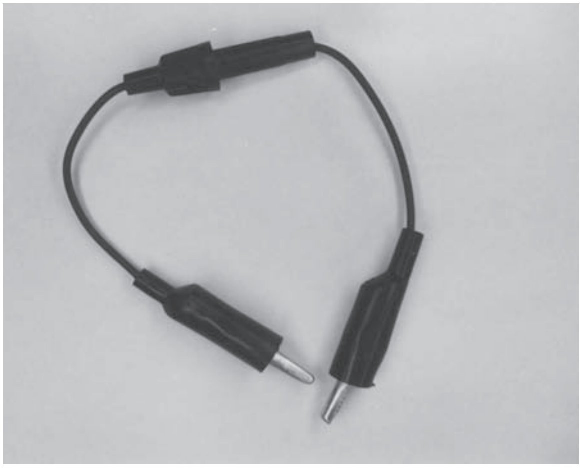


Figure 40–9
Fused jumper for shorting control components.
(Source: Delmar/Cengage Learning)

is recommended, Figure 40–9. The jumper contains a small amp value fuse such as 3 or 4 amperes. If the jumper should be accidentally connected across power, the fuse will blow instantly. Assume then that the thermostat was jumped; the fan motor started but the compressor did not.

The next step is to determine what could be the problem. Looking at the schematic, make mental notes of what could cause the compressor not to start.

1. CC contactor is defective.
2. Flow switch FL did not close.
3. The low-pressure switch, LP, is open.
4. The high-pressure switch, HP is open.
5. CC load contacts are burned out and not connecting power to the compressor.
6. The compressor overload is open.
7. The compressor start capacitor is bad.
8. The compressor motor is bad.

The next logical step is probably to determine if voltage is being applied to the coil of the compressor contactor. This can be done by jumping the thermostat and checking across CC coil with a voltmeter, Figure 40–10.

For this example, it will be assumed that the voltmeter indicated that there was no voltage applied to contactor coil CC.

THE HOPSCOTCH METHOD

A very common troubleshooting method is called the **hopscotch method**. As the name implies, you jump from one component to another until the open part of the circuit is found. In the example in Figure 40–10, the voltmeter is connected across the coil of contactor CC. To use the hopscotch method of troubleshooting, leave one voltmeter probe connected to one side of the transformer and connect the other probe on the other side of the next component in line, Figure 40–11. If the voltmeter indicates 24 volts, it means that the flow switch is open and preventing the compressor contractor from energizing. If the voltmeter indicates 0 volts, it means that there is still an open condition somewhere else in the circuit that is preventing the voltmeter from receiving a flow or current. The 0 volt reading does not mean that contact FL is closed. Contact FL could be open but there is something else open in the circuit ahead of it. In this example, it will be assumed that the voltmeter indicates 0 volt.

The next step is to hopscotch to the next component, which is the low pressure switch, Figure 40–12. If the voltmeter indicates a voltage of 24 volts, it is an indication that the low pressure switch is open. If the voltmeter indicates 0 volts, the voltmeter probe should be moved across the next component in line. For this example it will be assumed that the voltmeter indicates a voltage of 24 volts. The next step is to determine if the switch is defective or if the system is low on refrigerant.

THE OHMMETER

The ohmmeter is generally used in two primary ways:

1. To measure the amount of resistance in a circuit.
2. To test a circuit for continuity.

Assume that a service technician is sent on a service call. The only information given is that the air conditioner will not run. Using the same circuit in the previous example, assume that the technician places a jumper across the thermostat and discovers that the condenser fan operates but the

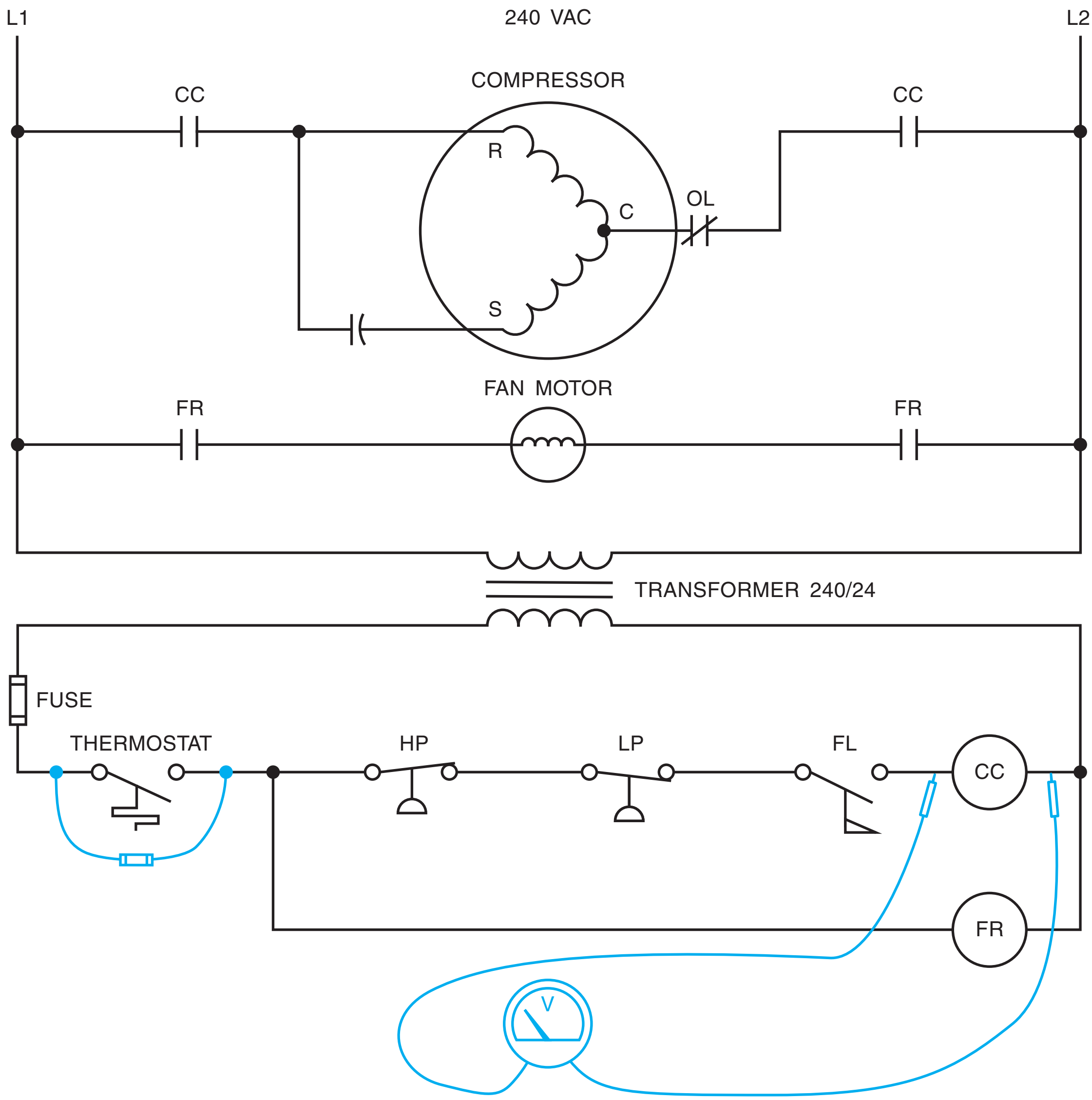


Figure 40–10
Measuring voltage across the compressor contactor. (Source: Delmar/Cengage Learning)

compressor does not. Now assume that he discovers that the compressor contactor is energized. The first step would be to test the voltage across the run/start and common terminals of the compressor, Figure 40–13. It will be assumed that the voltmeter indicates a value of 240 volts.

The next step is to make mental notes of what could cause this problem.

1. The compressor windings are open.
2. The overload relay is tripped.

Assume that the overload is checked and found not to be tripped. The next step is to check the compressor run and start windings for continuity and resistance. This is done by connecting one probe of an ohmmeter to the common terminal of

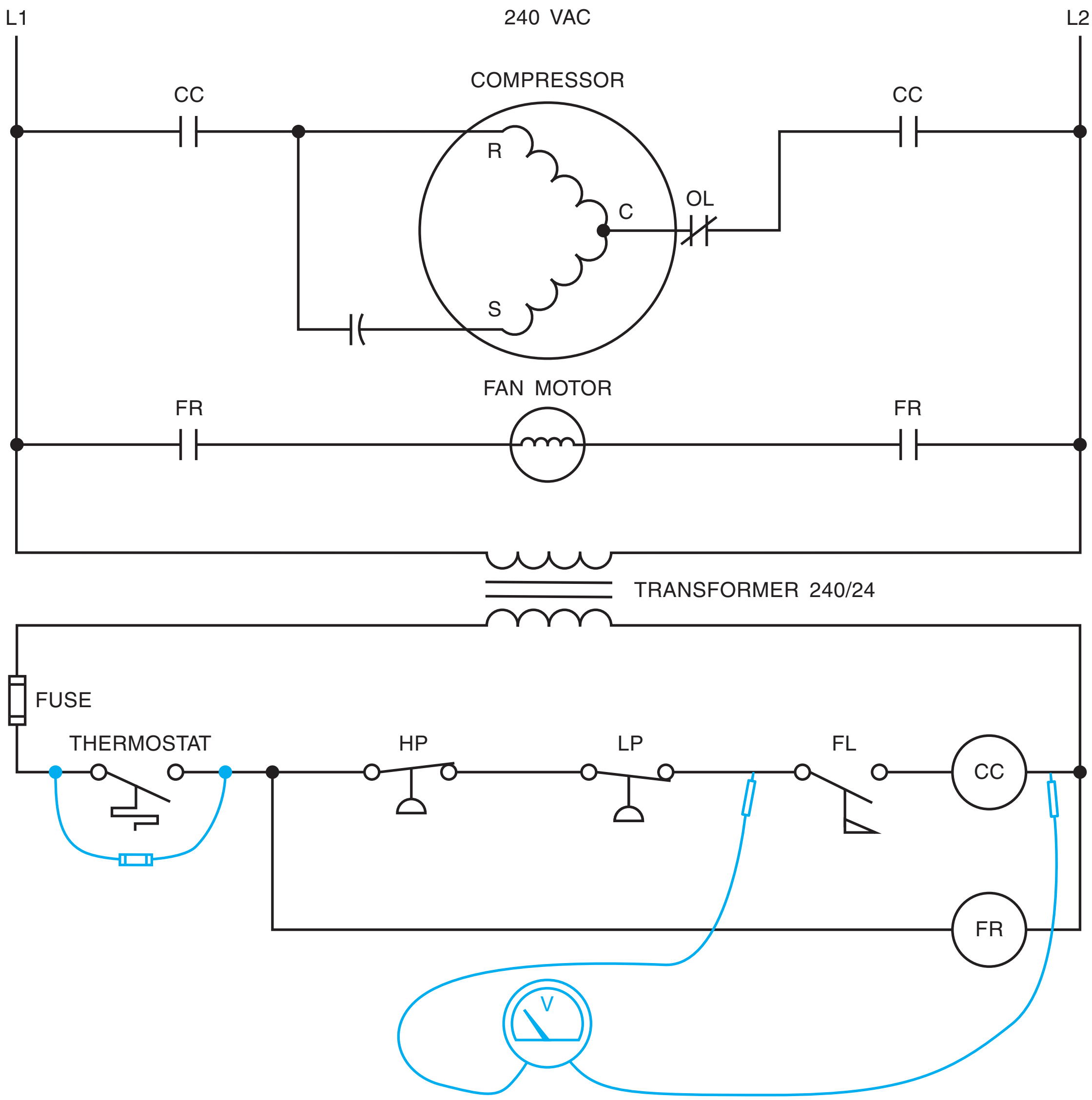


Figure 40–11
The voltmeter is connected to the next component in line. (Source: Delmar/Cengage Learning)

the compressor and the other terminal to the run and start terminals one at a time, Figure 40–14. The ohmmeter should indicate continuity between the common terminal and the run terminal and continuity between the common terminal and the start terminal. If it does not, it is an indication that the winding is open.

The resistance reading will generally give some indication as to the state of the winding, although trying to determine if a winding is shorted with an ohmmeter is a guess at best. The actual resistance of the winding is determined by the size and type of compressor motor and will probably not be known

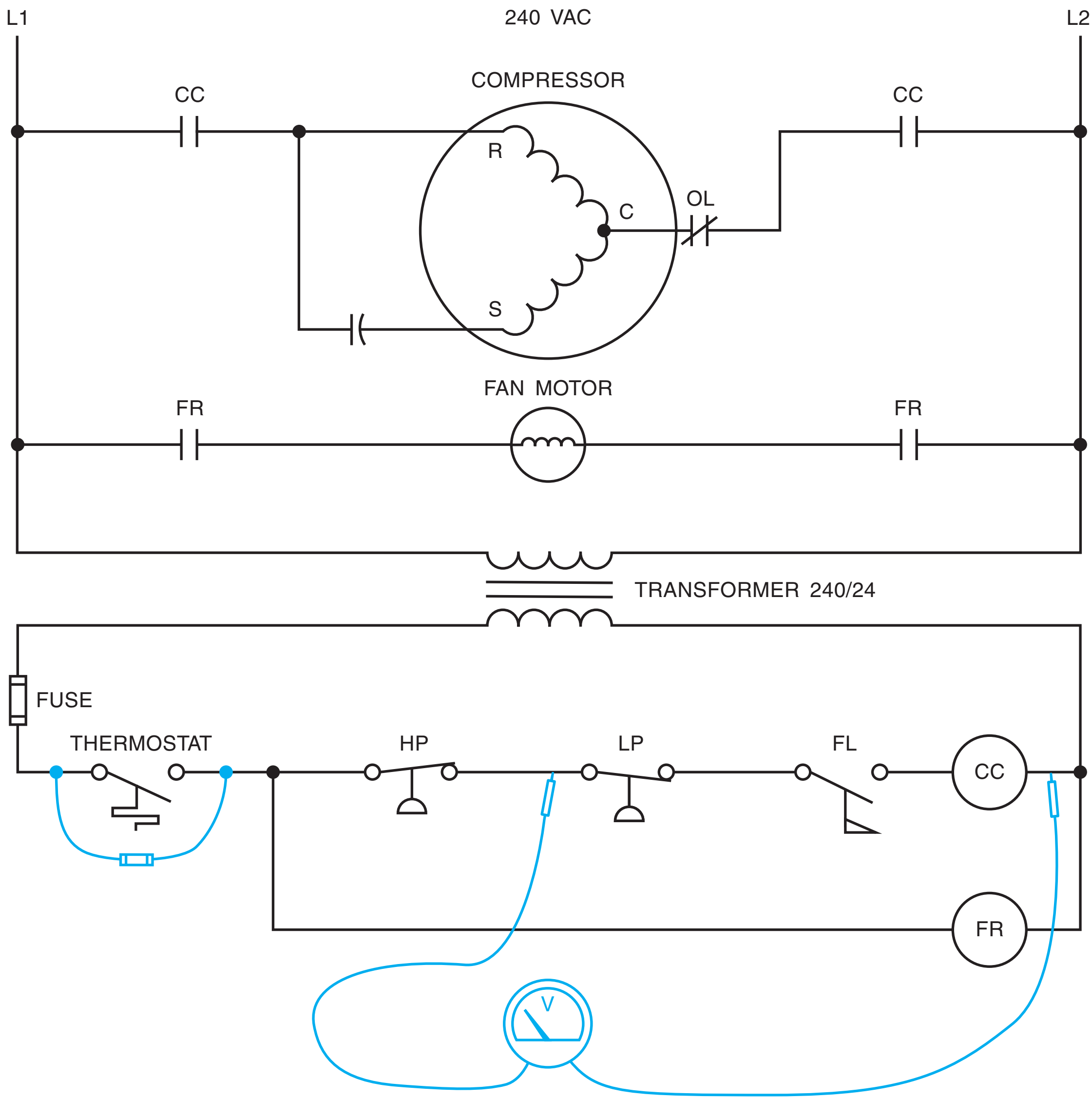


Figure 40–12
The next component in line is tested. (Source: Delmar/Cengage Learning)

by the service technician, but some general guidelines can be followed.

1. If the resistance of either winding is extremely low as compared with the other, there is a good possibility that the winding is shorted.
2. The start winding should be a little more resistive than the run winding.

The run and start windings should also be tested to ensure that they are not grounded. This can be done by connecting one side of the ohmmeter probe to the case of the compressor and testing for continuity to each winding, Figure 40–15. The ohmmeter should indicate infinite resistance if the winding are not grounded.

Another type of ohmmeter, called a megohmmeter or "megger," is often used to test the insulation of

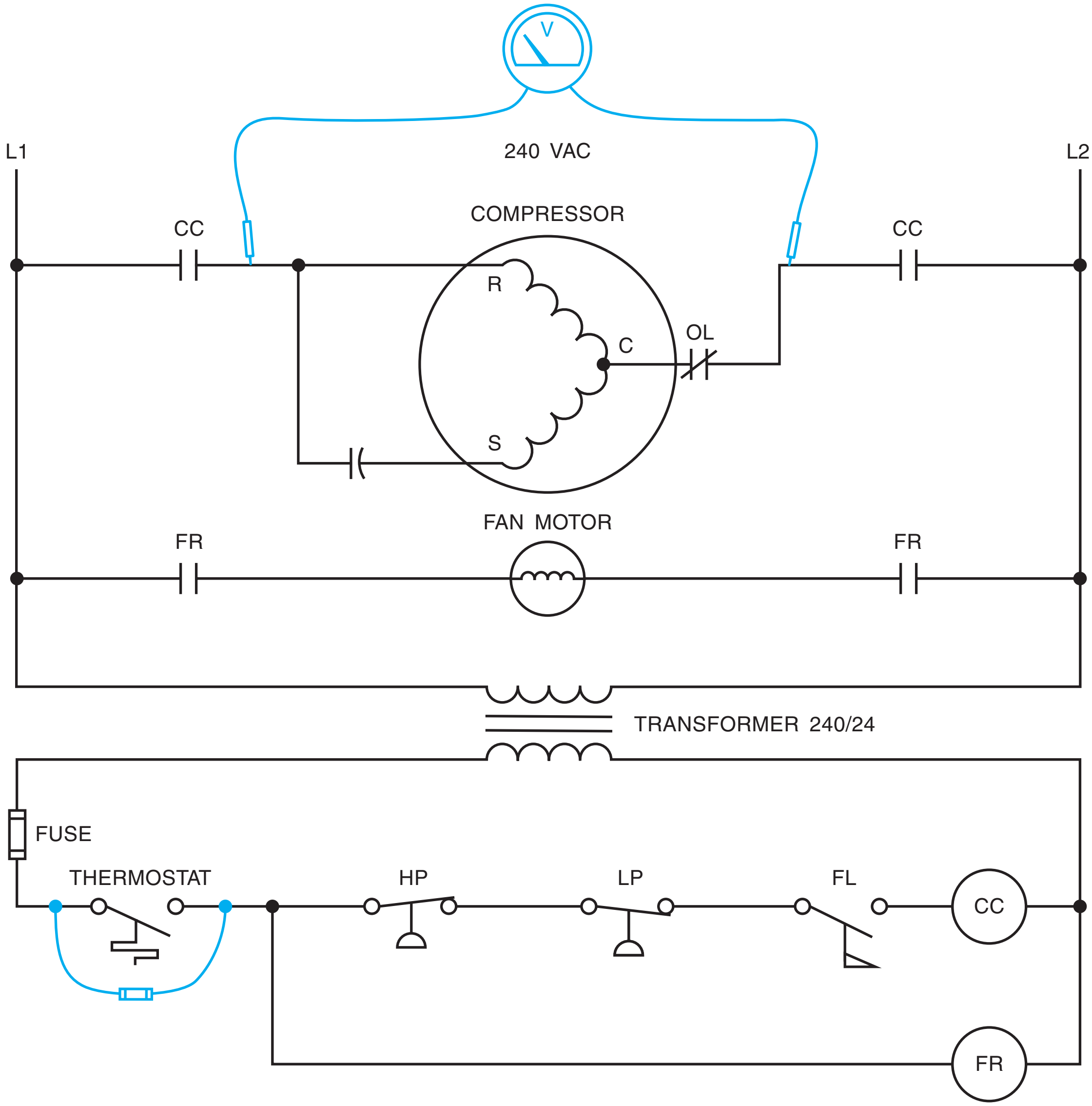


Figure 40–13
Testing voltage to the compressor. (Source: Delmar/Cengage Learning)

wire, Figure 40–16. The megohmmeter is designed to measure resistance in the range of millions of ohms. It is generally used to test the insulation of wire and also produces a much higher voltage than a standard ohmmeter. Often, the insulation around wire will appear to be good when tested with an ohmmeter, but breaks down when it is subjected to a high voltage. Ohmmeters generally use from 1.5 to 9 volts to supply current to the circuit being tested. Meggers generally use from 500 to 1,000 volts to supply current to the circuit being tested. This higher voltage will often reveal problems that a low voltage will not.

USING AN AMMETER

The ammeter is used to measure the actual amount of electricity flowing in a circuit. This can be extremely valuable when trying to determine if something

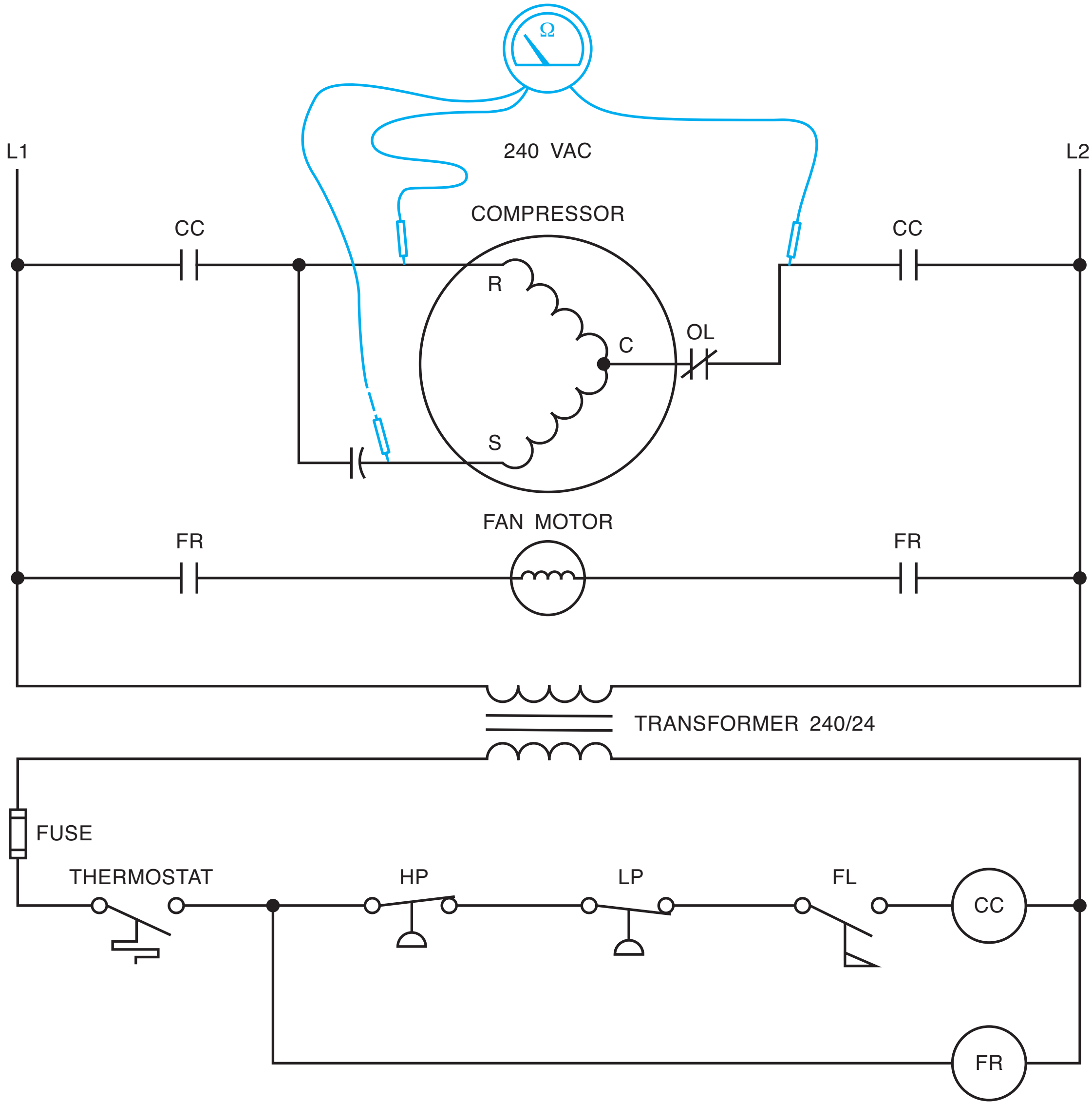


Figure 40–14
An ohmmeter is used to test the windings for continuity. (Source: Delmar/Cengage Learning)

is actually operating or not. Assume that you are troubleshooting an electric furnace. Also assume that the furnace has three stages rated at 5 kW each. The stages are generally sequenced so they come on one at a time. A very fast method of checking the furnace is to connect a clamp-on ammeter to the incoming line, turn on the heat, and watch the readings on the ammeter, Figure 40–17.

Because each element has a power rating of 5,000 watts, the ampere draw of each element can be determined using Ohm's law.

$$I = \frac{P}{E}$$

$$I = \frac{5000}{240}$$

$$I = 20.8 \text{ amperes}$$

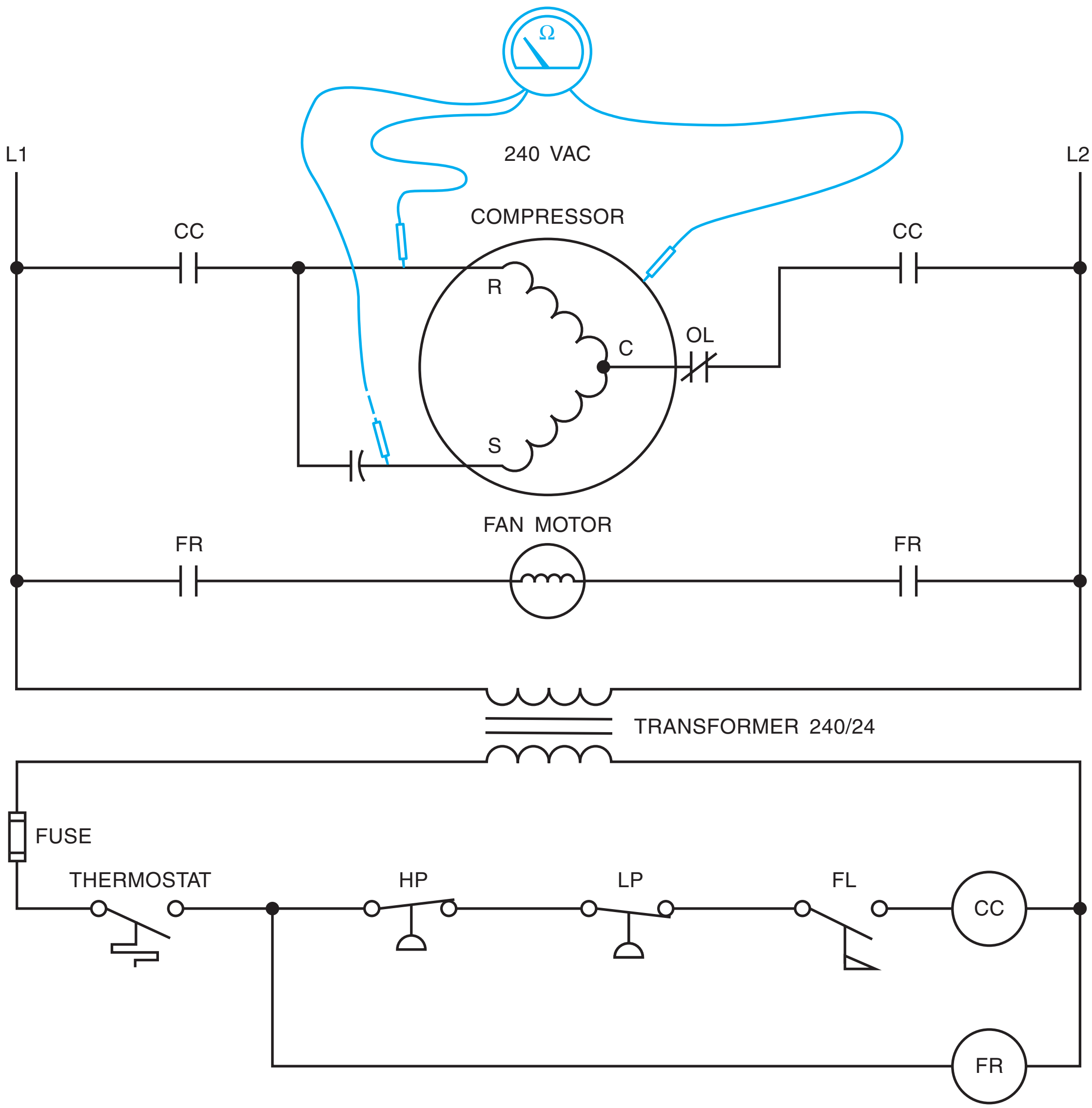


Figure 40–15
Each winding is tested for a grounded condition. (Source: Delmar/Cengage Learning)

When the furnace is energized, the ammeter should indicate a current flow of approximately 21 amperes. After a few minutes the current should increase to approximately 42 amperes (20.8 + 20.8 = 41.6), and after another delay the current should increase to approximately 62.5 amperes (20.8 × 3 = 62.4). A voltmeter could be used to determine if voltage is being applied to each element, but unless the power was turned off and the heating elements disconnected and tested with an ohmmeter, you could not be certain an element was not burned open. The ammeter permits a quick check of the unit and you know that each element is operating.

Figure 40–16 A megohmmeter for testing insulation resistance. (Source: Delmar/Cengage Learning)

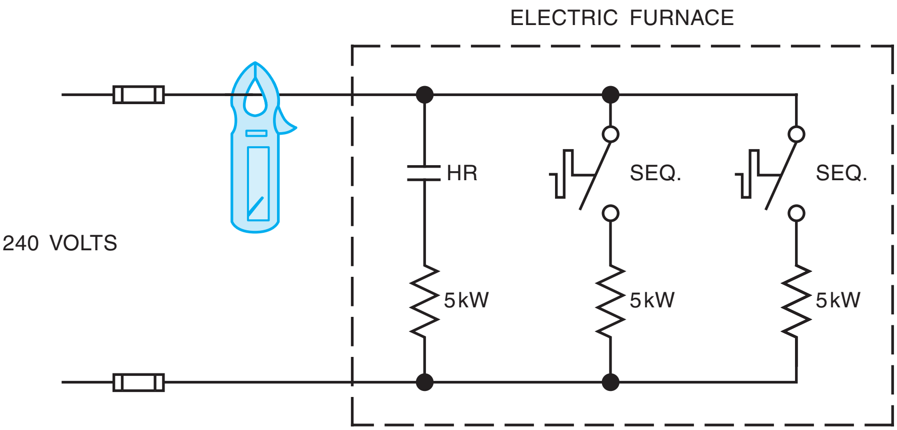


Figure 40–17 Testing an electric furnace with an ammeter. (Source: Delmar/Cengage Learning)

THE SHOTGUN METHOD

As stated previously, most technicians will adopt their own troubleshooting methods that are developed with time and experience. The *shotgun method* involves testing the circuit at various locations to determine trouble areas rather than following a step-by-step procedure as outlined in the hopscotch method. In this example, the circuit to be tested is a central air conditioner and electric heating system. Probably the best place to start is at the thermostat because it is readily accessible.

1. Check the power supply. To do this, set the fan switch to ON or MAN to see if the blower fan turns on. If it does, you have determined that the 24-volt supply is working. If the blower does not turn on, the problem could be the thermostat, fan relay, blower motor, run capacitor, 24-volt transformer, or main power supply to the transformer. At this point you have determined if the problem is with the inside unit or the outside unit.

2. Test the thermostat. Remove the thermostat from its base and check the wires connected to the thermostat base with a voltmeter to determine if 24 volts is available. If 24 volts is available, use a fused jumper to test the circuit components controlled by the thermostat. Connect one lead to the power terminal (R) and make connection to each of the other terminals to determine if there is a response. If there is a response to each of the terminals, the thermostat is defective.
3. If there was not a response to a particular circuit component, replace the thermostat on the base and check that component starting with the power supply. In this example, assume that the air conditioning unit did not respond.
4. Check the 240-volt power supply to the unit. This can be checked at the breaker, disconnect switch, or main contactor depending on which is most accessible. In this example it will be assumed that power is present at the main contactor.
    a. Check the output of the main contactor to determine if power is being supplied to the compressor. If not, check the 24-volt supply to the coil of the main contactor. If 24 volts is supplied to the coil, the contactor is defective.
5. If 24 volts is not present at the coil of the contactor, check the thermostat wires where they enter the outside unit. If power is not present, check the wiring between the thermostat and the outside unit.
6. If 24 volts is present at the unit, check any components between the 24-volt supply and the coil of the contactor. Components such as high-pressure switches, low-pressure switches, and so on are connected in series with the low-voltage circuit.

    Now assume that instead of no response at the outside unit, the condenser fan started but the compressor did not.

7. If 240 volts is available at the output of the main contactor, check all components, such as run and start capacitors, between the contactor and the compressor.
8. If all components between the contactor and compressor are good, check the power supplied to the compressor terminals. If power is present at the compressor terminals, disconnect power to the outside unit by opening the disconnect switch or circuit breaker.
9. Disconnect the power terminals connected to the compressor. Use an ohmmeter and check between each terminal to determine if there is an open circuit. Also check between each terminal and the compressor case to determine if there is a grounded circuit. Note: It is possible for the motor windings to be shorted and not be open or grounded. Shorted windings will cause the motor to draw an excessive amount of current or may not permit the compressor to start when power is supplied. An ohmmeter generally will not reveal this condition.
10. If the ohmmeter indicates an open circuit in the compressor, note if the compressor is hot to the touch. If so, the internal overload may be open. It cannot be determined if the compressor winding is open or if the internal overload is open until the compressor cools. This overload cannot be bypassed. If the compressor is hot, it may take hours for the overload to reset, depending on the temperature of the compressor, the ambient temperature, and whether the compressor is located in direct sunlight. The only way to know if the compressor is defective or if another problem caused the overload to open is to wait until the overload resets. It is recommended to leave the power disconnected to the outside unit until the compressor cools and allows the overload to reset. This will allow the technician to observe whether the compressor restarts or not.
11. Some of the circumstances that can cause the internal overload to open are:
    - Defective windings in the compressor, causing it to draw excessive current.
    - A stuck compressor.
    - A brief power interruption, such as a loss of power or someone opening the thermostat contacts and reclosing them.

- Lack of air flow across the condenser and compressor. This can be caused by a dirty condenser or anything blocking air to the condenser. The condenser fan can also be defective and thus prevented from obtaining full speed.
- Low voltage supplying the compressor.
- Over charge of refrigerant causing high head pressure. This would cause the compressor to draw excessive current.
- Low charge of refrigerant. The compressor could overheat because it depends on cool vapor returning from the evaporator to help cool the motor.
- Very high ambient temperature and being exposed to direct sunlight.

12. If the compressor eventually restarts, check the current draw of the unit and compare this reading to the nameplate current rating. If the current draw is greater than the full-load-amp (FLA) draw listed on the nameplate, determine if the problem is a defective compressor or one of the other causes listed.

SUMMARY

- Before it is possible to troubleshoot a circuit, the technician must have an understanding of how the circuit operates.
- The three main instruments used for troubleshooting are the voltmeter, ohmmeter, and ammeter.
- Power must always be disconnected from the circuit before using an ohmmeter.
- A complete circuit must exist before a voltmeter will indicate voltage.
- An ammeter is used to determine if current is actually flowing through the circuit.
- The hopscotch method of troubleshooting involves starting at one of the circuits and moving from component to component until the problem is discovered.

KEY TERMS

ammeter
electrical pressure
fused jumper
hopscotch method
measuring instruments
ohmmeter
voltmeter

REVIEW QUESTIONS

1. A voltmeter is connected across the terminals of an electric heating element. The voltmeter indicates a voltage of 240 volts. Is this a true test to determine if the heating element is operating?
2. What electrical measuring instrument should be used to determine if the heating element in question 1 is operating?

3. It is suspected that the high-pressure switch in a control circuit is open. Explain the steps in testing this component with an ohmmeter.
4. Refer to Figure 40–10. Assume that the voltmeter indicates a value of 24 volts, but the compressor contactor is not energized. What is the most likely problem?
   A. A jumper wire was not placed around the thermostat contacts.
   B. The flow switch is open.
   C. The coil of the CC contactor is open.
   D. The coil of the CC contactor is shorted.
5. Refer to the circuit in Figure 40–7. Assume that when a jumper is placed around the thermostat contacts, the fan motor starts, the compressor contactor energizes, but the compressor motor does not start. Which of the following could *not* cause this problem?
   A. The flow switch is not closing.
   B. The CC load contacts are defective.
   C. The compressor overload relay is open.
   D. The compressor start capacitor is defective.

UNIT 41 Room Air Conditioners

OBJECTIVES

After studying this unit the student should be able to:

- Identify circuit components on a schematic diagram
- Analyze a schematic diagram to determine how the circuit functions

In the previous units, basic symbols and rules for reading a schematic diagram have been covered. In actual practice, however, schematics do not always look like the classic textbook examples. Many schematic diagrams use a **legend** to aid in understanding. A legend is a list that shows a symbol or notation and gives the definition of that symbol or notation. The legend that will be used with the schematics presented in this unit is shown in Figure 41–1.

SCHEMATIC 1

The first circuit to be discussed is shown in Figure 41–2. First find the **major components** shown on the schematic: the switch, fan motor, compressor, capacitor, overload, and thermostat. Notice that these components may not be shown exactly as

Legend

SR — Start Relay
GND — Ground
T — Terminal Bushing

——— Factory Wiring

– – – – Field Wiring

⬡ Component Connection

Color Code

Bk or Blk — Black
Bl or Blu — Blue
Br or Brn — Brown
Grn — Green
Or or Orn — Orange
R — Red
Vio — Violet
Wht — White
Y-Bk — Yellow with Black Tracer
Y or Yel — Yellow

Figure 41–1
Schematic legend. (Courtesy of Carrier Corp.).

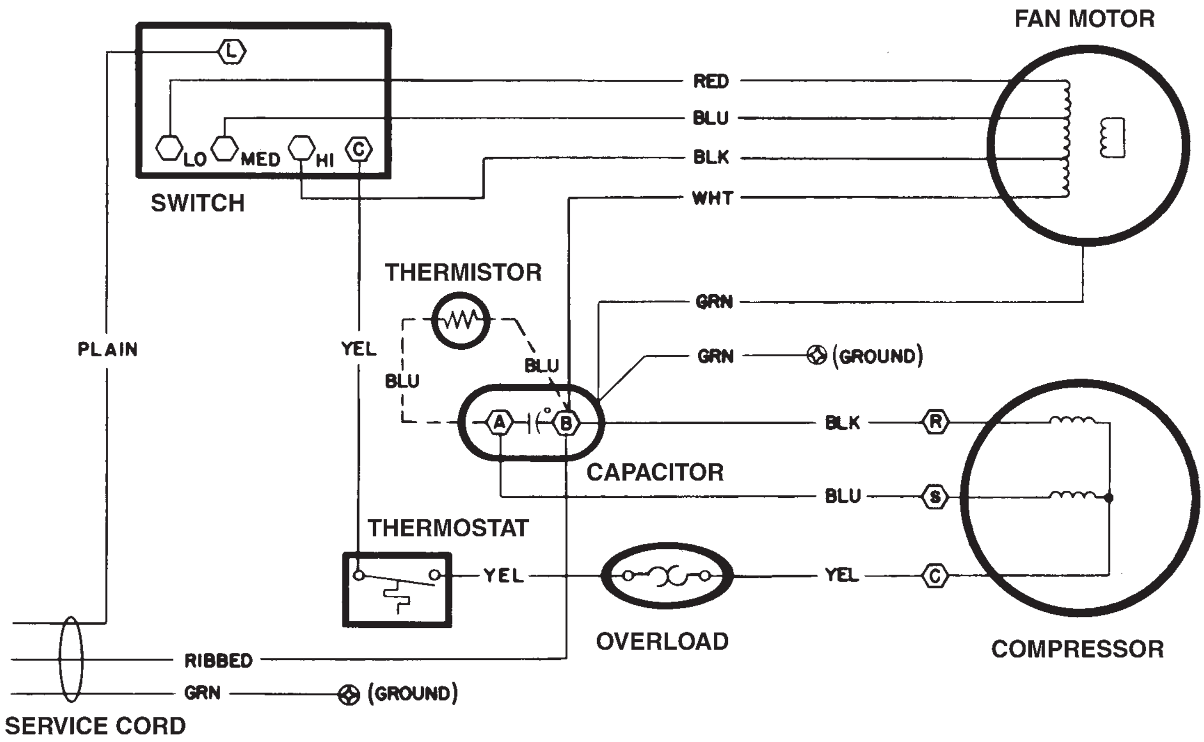
you would expect. Notice the overload symbol, for example. The symbol used is the same as the symbol for an overload heater discussed earlier in the text. There are, however, no overload contacts shown. The schematic is indicating the use of a small, single-phase bimetal overload unit that acts as both heater and overload contact.

Next, find and examine the fan motor. Notice that this motor has several windings that indicate that it is used for multispeed operation. Notice also that there is no capacitor connected to this motor. The small winding shown separate is the start winding. Because there is no start or run capacitor shown, this motor is a resistance start induction run. Notice that the white wire is connected from the motor to B terminal of the capacitor and then to one lead of the service chord. This indicates that the white wire is common to the other windings. Now trace the connection of the red, blue, and black wires. The red wire is connected to the LO speed position on the switch; the blue wire is connected to the MED speed position and the black wire is connected to the HI speed position.

Next, examine the compressor. Notice that two windings are shown. Each winding is connected to a terminal. One terminal is labeled with an R to represent the run winding. The middle terminal is labeled with an S, which represents the start winding terminal, and the third terminal is labeled with a C, which indicates the common terminal. Trace the common terminal through the overload and thermostat to terminal C on the switch. Notice that the thermostat and overload are connected in series with the compressor. Now trace the run lead of the compressor. Notice that it is connected to the B terminal of the capacitor. This shows that the run winding is connected to the common side of the service chord. Now trace the start lead to the A side of the capacitor. Notice that the capacitor is connected in series between the common side of the service chord and the start winding. The thermistor connected across the capacitor terminals is used to decrease the capacitance connected in series with the compressor after the compressor is in operation. Recall that a thermistor is a temperature-sensitive resistor. This thermistor has a negative temperature coefficient, which means that it will have a very high resistance when it is cool. When its temperature increases, its resistance will decrease. When the compressor is first started, the thermistor is cool because no current has been flowing through it. This causes its resistance to be much greater than the capacitive reactance of the capacitor. The full amount of the capacitor is now connected in series with the start winding.

As current flows through the thermistor, its temperature begins to increase. This causes a decrease in its resistance, which permits more current to flow. As the resistance of the thermistor decreases, the effect of the capacitor on the motor decreases also. The effect is very similar to having a compressor that has both a start and run capacitor in the circuit for starting, and then disconnecting the start capacitor and permitting the motor to operate with the run capacitor only.

The last component to be discussed is the switch. Notice that it is not shown with internal electrical connections. There is a legend at the bottom of the schematic, however, that shows which terminals are connected when the switch is set in different positions. In the LO position, for example, terminal L is connected to both the LO fan speed position and the C position, which permits the thermostat to control the compressor.



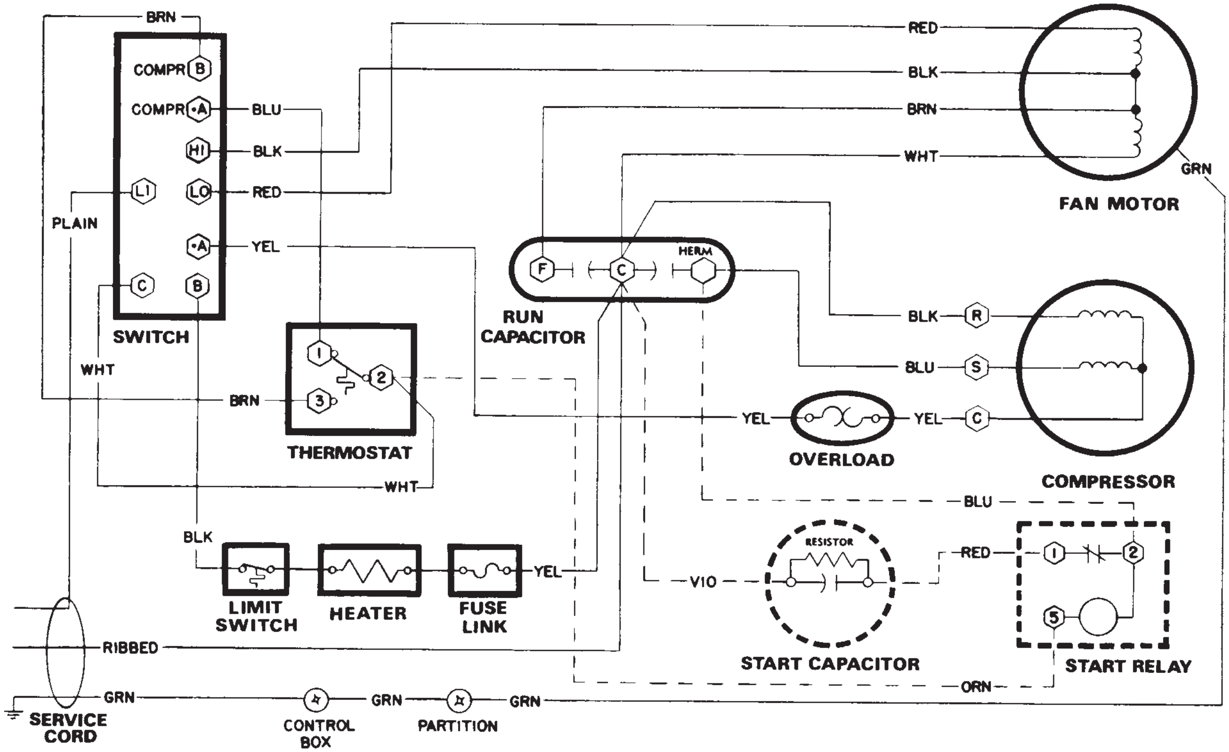
SWITCH POSITION	CONTACTS MADE
LO	L to C, L to LO
MED	L to C, L to MED
HI	L to C, L to HI
OFF	None

Figure 41–2
Schematic diagram. (Courtesy of Carrier Corp.).

SCHEMATIC 2

The second schematic to be discussed is shown in Figure 41–3. This schematic is for another room-type air conditioner, but it has some added components. This unit is used to provide heat as well as cooling. An **electric resistance heating element** is used to provide heat in cool weather. Notice also the addition of the start capacitor and start relay. The thermostat in this circuit is **double-acting** instead of a single-pole single-throw. This permits the same thermostat to be used for both heating and cooling. Notice also that the run capacitor is different. This capacitor is actually two capacitors contained in the same case. The junction point between the two capacitors is connected to one side of the service chord. The fan motor in this unit is different also. Notice that this fan used a run capacitor connected in series with the start winding of the motor at all timers. This motor is a permanent split-capacitor motor. Notice that this motor has two speeds instead of three.

The start capacitor is connected in parallel with the run capacitor to increase the starting torque of the compressor. The resistor shown connected across the terminals of the start capacitor is a relatively high value of fixed resistance used to discharge the capacitor when it is disconnected from



SWITCH POSITION	CONTACTS MADE
FAN	H1 to L1
HI COOL	Compr A and H1 to L1, A to C
LO COOL	Compr A and LO to L1, A to C
HI HEAT	Compr B and H1 to L1, B to C
LO HEAT	Compr B and LO to L1, B to C
OFF	None

Figure 41–3
Room air conditioner circuit. (Courtesy of Carrier Corp.).

the circuit. Notice the start relay. The start capacitor is connected in series with the normally closed contact. This is a potential starting relay, which senses the voltage induced in the start winding and opens the contact when the motor reaches about 75% of its full speed.

In this circuit, the switch is the main controller. For example, trace the circuit when the switch is placed in the high cool position. The legend at the bottom of the schematic indicates that when the switch is in the HI cool position, terminals COMPR A and HI are connected to terminal L1, and terminal A is connected to terminal C. When HI is connected to L1, the fan motor will operate in its high speed. When terminal COMPR A is connected to L1, a current path is provided to terminal 1 of the thermostat. Terminal 2 is connected to terminal C of the switch. Since switch terminal A is connected to switch terminal C, power is connected to the compressor motor through the thermostat contact. When the thermostat is connected in this manner, an increase in temperature will cause the thermostat contacts to close and a decrease in temperature will cause them to open.

Now assume that the switch has been set to the low heat position. The switch legend indicates that terminals COMPR B, and LO are connected to L1, and terminal B is connected to terminal C. When LO is connected to L1, the fan motor operates in the low speed position. When terminal COMPR B is connected to L1, power is provided to terminal 3 of the thermostat. Terminal 2 is connected to terminal C of the switch. Since switch terminal B is connected to the resistance heater through the high limit switch and fuse, the thermostat controls the operation of the heater. When the thermostat is connected in this manner, a decrease in temperature will cause the thermostat contacts to close and an increase in temperature will cause them to open.

SUMMARY

- Legends are sometimes used with schematic diagrams to aid in understanding.
- A legend is a list of symbols and/or notations and gives the definition of these symbols and/or notations.
- When using a schematic to interpret the operation of a circuit, it is generally helpful to identify the major components in the circuit first.

KEY TERMS

double-acting
electric resistance heating element
legend
major components

REVIEW QUESTIONS

1. What is a legend?
2. Refer to Figure 41–2. What would be the action of this circuit if the overload relay should burn open?
3. What purpose does the thermistor connected in parallel with the capacitor serve?
4. In Figure 41–2, what switch connections are made when the switch is in the HI position?
5. In Figure 41–3, why is the thermostat switch as a single-pole double-throw?
6. In Figure 41–3, what do the dashed lines showing connection between the start capacitor and start relay to other parts of the circuit mean?
7. In Figure 41–3, what color wire is connected between terminal 2 of the thermostat and terminal C of the switch?
8. What color wire is connected between terminal 2 of the thermostat and the start relay?
9. In Figure 41–3, if no continuity is shown when one lead of an ohmmeter is connected to switch terminal A and the other is connected to terminal C of the compressor, what does it mean?
10. In Figure 41–3, to what two points should the terminals of an ohmmeter be connected to check the continuity of the resistance heater circuit?

TROUBLESHOOTING QUESTIONS

Refer to the schematic shown in Figure 41–3 to answer the following questions.

1. Assume that the switch has been set in the HI HEAT position. Now assume that the thermostat controls the operation of the electric heating element, but does not control the operation of the fan motor. Which of the following could cause this condition?

   A. The thermostat is defective.

   B. The high limit switch is stuck in the closed position.

   C. The switch is not making connection between contacts B and C.

   D. There is nothing wrong with the unit. This is normal operation for this unit.

2. When the switch is set in the LO COOL position, the unit will operate normally. When the switch is set in the HI COOL position, the compressor will operate, but the fan motor will not. Which off the following could cause this condition?

   A. The fan motor winding between the red and black wire is open.

   B. The fan motor winding between the black and brown wire is open.

   C. The switch is not making connection between terminals COMPR A and HI.

   D. The capacitor section between terminals C and F is defective.

3. When the switch is set in HI COOL or LO COOL position, the unit will operate normally. When the switch is set in HI HEAT or LO HEAT position, the fan motor will operate normally, but the unit will not provide any heating. Which of the following could cause this condition?

   A. The thermostat is not making connection between 2 and 3.

   B. The limit switch is open.

   C. The fuse link is open.

   D. All of the above.

4. When the switch is set in the LO COOL position, the unit will operate normally. When the switch is set in the HI COOL position the fan motor will operate but the compressor will not operate. Which of the following could cause this condition?

   A. The overload unit is open.

   B. The switch is not making contact between terminals A and C.

   C. The potential starting relay is defective.

   D. The thermostat is defective.

5. Assume that the switch has been set in the LO COOL position, and the fan motor operates normally. When the thermostat contact closes between terminals 1 and 2, the compressor hums but does not start. An ohmmeter test of the compressor is as follows:

R to C 2 ohms

S to C 6 ohms

R to S 8 ohms

R to case infinity ohms

S to case infinity ohms

Which of the following would *not* cause this problem?

A. Overload is open.

B. The capacitor between terminals C and HERM is defective.

C. The start capacitor is defective.

D. The potential starting relay is defective.

UNIT 42

A Commercial Air Conditioning Unit

OBJECTIVES

After studying this unit the student should be able to:

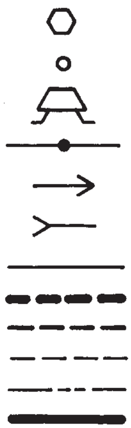
- Recognize electrical components from the symbols on the schematic
- Discuss the operation of a commercial air conditioning unit
- Interpret a three-phase schematic diagram

In this unit, a commercial air conditioning system will be discussed. The legend for this schematic is shown in Figure 42–1. The schematic to be discussed is shown in Figure 42–2. Notice that this control system contains several devices not normally found in a residential system. The compressor, for example, is operated by a **three-phase squirrel-cage induction motor**. It can be seen that the motor is three phase by the wye connection of the stator winding. It can be determined that the motor is a squirrel cage because it has no external resistors that would be used for the rotor circuit of a wound rotor induction motor. There is also no DC circuit that would be required to excite the rotor of a three-phase synchronous motor.

The condenser fan motor is a single-phase permanent split-capacitor motor. Notice that the condenser fan motor is connected in parallel with two

LEGEND

C	— Contactor
CC	— Cooling Compensator
CH	— Crankcase Heater
Comp or Compr	— Compressor
CPCS	— Compressor Protection Control System
CR	— Control Relay
CT	— Current Transformer
FC	— Fan Capacitor
FM	— Fan Motor
FS	— Fan Switch
FT	— Fan Thermostat
HC	— Heating Control
HPS	— High Pressure Switch
HR	— Holding Relay
IFM	— Indoor Fan Motor
IFR	— Indoor Fan Relay
IP	— Internal Protector
LPS	— Low Pressure Switch
OL	— Overload
QT	— Quad Terminal
R	— Resistor
RC	— Run Capacitor
Recep	— Receptacle
Res	— Bleed Resistor
SC	— Start Capacitor
SR	— Start Relay
ST	— Start Thermistor
TC	— Thermostat, Cooling
TD	— Time Delay
Therm	— Thermostat
TM	— Timer Motor
Tran or Trans	— Transformer



Component Connection (Marked)
Component Connection (Unmarked)
Field Splice
Splice
Plug
Receptacle
Factory Wiring
Field Power Wiring
Field Ground Wire
Field Control Wiring (NEC, Class II)
Alternate Wiring
Indicates common potential (Does not represent wire)

Figure 42–1
Schematic legend. (Courtesy of Carrier Corp.).

lines of the compressor. When contactor C energizes, both C contacts close and connect both the compressor and condenser fan motors to the line.

The **crankcase heater** is shown directly below the condenser fan motor, and is connected to terminals 21 and 23. Notice the crankcase heater is energized at all times. As long as power is connected to the circuit, the crankcase heater will be energized.

The control transformer contains two primary windings and two secondary windings. This transformer can be connected to permit a 460- or 230-volt connection to the primary, and the secondary can provide 230 or 115 volts. In the circuit shown, the primary winding is connected in series, which permits 460 volts to be connected to it. The secondary winding is also connected in series, which provides an output voltage of 230 volts.

The 230-volt circuit is used to operate a short-cycle timer circuit. This is the same circuit that was discussed in Unit 35.

The 24-volt circuit is shown at the bottom of the schematic. Notice that only the secondary of the transformer is shown. This is indicating that its power can be derived from almost anywhere. The primary of this transformer could be connected to a 120-volt circuit inside the building. This circuit contains the high- and low-pressure switches. If one of them should open, it will have the same effect as opening the thermostat.

Notice that the **indoor fan relay (IFR)** is shown, but the fan motor is not. In a commercial location, there may actually be several fans operated by the IFR relay. In practice, the IFR relay may be used to control the coils of other relays, which connect the fan motors to the line.

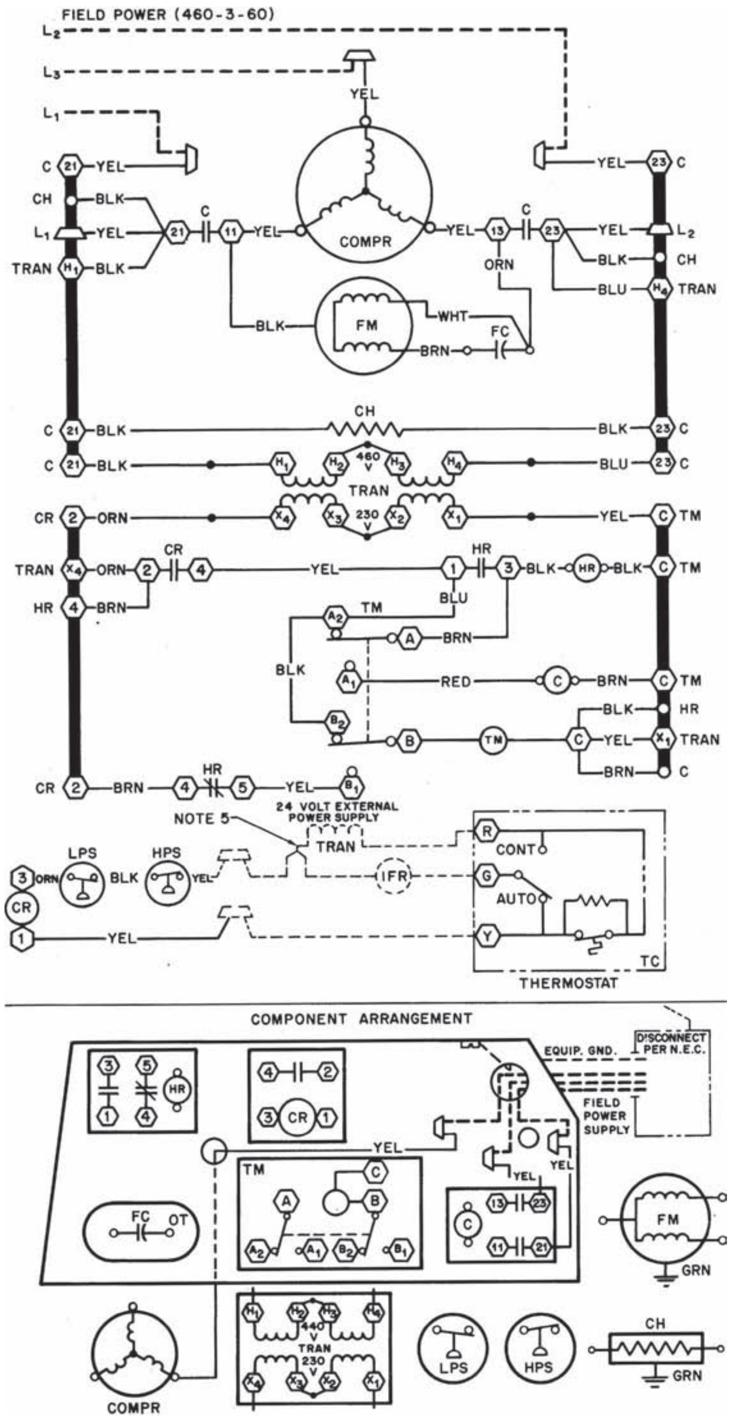


Figure 42–2
Schematic diagram. (Courtesy of Carrier Corp.).

The thermostat is a single-pole single-throw contact. The resistor shown connected around the thermostat contact represents the heat anticipator. A switch is also provided that will permit the indoor fan to be operated automatically or manually.

The last item shows the component arrangement. This is used to aid the service technician in locating the different control components in the system.

SUMMARY

- The compressor in this example circuit is powered by a three-phase squirrel-cage motor.
- The windings in the compressor motor are connected in a wye configuration.
- The condenser fan motor is a single-phase permanent-split capacitor motor.
- The control transformer contains two primary and two secondary windings.
- The thermostat, low-pressure switch, and high-pressure switch are connected to a 24-volt system.
- The control system for this unit contains a short-cycle timer.

KEY TERMS

crankcase heater
indoor fan relay (IFR)
three-phase squirrel-cage induction motor

REVIEW QUESTIONS

1. What does the term CC mean if seen on a control schematic?
2. What does the term CPCS mean if seen on a schematic?

   Refer to Figure 42–2 for the following questions.
3. If it is desired to change the voltage controlling the short-cycle timer from 230 volts to 115 volts, what transformer leads should be connected together?
4. Assume the system has stopped operation. A voltmeter is connected across the LPS switch terminals and it indicates 24 volts. The voltmeter is then connected across the HPS switch and it indicates 0 volts. Which switch is stopping the operation of the circuit?
5. When the system is operating normally, how much voltage should be seen across the CR relay coil?

TROUBLESHOOTING QUESTIONS

Refer to the schematic shown in Figure 42–2 to answer the following questions.

1. Referring to the schematic in its present state, will the compressor start with the thermostat in the closed position? Explain your answer.

   A. Yes

   B. No

2. What voltage is used to operate the short-cycle timer and compressor relay?

   A. 460 VAC

   B. 230 VAC

   C. 120 VAC

   D. 24 VAC

3. What relay controls the operation of the condenser fan motor?

   A. IFR

   B. HR

   C. C

   D. CR

4. Which of the following components is not shown on the schematic?

   A. COMPRESSOR MOTOR

   B. CONDENSER FAN MOTOR

   C. THERMOSTAT

   D. EVAPORATOR FAN MOTOR

5. Assume that the unit is in operation and suddenly stops. A voltmeter test reveals the following information:

   Voltage across L_1, L_2, and L_3 = 460 VAC
   Voltage across X_1 to X_4 of the control transformer = 230 VAC
   Voltage across CR coil = 24 VAC
   Voltage across terminals 2 and 4 of the CR contact = 230 VAC
   Voltage across coil C = 0

   What is the most probable cause of trouble? Explain your answer.

   A. CR coil is open.

   B. CR contacts are stuck closed.

   C. Coil HR of the short-cycle timer is open.

   D. Coil C is open.

UNIT 43

Heat-Pump Controls

OBJECTIVES

After studying this unit the student should be able to:

- Describe the operation of a heat pump
- Discuss the function of a double-acting thermostat in a heat-pump system
- Discuss the operation of a sequence timer
- Describe the operation of the defrost thermostat and timer

A heat pump is a device that provides both heating and air conditioning within the same unit. In the cooling cycle, the outside heat exchange unit is used as the condenser and the inside heat exchanger is used as the evaporator. When the heat pump is used for heating, the reversing valve reverses the flow of refrigerant in the system and the outside heat exchanger becomes the evaporator. The inside heat exchanger becomes the condenser. Heat pumps also contain some type of back-up heating system that is used when the outside temperature is too low to make heat transfer efficient. The most common type of back-up heat is electric-resistance heat.

Heat pumps contain other control devices that are generally used only with heat-pump equipment, such as two-stage thermostats, sequence relays, and defrost timers.

TWO-STAGE THERMOSTATS

The two-stage thermostat is a thermostat that contains two separate mercury contacts. It is similar to the programmable thermostat except that the two mercury contacts cannot be set independently of each other. The mercury contacts of the two-stage thermostat are so arranged that one contact will make connection slightly ahead of the other. For example, assume the heat pump is being used in the heating mode. Now assume that the temperature drops. One of the contacts will make connection first. This contact turns on the compressor and heat is provided to the living area. If the compressor can provide enough heat to raise the temperature to the desired level, the second mercury contact does not make connection. If the compressor cannot provide the heat needed, the second mercury contact will close and turn on the electric-resistance heating elements to provide extra heat to the living area.

THE SEQUENCE TIMER

The **sequence timer** is an on-delay timer used to connect the heating elements to the line in stages instead of all at once. Most sequence timers contain two or three contacts and are operated by a small heating element that heats a bimetal strip. When the bimetal strip becomes hot enough, it snaps from one position to another and closes the two contacts. A photograph of this type of timer is shown in Figure 43–1.

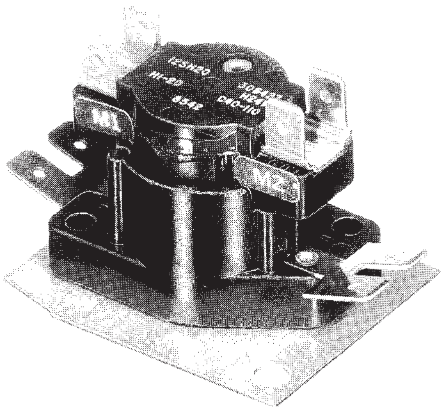


Figure 43–1
Sequence relay. (Courtesy of Emerson Electric Co., White-Rodgers Division).

DEFROST TIMER

When the heat pump is used in the heating mode of operation, it removes heat from the air and delivers it inside the living area. This means that the outside heat exchanger is being used as the evaporator and cold refrigerant is circulated through it. Any moisture in the air can cause frost to form on the coil and reduce the airflow through it. This will reduce the efficiency of the unit. For this reason, it is generally necessary to defrost the outside heat exchanger. Defrosting is done by disconnecting the condenser or outside fan motor and reversing the flow of refrigerant through the coil. This causes the unit to temporarily become an air conditioner and warm refrigerant is circulated through the coil.

Before the defrost cycle can be activated, two separate control conditions must exist. The **defrost thermostat**, located on the outside heat exchanger, must be closed; and the **defrost timer** must permit the defrost cycle to begin. A schematic diagram of a basic defrost control circuit is shown in Figure 43–2. Notice that the defrost timer is connected in parallel with the compressor. This means that the timer can operate only when the compressor is in operation. Notice also that the defrost cycle energizes the **reversing valve solenoid**. This means that this unit is in the heating mode when the solenoid is deenergized.

Notice the defrost timer contains two contacts, DT1 and DT2. DT1 is normally open and DT2 is normally closed. The defrost relay (DFR) contains three contacts. DFR1 is normally closed and is connected in series with the outside fan motor. DFR2 is normally open and is connected in parallel with contact DT1. Contact DFR3 is normally open and is connected to the reversing valve solenoid.

The schematic shown in Figure 43–3 illustrates the condition of the circuit when the defrost cycle first begins. Notice that the defrost timer (DT) has caused contact DT1 to close, but contact DT2 has not opened. The contacts of the defrost timer are operated by two separate cams. The cams are so arranged that contact DT1 will close before DT2 opens.

The schematic in Figure 43–4 illustrates the condition of the circuit immediately after the defrost relay has energized. Notice that all DFR contacts

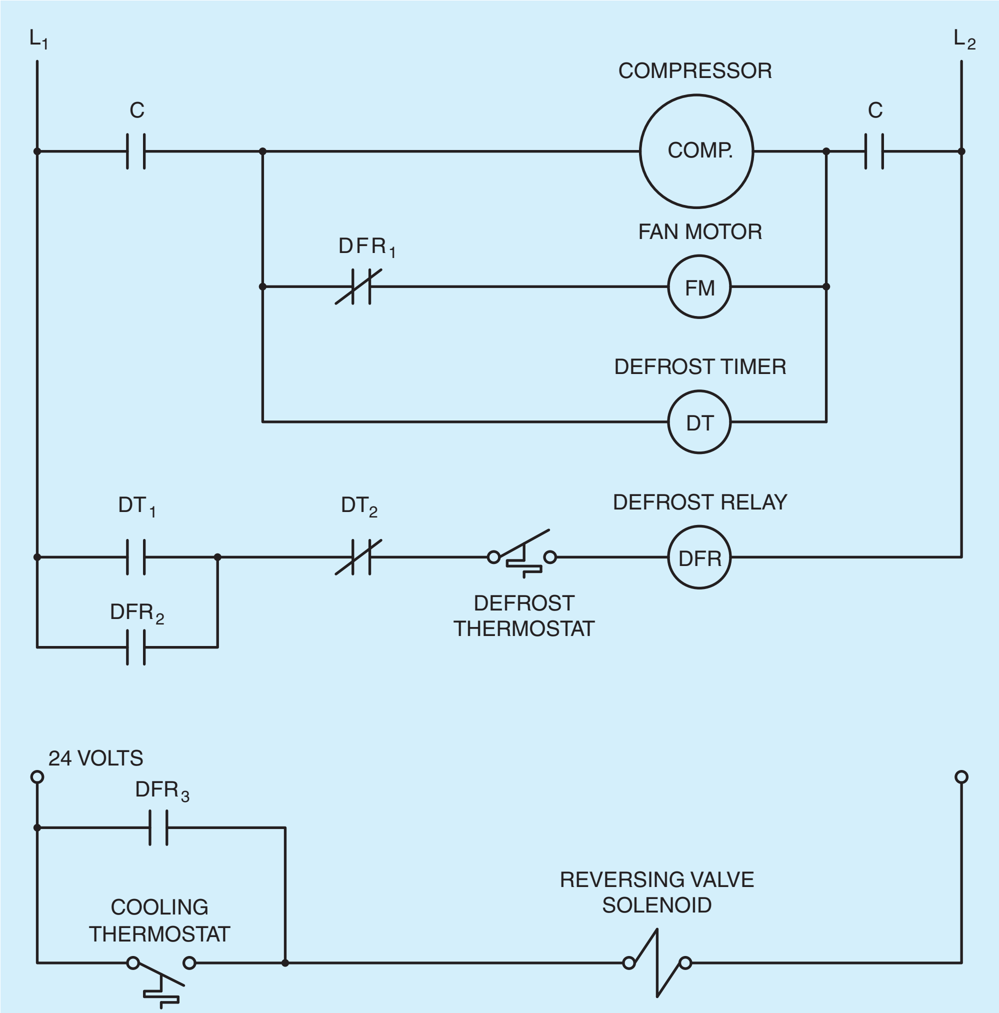


Figure 43–2
Defrost cycle circuit. (Source: Delmar/Cengage Learning)

have changed position. DFR1 contact is now open and the outside fan motor has been disconnected from the circuit. DFR2 contact is closed and is used as a holding contact around contact DT1. DFR3 contact is closed and provides current to the reversing valve solenoid to reverse the flow of refrigerant in the system.

The schematic shown in Figure 43–5 illustrates the condition of the circuit after contact DT1 reopens. Notice that contact DFR2 maintains a current flow path around the now open DT1 contact and the defrost cycle is permitted to continue. The unit will remain in the defrost cycle until the defrost thermostat is satisfied and opens the circuit, or the defrost timer causes the DT2 contact to open. When this occurs, the system will change back to its original condition shown in Figure 43–2.

Electronic Defrost Timers

Many units now employ an electronic defrost timer similar to the one shown in Figure 43–6. This timer has a fixed 10-minute defrost time. The time interval between defrost cycles can be set by

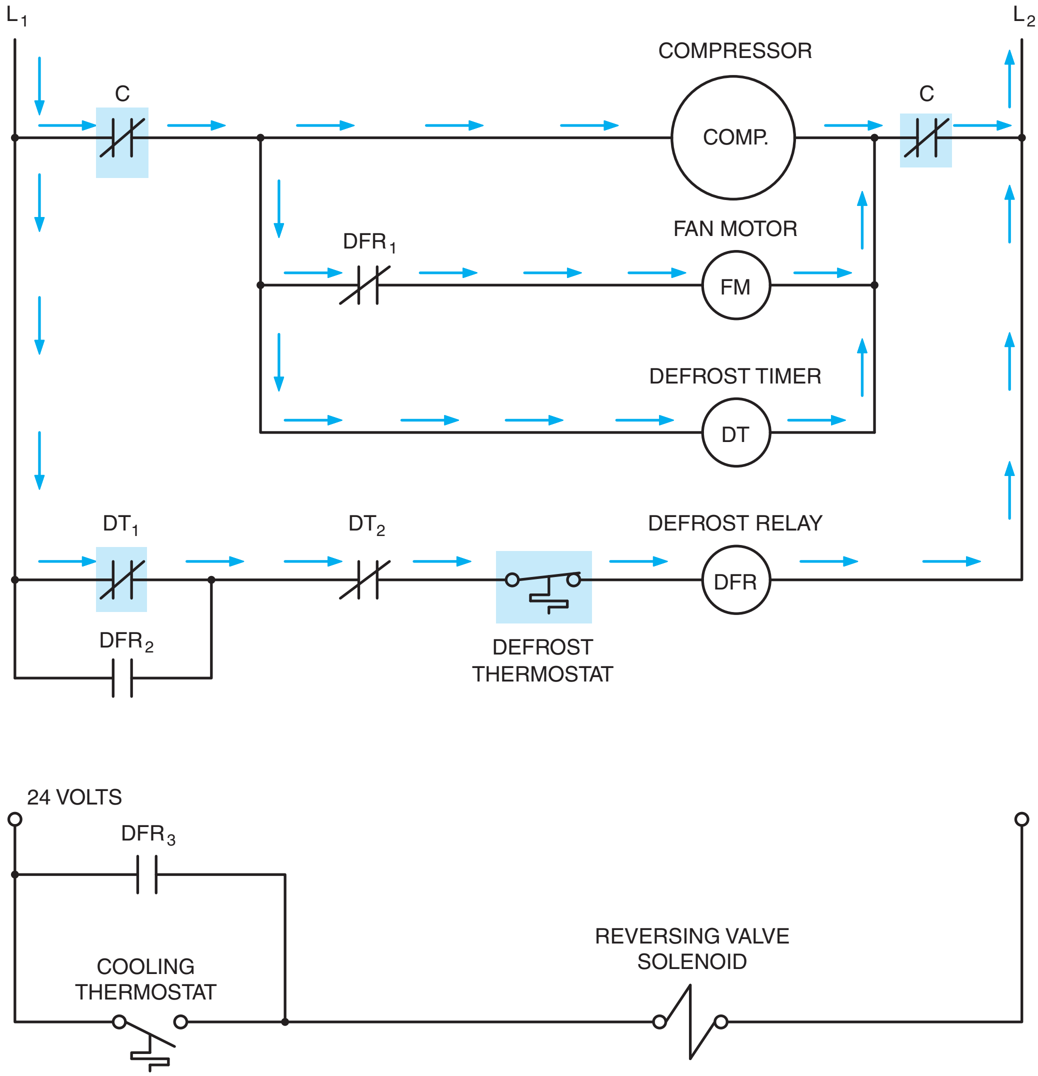


Figure 43–3
Initial circuit operation. (Source: Delmar/Cengage Learning)

moving a jumper lead to the proper pin. The time interval can be set for 30, 60, or 90 minutes. Two pins marked TEST can be shorted to reduce the defrost time by a factor of 2, 5, and 6 seconds. This permits the service technician to test the unit without waiting a long period of time. The HOLD terminal permits the timer to accumulate time only during the time that the compressor is in operation. The connection diagram for this module is shown in Figure 43–7.

THE FULL SYSTEM SCHEMATIC

A schematic for a residential, heat-pump unit is shown in Figure 43–8. The legend for the schematic is shown in Figure 43–9. Notice in Figure 43–8 that the schematic is divided into three main sections. One section shows the **outdoor compressor controls**. The second section shows the **indoor resistance heat** and blower-fan controls, and the third section shows the **low-voltage controls**.

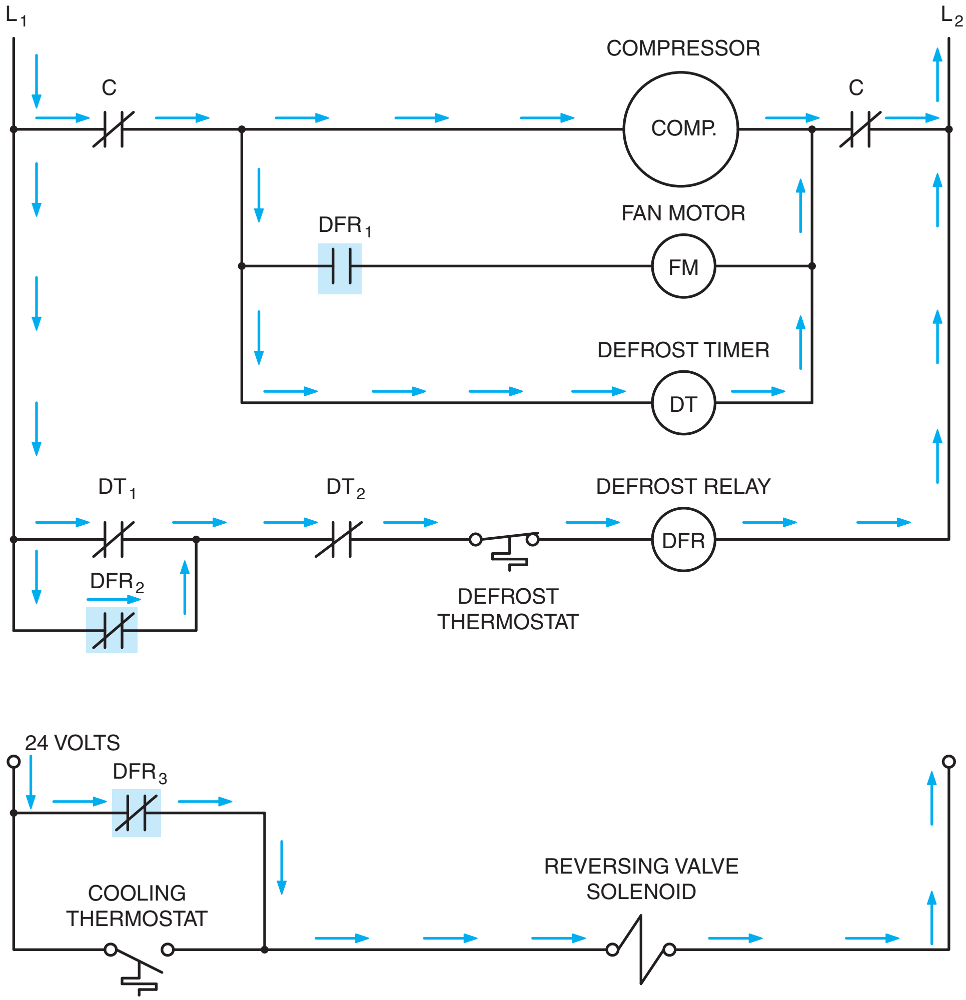


Figure 43–4
Defrost relay energizes. (Source: Delmar/Cengage Learning)

To begin the study of this control system, locate the low-voltage section of the schematic. It is divided into three sections. One section is located directly below the blower fan motor. Notice the 24-volt transformer used to provide needed power. Now locate the **terminal board** directly to the left of the control transformer. The terminal board shows terminal connections marked inside hexagon-shaped figures. Starting at the top and going down they are R, G, O, Y, and so on. Now locate the second control section directly under the outdoor unit schematic. Notice the terminal board contains some of the same letter connection points as the other terminal board. Now locate the thermostat. Notice the thermostat contains **terminal markings** that are the same as the other two boards. These terminal markings are used to aid in tracing the circuit. For example, locate the terminal marked Y on the thermostat. Now, locate the terminal marked Y on the board closest to the control transformer. Finally, locate the terminal marked Y on the terminal board located under the outdoor unit. If the wires are traced, it will

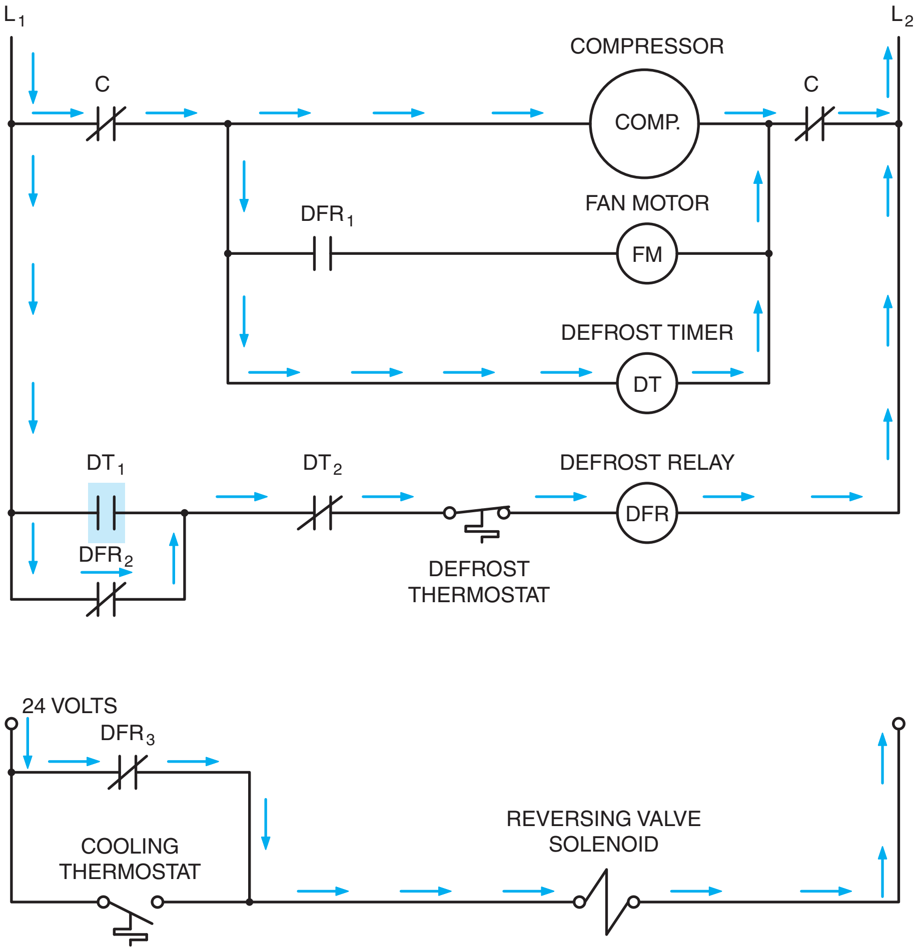


Figure 43–5
Defrost timer opens DT1 contact. (Source: Delmar/Cengage Learning)

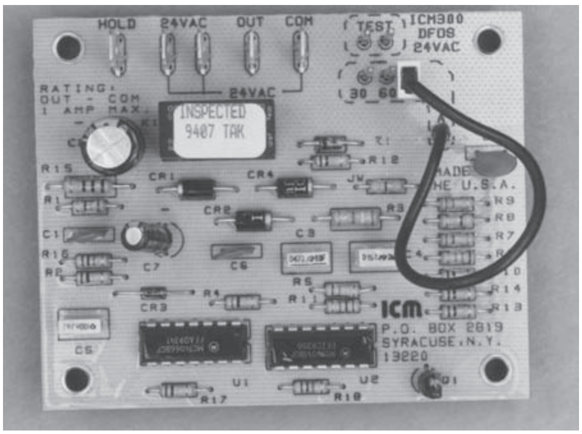


Figure 43–6
Electronic defrost timer module. (Source: Delmar/Cengage Learning)

be seen that all of the terminals marked Y are connected together. This is true for all the other terminals that are marked with the same letter. Terminal markings are often used to help simplify a schematic by removing some to the connecting wires. The circuit shown in Figure 43–10 is very similar to the schematic in Figure 43–8 except that the terminal markings are used instead of connecting wires.

Notice the use of the two-stage thermostat in the schematic shown in Figure 43–8. The thermostat is so constructed that contact H1 will close before H2. Also, contact CO will close before C1. Also notice that the thermostat has an emergency heat position that permits the switch to override the thermostat and the electric resistance heaters to be connected in the circuit on a call for heat. Notice also that

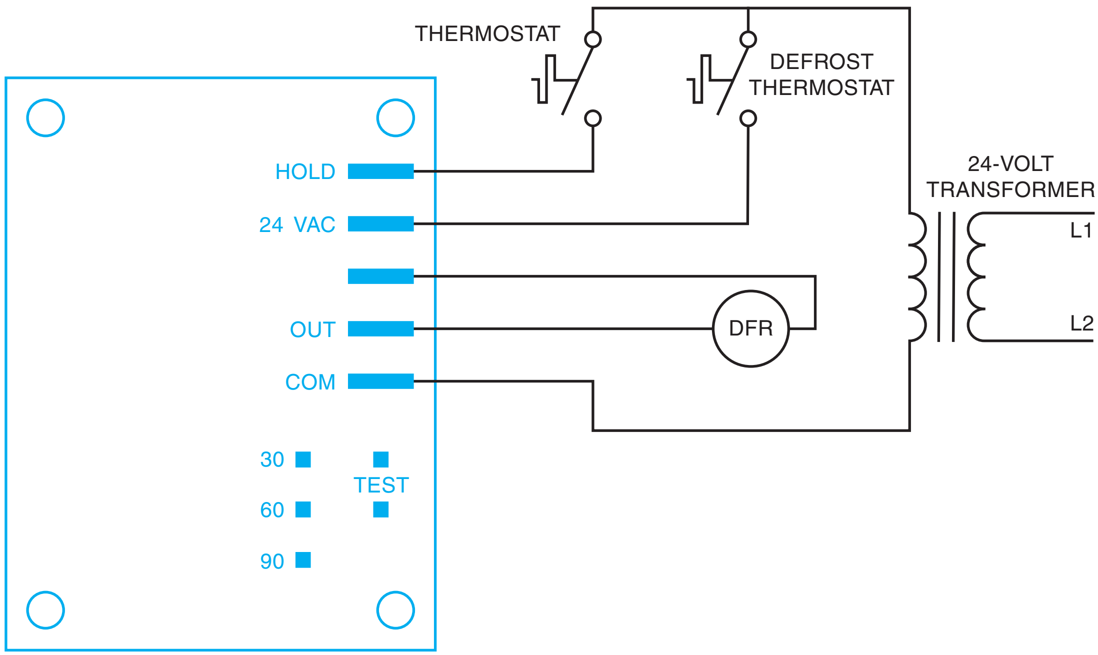


Figure 43–7
Connection for a typical electronic defrost timer. (Source: Delmar/Cengage Learning)

this control uses an outdoor thermostat (ODT). The ODT senses the outside temperature and permits sequence relays 1 and 2 to operate only if the outside temperature is below a certain level.

Locate the three sequence relay coils, SEQ1, SEQ2, and SEQ3. Trace the operation of the circuit when sequence relay 1 is energized. The two SEQ1 contacts located in the resistance heat section close and connect the heating elements to the line. A third SEQ1 contact is connected in series with SEQ2 timer. When this contact closes, SEQ2 timer can begin operation provided the outdoor thermostat is closed. When this timer completes its time sequence, all SEQ2 contacts close. The two SEQ2 contacts located in the resistance heat section connect the second bank of resistance heaters to the line. The third SEQ2 contact permits current to flow to SEQ3 timer. At the end of its time cycle, the two SEQ3 contacts located in the resistance heater section close and connect the third bank of heaters to the line.

Locate the blower fan motor. Notice that this is a multispeed fan motor. Only two of the speeds are used, however. High speed is used when the fan control relay is energized by the thermostat. Notice that when the normally open FR contacts close, high speed is connected to the line. Also notice that the normally closed FR contacts are connected to the first SEQ1 contact. When SEQ1 contact closes, the second fan speed is connected to the line.

Now locate the defrost timer and defrost relay. Trace the action of the circuit as described earlier in this unit. Notice that the DFR contact located between

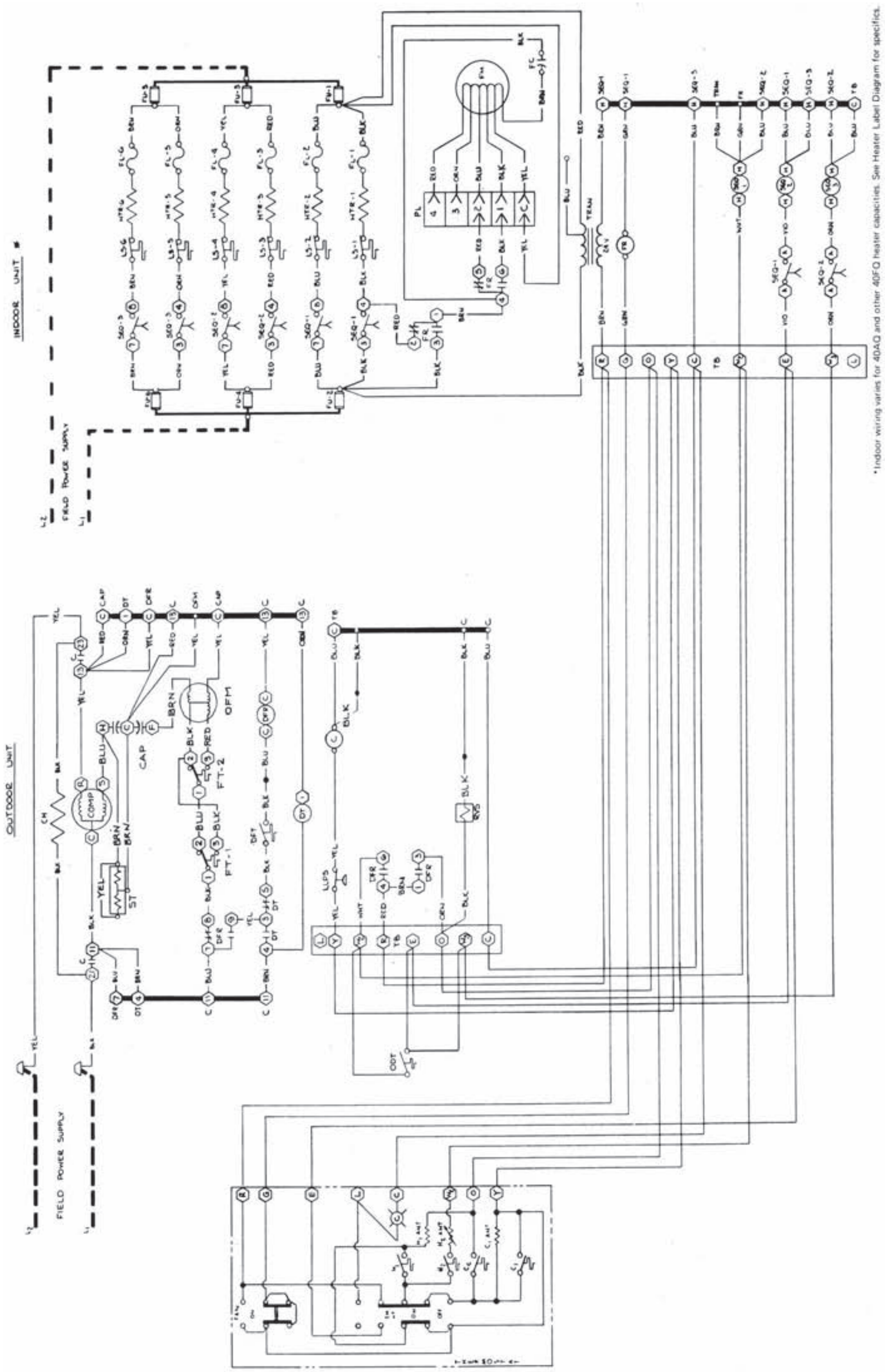


Figure 43–8
Heat-pump circuit.
(Courtesy of Carrier Corp.).

LEGEND

Ant.	—	Anticipator
C	—	Contactor
Co	—	First-Stage Cooling Thermostat
C1	—	Second-Stage Cooling Thermostat
Cap.	—	Capacitor
CH	—	Crankcase Heater
Comp	—	Compressor
DFR	—	Defrost Relay
DFT	—	Defrost Thermostat
DT	—	Defrost Timer
Em Ht	—	Emergency Heat
EHR	—	Emergency Heat Relay
FC	—	Fan Capacitor
FL	—	Fuse Link
FT	—	Fan Thermostat
Fu	—	Fuse
H1	—	First-Stage Heating Thermostat
H2	—	Second-Stage Heating Thermostat
Htr	—	Heater
IFM or FM	—	Indoor Fan Motor
IFR or FR	—	Indoor Fan Relay
LLPS	—	Liquid Line Pressure Switch
LS	—	Limit Switch
ODT	—	Outdoor Thermostat
OFM	—	Outdoor Fan Motor
Pl	—	Plug
QT	—	Quad Terminal
RC	—	Run Capacitor
RVS	—	Reversing Valve Solenoid
SC	—	Start Capacitor
Seq	—	Sequencer
SR	—	Start Relay
ST	—	Start Thermistor
TB	—	Terminal Board
Tran	—	Transformer

Indicates Common Potential Only. Does Not Represent Wire.

Factory Wiring

Field Power Wiring

Field Control Wiring

Field Splice

Component Connection (Marked)

Component Connection (Unmarked)

Junction

Figure 43–9
Schematic legend. (Courtesy of Carrier Corp.).

terminals 4 and 6 is used to override the outdoor thermostat. This permits the resistance heaters to be used during the defrost cycle, preventing cold air from being blown in the living areas during the time the unit is operating as an air conditioner.

Now locate the two outside fan-speed control thermostats labeled FT1 and FT2. Notice that when FT1 is in the position shown it permits FT2 to operate the fan in either high speed or low speed. When FT1 changes position and makes connection between terminals 1 and 3, it connects the fan in the high-speed position and FT2 has no control over the speed.

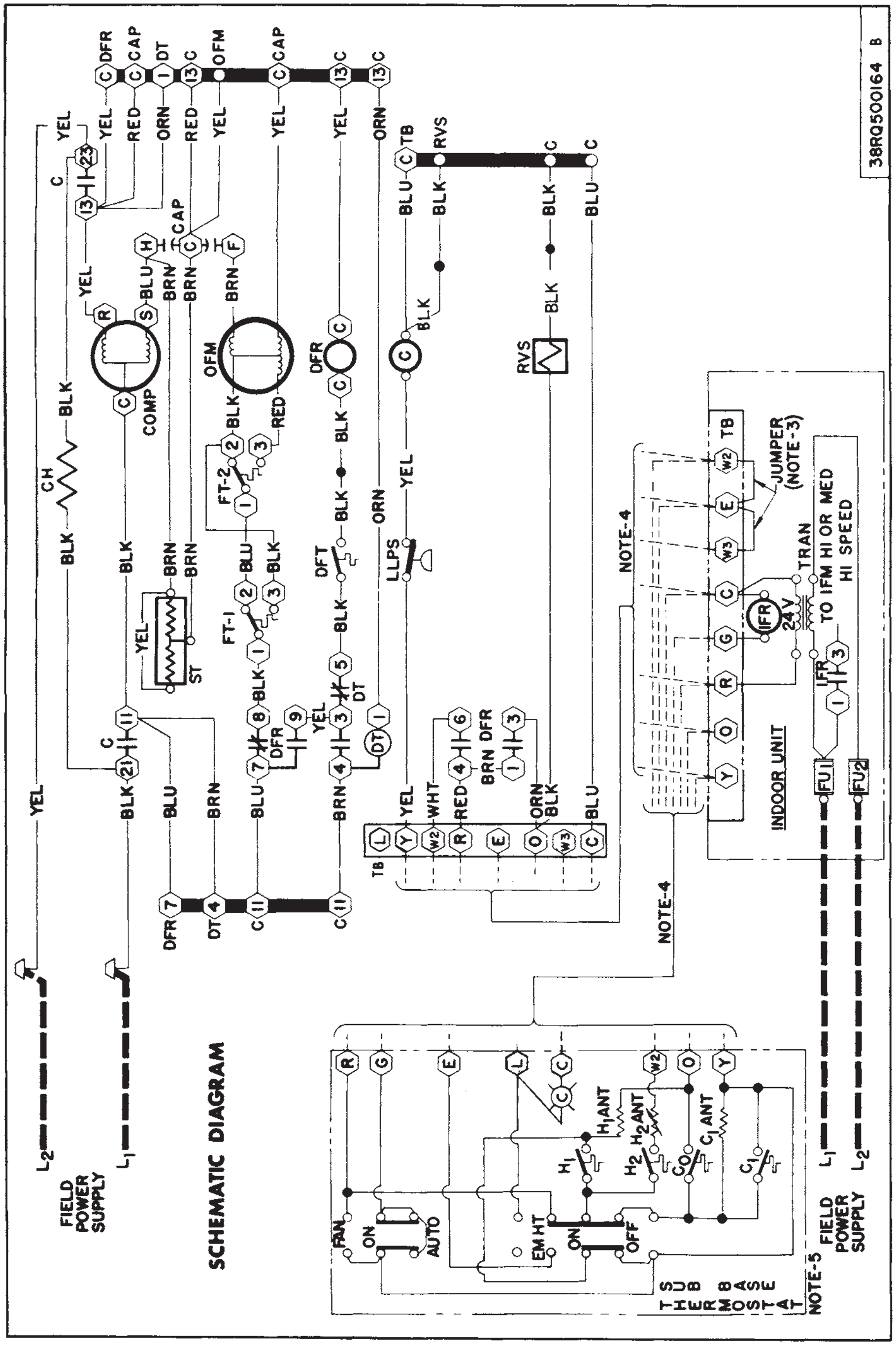


Figure 43–10 Terminal identification is used to simplify schematic. (Courtesy of Carrier Corp.).

SUMMARY

- A heat pump is a device that provides both heating and cooling within the same unit.
- Heat-pump systems contain a back-up heating system that is used when the outside ambient temperature is too low to provide enough heat transfer.
- The double-acting thermostat contains two separate sets of contacts.
- The first contact of a double-acting thermostat turns the heat-pump compressor on. The second contact turns the strip heaters on.
- Sequence timers are used to turn the strip heaters on in stages instead of all at one time.
- The defrost timer is used to reverse the flow of refrigerant at periodic intervals to melt any accumulation of frost on the outside evaporator coil.

KEY TERMS

defrost thermostat
defrost timer
indoor resistance heat
low-voltage controls
outdoor compressor controls
reversing valve solenoid
sequence timer
terminal board
terminal markings

REVIEW QUESTIONS

1. What is the purpose of terminal markings?
2. What two control components must be in a closed position before a heat pump is permitted to go into the defrost cycle?
3. The thermostat shows a small pilot light connected between terminals L and C. What condition of the thermostat turns this light on?
4. What is the purpose of the outdoor thermostat?
5. What is the operating voltage of the reversing valve solenoid?

TROUBLESHOOTING QUESTIONS

Refer to the schematic shown in Figures 43–8 and 43–10 to answer the following questions.

1. Assume that the unit is set in the heating mode and that thermostat contact H_1 closes. Also assume that when H_1 closed, the indoor fan motor and outside fan motors started, but the compressor motor did not. Which of the following could cause this condition?

   A. The liquid line pressure switch is open.

   B. Coil C is open.

   C. The compressor motor is defective.

   D. All of the above.

2. If the unit is set in the heating mode and thermostat contact H_1 closes, what is the normal action of the unit?

A. The heat strips, indoor fan motor, outdoor fan motor, and compressor turn on.

B. The indoor fan motor, outdoor fan motor, and compressor turn on.

C. The heat strips and indoor fan motor turns on.

D. The heat strips, outdoor fan motor, indoor fan motor, compressor, and reversing valve turn on.

3. Assume that cooling thermostat C_0 is closed and C_1 is open. What is the normal operating sequence of the unit?

A. The indoor fan motor, outdoor fan motor, and compressor turn on.

B. Only the indoor fan motor turns on.

C. The indoor fan motor, outdoor fan motor, reversing valve, and compressor turn on.

D. The reversing valve turns on.

4. Assume that fuses FL_1 and FL_2 connected to strip heaters HTR-1 and HTR-2 are blown. Now assume that thermostat HT_1 closes and starts the heat pump compressor, but the outside temperature is too low to permit the heat pump to sufficiently heat the dwelling and thermostat H_2 closes also. What will be the action of the unit?

A. The compressor will continue to run, but the heat strips will not activate because they are staged and must operate in proper sequence.

B. The heat pump compressor stops operating because thermostat H_2 prevents both the compressor and heat strips from being turned on at the same time.

C. The compressor continues to operate and after some period of time sequencer 1 will time out and turn on sequencer 2 energizing heating elements HTR-3 and HTR-4. If enough time elapses, sequencer 2 will time out and turn on sequencer 3 which energizes heating elements HTR-5 and HTR-6.

D. The compressor will eventually be disconnected from the line due to high pressure because the inside blower cannot operate in the heating mode if the first bank of strip heaters fail to operate.

5. The schematic shows a small lamp connected between terminals C and L on the thermostat. What is this lamp used to indicate?

A. The compressor is in operation.

B. The compressor motor has failed.

C. The unit is in the defrost mode.

D. The thermostat has been set for emergency heat.

UNIT 44

Packaged Units: Electric Air Conditioning and Gas Heating

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of an air conditioning system that operates in conjunction with a gas heating system
- Interpret the schematic diagram for the air conditioning system
- Interpret the schematic diagram for the heating system

The schematic shown in Figure 44–1 is for a unit that contains both electric air conditioning and gas heating in the same package. This drawing shows both a connection diagram and a schematic diagram of this unit.

This diagram shows mainly the heating and blower controls. At the bottom of the schematic diagram is a component labeled **condensing unit**. This is the only reference to the air conditioning compressor and condenser fan on this schematic. This is not uncommon for a packaged unit.

THE COOLING CYCLE

The thermostat shows four terminal connections. The terminal labeled R is connected to one side of the 24-volt control transformer. When the thermostat is in the cooling position, an increase in temperature

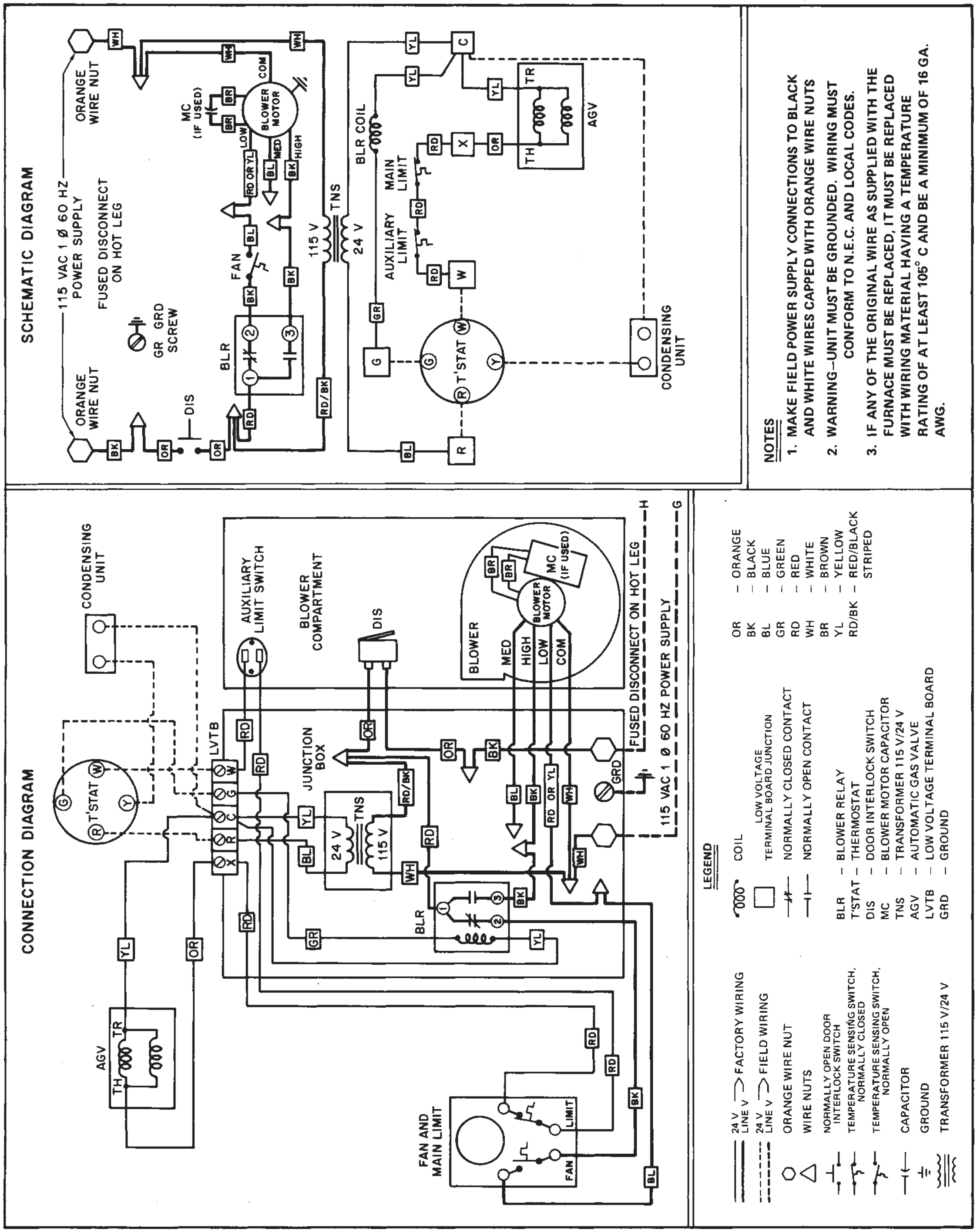


Figure 44–1
Schematic for an air conditioning and heating package unit. (Source: Delmar/Cengage Learning)

will cause terminal R to make connection with terminals G and Y. When power is applied to terminal Y, a circuit is completed to the condensing unit. The other side of the condensing unit is connected to terminal C, which completes the circuit back to the control transformer. This starts the air conditioning compressor and condenser fan.

Terminal G of the thermostat is connected to the blower relay coil (BLR). When BLR coil energizes, both BLR contacts change position. The normally closed contact opens and prevents the possibility that power can be applied to the low-speed terminal of the blower fan motor. The normally open contact closes and connects power to the high-speed terminal of the motor. Notice that the indoor blower fan operates in the high-speed position when the air conditioning unit is started.

THE HEATING CYCLE

When the thermostat is in the heating position, a decrease of temperature will cause the thermostat to make connection between terminals R and W. This permits a circuit to be completed through the automatic gas valve (AGV). When the AGV is energized, gas is permitted to flow to the main burner where it is ignited by the pilot light. Two high-limit contacts are connected in series with the automatic gas valve. One is labeled **auxiliary limit**, and the other is labeled **main limit**. The wiring diagram shows the main limit to be located in the fan-limit switch. The auxiliary limit switch is in a separate location. Both of these switches are normally closed and are shown to be temperature activated. The schematic also shows that an increase in temperature will cause them to open. Because both are connected in series with the AGV, the circuit will be broken to the valve if either one opens.

In the heating cycle, the indoor blower fan is controlled by the fan switch. The fan switch is temperature activated. After the gas burner has been turned on, the temperature of the furnace increases. When the temperature has risen to a high enough level, the fan switch will close and connect the low-speed terminal of the blower motor to the power line. Notice that the fan switch is connected in series with the normally closed BLR contact. When BLR relay is deenergized, the fan switch is permitted to control the operation of the blower fan. The blower fan relay permits the fan to operate in low speed when the unit is in the heating cycle, and in high speed when the unit is in the cooling cycle.

THE DOOR INTERLOCK SWITCH

The **door interlock** is shown on the schematic as a normally open push button labeled (DIS). The function of this switch is to permit the unit to operate only when the furnace door is closed. When the door is opened, the 120-volt power supply is broken to the unit. Most door interlock switches are so designed that they are actually a two-position switch. When the door is open, the switch can be pulled out. This causes the switch to make connection so the unit can be serviced.

ELECTRONIC CONTROL OF BLOWER MOTOR AND COMPRESSOR LOCK-OUT

Many units employ electronic control for some of their functions. Troubleshooting for electronic circuit boards is generally accomplished by determining if the board has the proper input information to obtain an output. If the inputs and outputs are correct, the board is good and the problem lies somewhere else in the circuit. The circuit board shown in Figure 44–2 is designed to control the blower for a cooling unit with gas or electric heat.

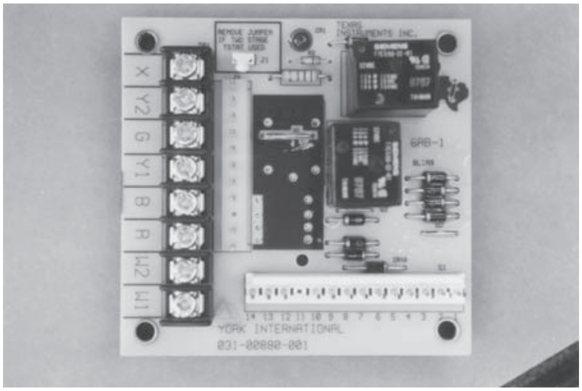


Figure 44–2
Blower motor and compressor lock-out control board.
(Source: Delmar/Cengage Learning)

The circuit board also provides lock-out protection for the compressor.

LOCK-OUT PROTECTION

Lock-out protection involves the use of a high-impedance relay that becomes connected in series with the compressor contactor coil in the event of a problem with the compressor circuit. In the circuit shown in Figure 44–3, the coil of the **lock-out relay** is connected in parallel with the normally closed safety switches used to help protect the compressor. Under normal conditions the high-pressure switch, low-pressure switch, and the low evaporator temperature switch are closed and provide a complete circuit to the compressor contactor coil. Because the lock-out relay coil is connected in parallel with these switches, almost no voltage is dropped across the LOR coil and it remains turned off. If one of the switches should open, however, the lock-out relay coil becomes connected in series with the compressor contactor coil, Figure 44–4. Because the impedance of the lock-out relay coil is much higher than the compressor contactor coil, almost all the 24 volts is dropped across the LOR coil and very little voltage is across the CC coil. The compressor contactor cannot energize because of the low voltage applied to the coil.

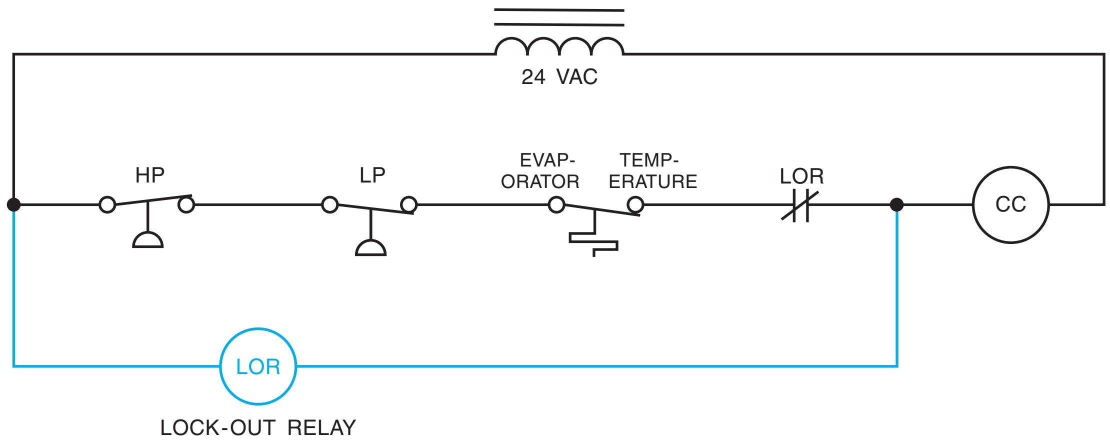


Figure 44–3
Basic lock-out circuit. (Source: Delmar/Cengage Learning)

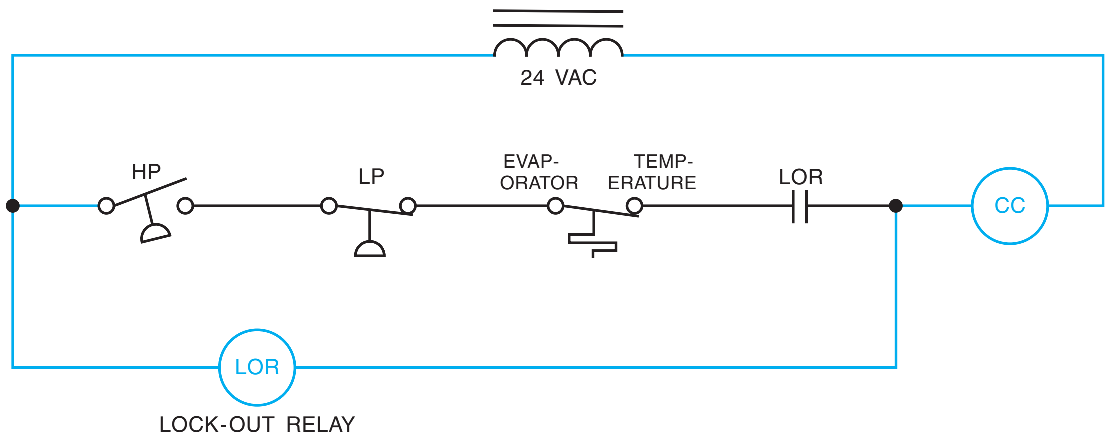


Figure 44–4
A circuit exists through the LOR coil and CC coil. (Source: Delmar/Cengage Learning)

The normally closed LOR contact connected in series with the compressor contactor coil opens. If the high-pressure switch should close, the now open LOR contact prevents the compressor contactor from energizing. The circuit will remain in this condition until the control power is turned off and the lock-out relay coil deenergizes. The line voltage connections for the blower control and lock-out relay circuit board are shown in Figure 44–5. The circuit board and basic controls are shown in Figure 44–6.

CIRCUIT OPERATION

When the heating thermostat contact closes, a circuit exists to the time delay relay (TDR) and draft motor relay (DMR), Figure 44–7. Power is also supplied to the ignition control module. The draft motor controls the centrifugal switch connected to the thermostat input of the ignition control module. Its function is used to insure that gas will not be supplied to the burner unless the draft motor is in operation.

In Figure 44–8, it is assumed that the centrifugal switch has closed and permitted the gas burner to ignite. It is also assumed that the time delay relay has permitted TDR contacts to close. When the TDR contacts close, a current path is provided to the coil of the K3 relay causing all K3 contacts to change position. When the normally open K3 contact closes, a current path is provided to the coil of the 2M contactor. When 2M energizes, the blower motor turns on, Figure 44–5. The circuit will continue to operate in this manner until the thermostat contacts reopen.

OPERATION OF THE COMPRESSOR LOCK-OUT RELAY

The compressor lock-out relay can operate only when the thermostat is set in the cooling mode. In Figure 44–9 it is assumed that the thermostat has been set for the cooling mode and the thermostat contact is closed. The main current path is through the normally closed K1 contact, low-pressure switch, high-pressure switch, and evaporator temperature switch to the coil of 1M contactor. The current takes this path because of the high impedance of coil K1. When coil 1M energizes, the compressor and condenser fan start, Figure 44–5. There is also a current path through the thermostat fan switch, the normally closed K3 contact and 2M coil. When the 2M coil energizes, the evaporator fan motor starts. The circuit will continue to operate in this manner until the thermostat contact opens or some other problem occurs.

Now assume that the low-pressure switch opens, Figure 44–10. The open circuit caused by the open low-pressure switch now connects coil K1 in series with coil 1M. Because coil K1 has a much higher impedance than 1M, most of the voltage is across K1 and not 1M, causing the K1 relay to energize and the 1M contactor to deenergize. The normally closed K1 contacts open and the normally open K1 contacts close. When the normally open K1 contacts close, a current path is provided to the compressor lock-out indicator. The now open K1 contact prevents the compressor from restarting if the low-pressure switch should reclose. The circuit will remain in this condition until the control power is interrupted.

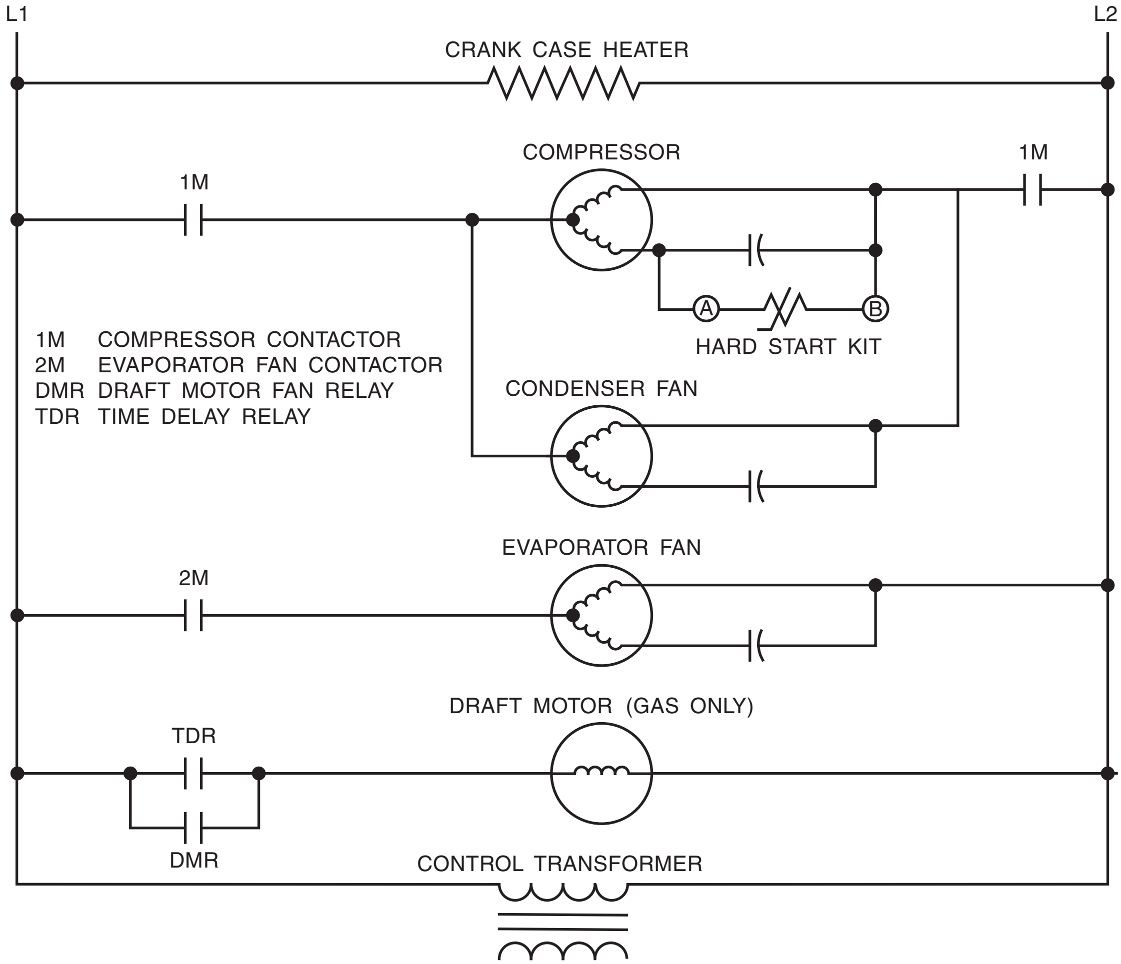


Figure 44–5
Line voltage circuit. (Source: Delmar/Cengage Learning)

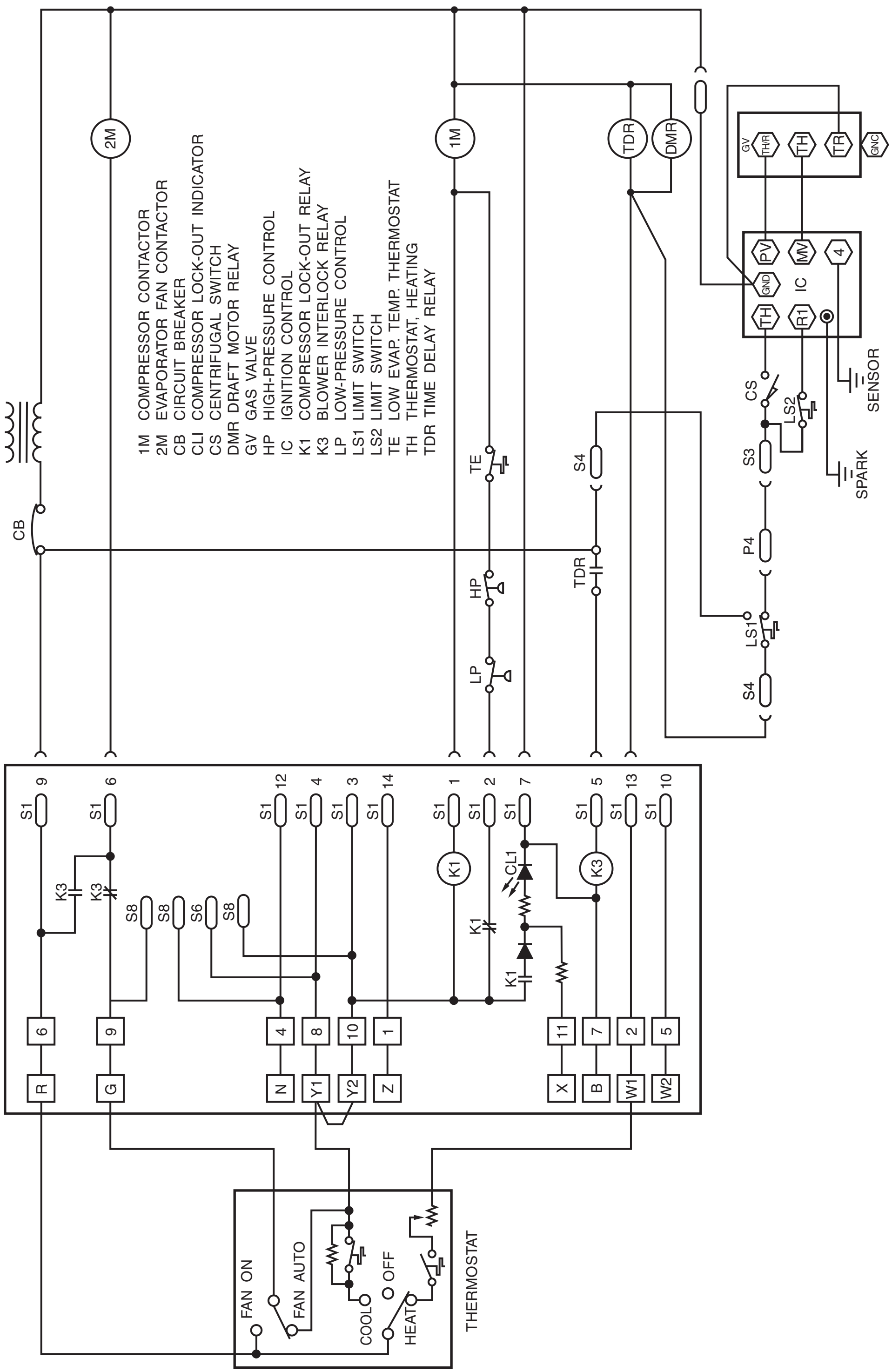


Figure 44–6
Control circuit for a cooling unit and gas heat. (Source: Delmar/Cengage Learning)

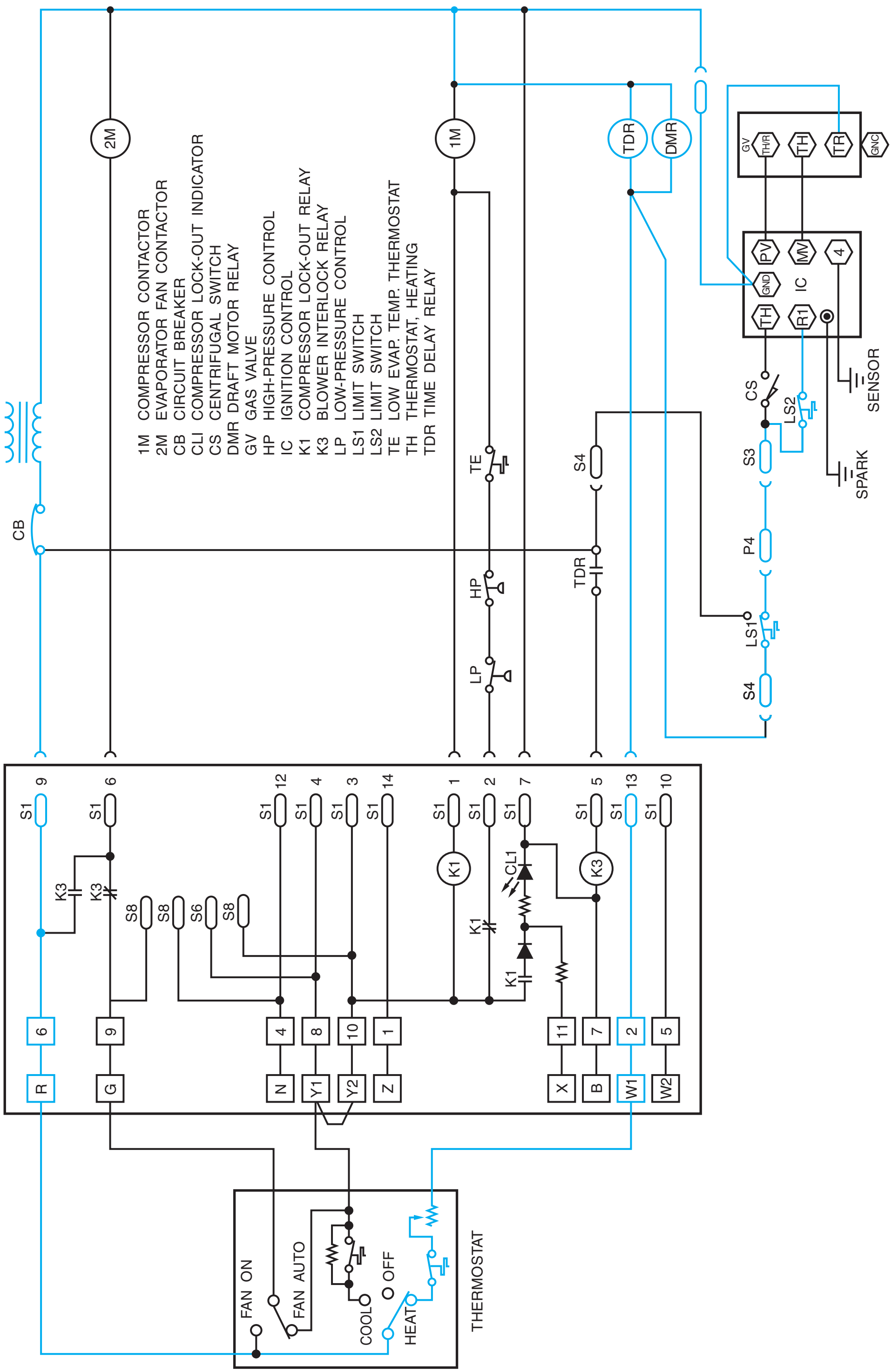


Figure 44–7
The heating thermostat contact closes. (Source: Delmar/Cengage Learning)

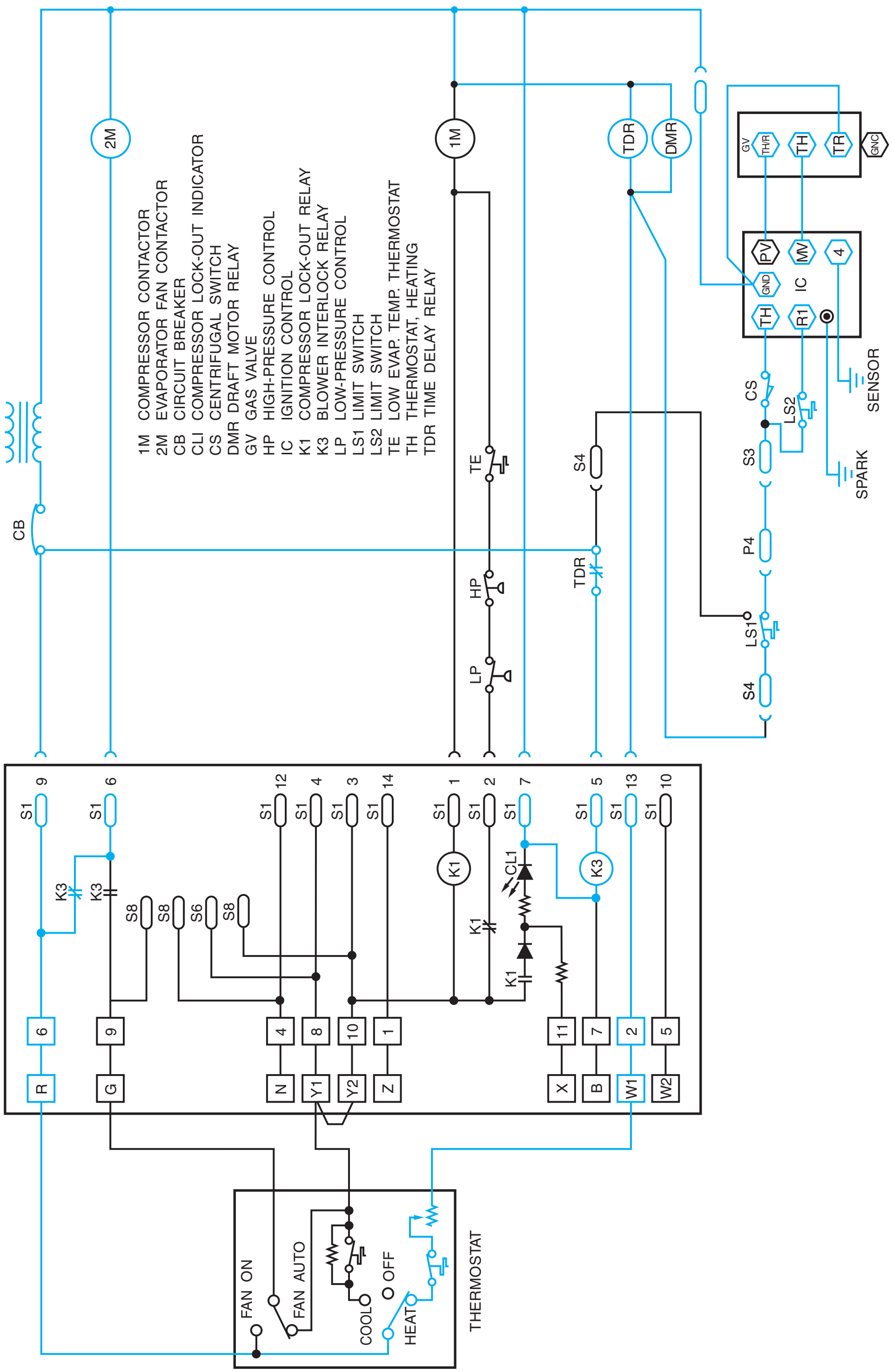


Figure 44–8
The blower motor turns on after a time delay. (Source: Delmar/Cengage Learning)

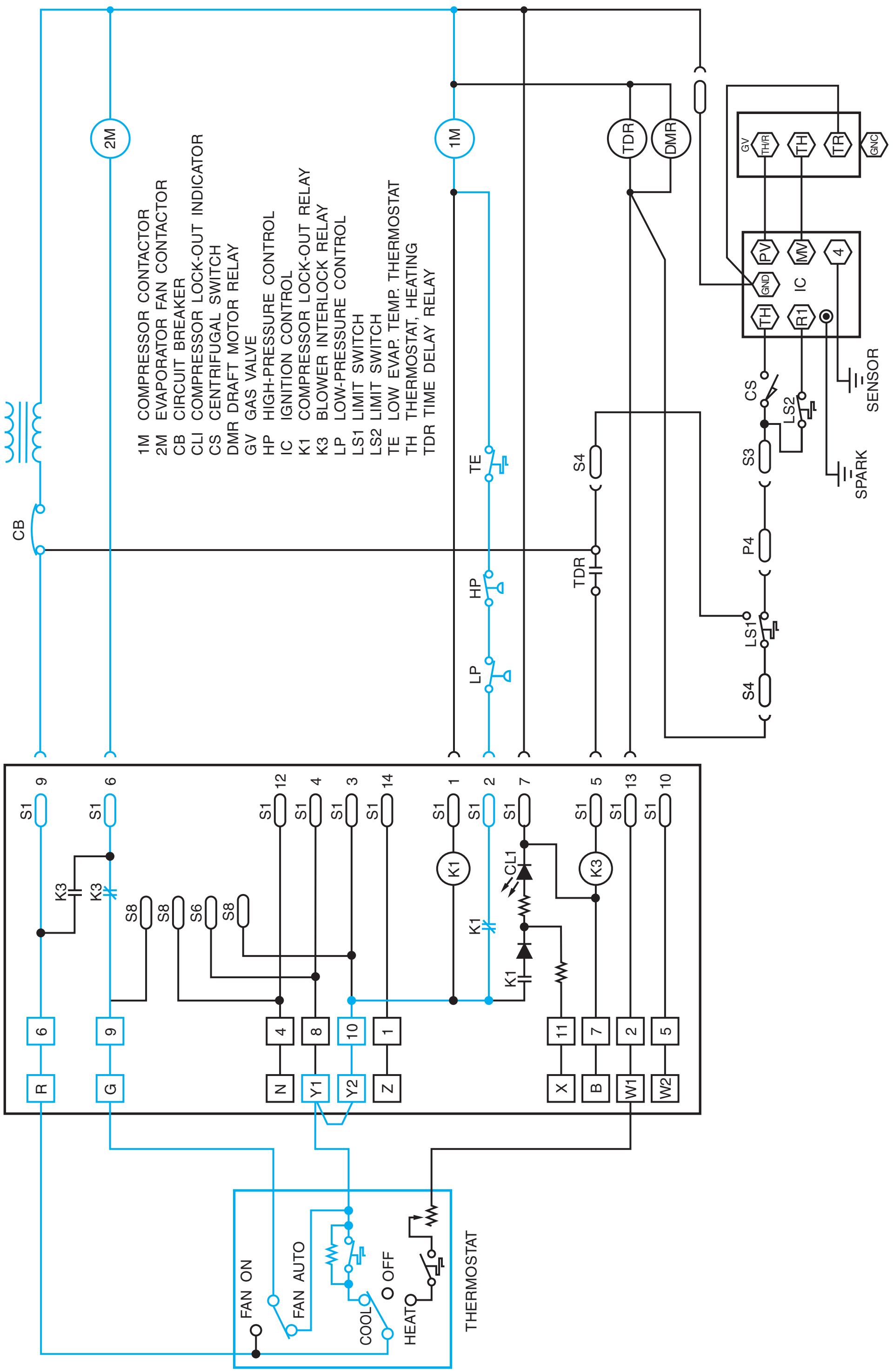


Figure 44–9
Circuit during normal cooling cycle. (Source: Delmar/Cengage Learning)

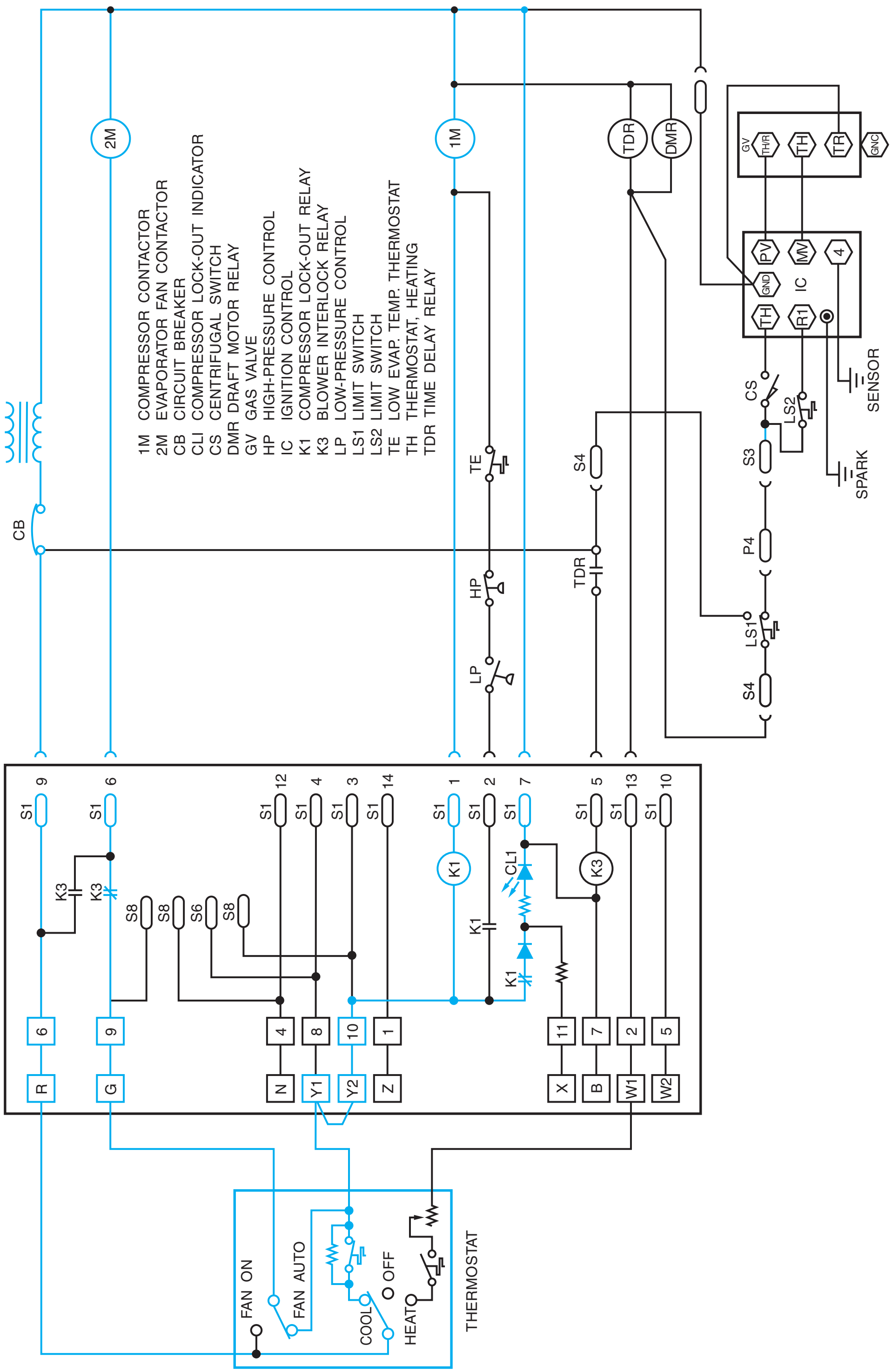


Figure 44–10
The lock-out relay has energized. (Source: Delmar/Cengage Learning)

SUMMARY

- The schematic diagram in this example shows mostly the operation of the heating system.
- The thermostat in this diagram has four terminals labeled R, G, Y, and C.
- The thermostat is connected to the 24-volt side of the transformer.
- The heating system contains two high-limit switches.
- Both of the high-limit switches are connected normally closed and are connected in series with the automatic gas valve.

KEY TERMS

auxiliary limit
condensing unit
door interlock
lock-out relay
main limit

REVIEW QUESTIONS

Refer to the schematic shown in Figure 44–1 for the following questions.

1. The unit will operate normally in the cooling cycle. When the unit is switched to the heating cycle, the gas burner will not ignite. List four possible problems.
2. The blower fan will operate normally in the cooling cycle. In the heating cycle, however, the fan will not operate. List three possible problems.
3. The unit will not operate in the heating or cooling cycle. A voltage check shows that there is no low voltage for operation of the control circuit. List three possible problems.
4. A lock-out protection circuit involves connecting the coil of the lock-out relay in series with the coil of the compressor contactor. When this circuit is energized, why is most of the voltage across the lock-out relay coil and very little across the compressor contactor coil?
5. Once the lock-out relay has been energized, what must be done to reset the circuit?

TROUBLESHOOTING QUESTIONS

Refer to the schematic shown in Figure 44–1 to answer the following questions. Note that this drawing is a combination of both a schematic and a wiring diagram. Also note that most of the control shown is of the heating system. The air conditioning part of this unit is referred to as "condensing unit" on the diagram. The thermostat contact arrangement is not shown in this diagram, but recall that in the cooling mode, terminals G and Y make connection with terminal R when the thermostat contact closes. In the heating mode, terminal R makes connection with terminal W when the thermostat contact closes.

1. When the unit is in the heating mode, what controls the operation of the blower motor?
   A. Thermostat
   B. Fan relay
   C. Fan switch
   D. Main limit switch
2. When the unit is used in the heating mode, which blower fan speed is used?
   A. HIGH
   B. MED
   C. LOW
3. Assume that when in the heating mode, the gas burner will start when the thermostat calls for heat, but the blower motor will not run and eventually the burner is turned off by the main limit switch. Now assume that when the fan switch on the thermostat is moved to the manual position, the blower motor begins operating. List three conditions that could cause this problem.
   A. ______________________________
   B. ______________________________
   C. ______________________________
4. When the unit is in the cooling mode, which thermostat terminal controls the operation of the blower motor?
   A. R
   B. W
   C. Y
   D. G
5. Describe the operation of the door interlock switch.
   A. The door interlock switch will prevent the unit from operating in either the heating or cooling mode. If the unit is in operation and the door is opened, the unit will stop operation. If the unit is not operating it cannot start in either the heating or cooling mode.
   B. The door interlock switch will prevent operation in the heating mode only.
   C. The door interlock switch will prevent operation in the cooling mode only.
   D. The door interlock switch will prevent the unit from starting in either the heating or cooling mode, but if the unit is in operation when the door is opened, it will continue to operate until the thermostat is satisfied.

To answer the following questions, refer to the schematic diagram in figure 44–6.

6. Assume that the thermostat is set in the heating mode and that the heating thermostat contact closes. Now assume that the DMR relay coil is defective. Will the gas burner operate? Explain your answer.
7. Which relay controls the operation of the 2M contactor when the unit is in the heating mode?
8. Is the CLI indicator a __________?
   A. Incandescent lamp.
   B. Neon lamp.
   C. Light-emitting diode.
   D. The print does not indicate the type of light producing device.

SECTION 7

Ice Maker and Refrigeration Controls

UNIT 45

Household Ice Makers

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the operation of a compact-type ice maker
- Describe the operation of the water valve and flow washer
- Discuss the sequence of events that takes place during each stage of the ice maker's operation
- Discuss the operation of a flex tray ice maker

Ice makers can be divided into two major categories, household and commercial. Unlike commercial units, household ice makers do not recirculate water. They fill a tray or mold and the water is allowed to freeze. Various methods are used to sense when the water has been frozen and to eject the ice from the tray.

Commercial ice makers generally recirculate the water during the freeze cycle. The one reason for this is that pure water freezes faster than water containing impurities and minerals. The ice formed is more pure and clearer in color. This does not apply to flaker-type machines, however. Flaker or crushed-ice machines use an auger to scrape ice off an evaporator after the water has been frozen.

Some cube-type machines freeze water in the shape of the cube, and others freeze water as a slab. The slab-type machines use a grid of cutter wires to cut the frozen slab into cubes.

HOUSEHOLD ICE MAKERS

One of the most widely used household ice makers is the **compact**, Figure 45–1. Although a newer model has been introduced, many of these original units are still in operation. The basic operation of this unit is as follows:

1. An electric solenoid valve, Figure 45–2, turns on and fills the tray or mold with water. The valve contains a **flow washer** that meters the amount of water. The washer is designed to work with pressures that range between 15 and 100 psi. The length of time the water is permitted to flow is controlled by a cam operated by a small electric motor. The time can be adjusted by moving the water solenoid switch closer to or farther away from the cam. The amount of water needed to fill the mold is approximately 135 cc or 4 oz. It should be noted that insufficient water causes the thermostat to cool too quickly, causing the ice maker to eject hollow cubes.
2. A thermostat senses when the water is frozen. It is mounted directly on the mold by a spring clip. The thermostat controls the start of the ejection and refill cycle.
3. When the thermostat contact closes, it turns on the **mold heater** and motor. The motor operates the timing cam and ejector blades. The ice maker is so designed that the **ejector blades** can stall against the ice cubes without causing harm to the motor or mechanical parts. When the heater has warmed the mold sufficiently, the ice cubes are pushed out by the ejector blades.
4. During the ejection cycle, the shutoff arm rises and lowers. The shutoff arm senses the height of ice in the holding bin. If the bin is not full, the arm returns to its original position and the ice maker is permitted to eject ice cubes again after they have been frozen. If the holding bin is full, however, the arm cannot return to its normal position and the next ejection cycle cannot begin. The ice maker can be manually turned off by raising the shutoff arm above its normal range of travel.

The ice maker will normally permit the ejector blades to make two revolutions before the thermostat reopens its contact and permits the process to stop at the end of the cycle. If the ejector blades make only one revolution, the ice cubes will be left on top of the blades instead of being dumped into the holding bin. This is not a problem, however, because the cubes will be dumped at the beginning of the next ejection cycle. Near the end of the cycle the mold is refilled with water.

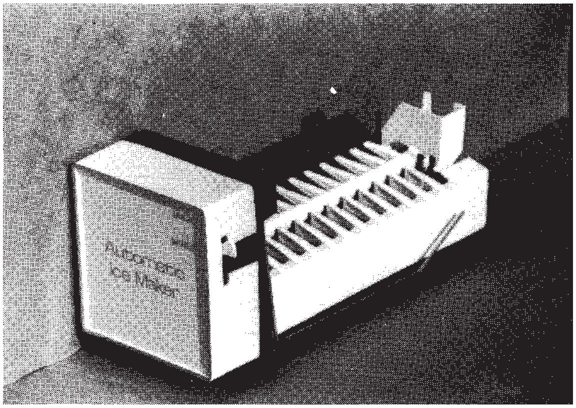


Figure 45–1
Early model of a compact ice maker. (Source: Delmar/Cengage Learning)

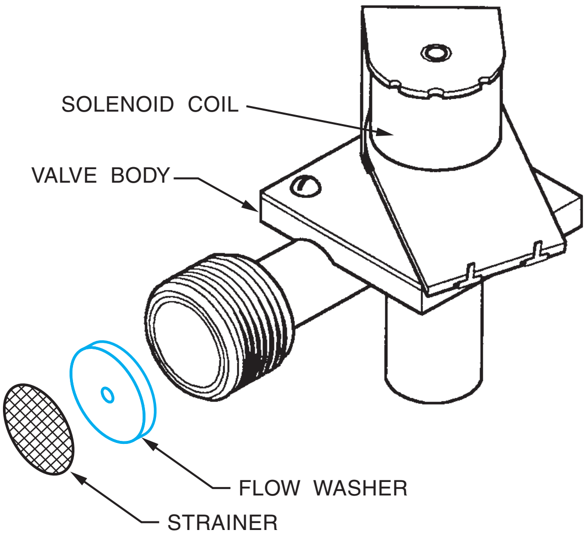


Figure 45–2
Water valve. (Source: Delmar/Cengage Learning)

OPERATION OF THE CIRCUIT

The basic circuit for the compact ice maker is shown in Figure 45–3. The circuit is shown during the freeze cycle. It is assumed that the mold has been filled with water and the thermostat contact is open. The shutoff arm is in its normal position, indicating that the holding bin is not full. Note the position of the ejector blade and the shutoff arm.

Figure 45–4 shows the circuit at the beginning of the ejection cycle. At this time, the thermostat has cooled sufficiently for its contact to close. A current path now exists through the mold heater and motor, and the ejector blades begin to turn.

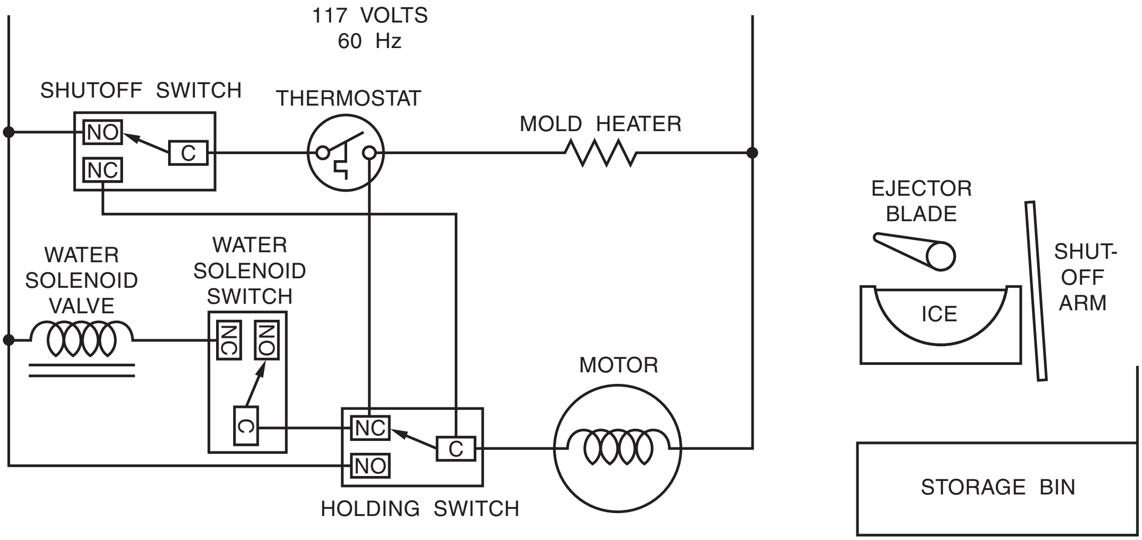


Figure 45–3
Basic circuit for the compact ice maker. (Source: Delmar/Cengage Learning)

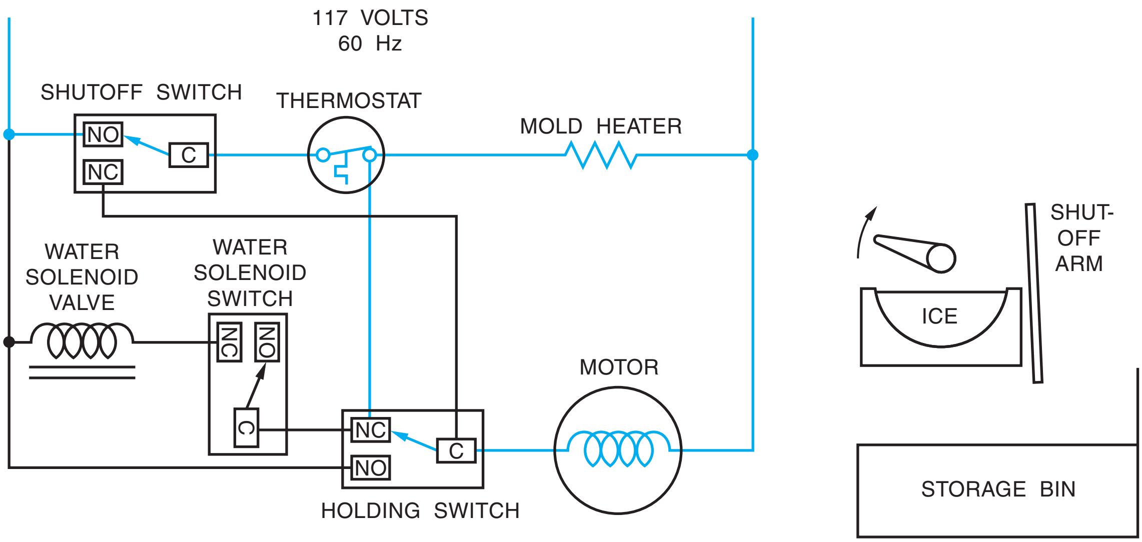


Figure 45–4
Beginning of the ejection cycle. (Source: Delmar/Cengage Learning)

As the motor turns the ejector blades and timing cam, the **holding switch** changes position and the shutoff arm begins to rise, Figure 45–5. The function of the holding switch is to maintain the circuit until the cam returns to the freeze, or off, position.

In Figure 45–6, the timing cam causes the shutoff arm to rise and fall, making the shutoff switch change position. When the ejector blades reach the ice in the mold, the motor will stall until the ice cubes are thawed loose by the mold heater. Notice that the circuit to both the heater and motor has

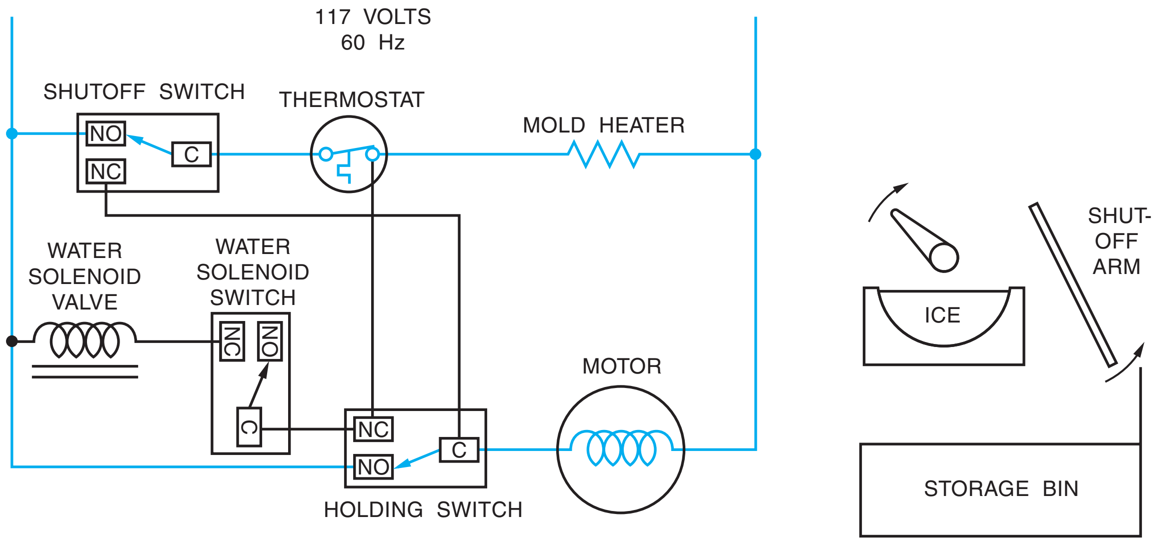


Figure 45–5
The shutoff arm begins to rise. (Source: Delmar/Cengage Learning)

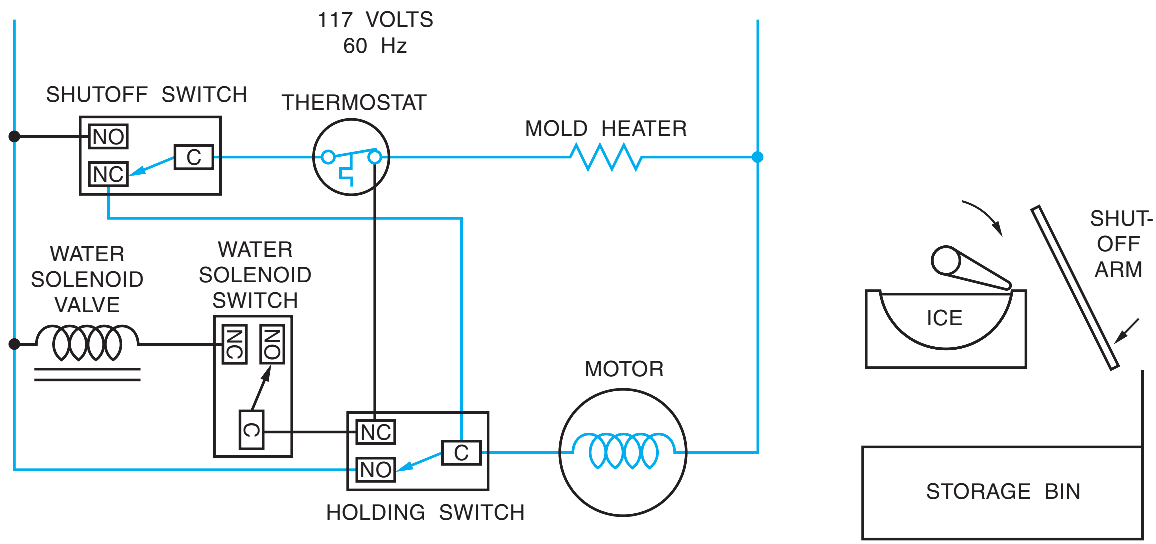


Figure 45–6
The shutoff switch changes position. (Source: Delmar/Cengage Learning)

been maintained by the holding switch. Note that it is possible for the thermostat to open its contact at any point in this process. If this should occur, power is turned off to the mold heater but maintained to the motor by the holding switch.

Near the completion of the first revolution of the ejector blades, the timing cam closes the water solenoid switch, Figure 45–7. Although the water solenoid switch is now closed, current cannot flow through the coil. As long as the thermostat contact is closed, the same voltage potential is applied to both sides of the water solenoid coil. Because there is no potential difference across the coil, no current can flow and the water valve does not open to permit water flow into the mold.

At the end of the first revolution, Figure 45–8, the shutoff arm and ejector blades have returned to their normal position and the timing cam has reset

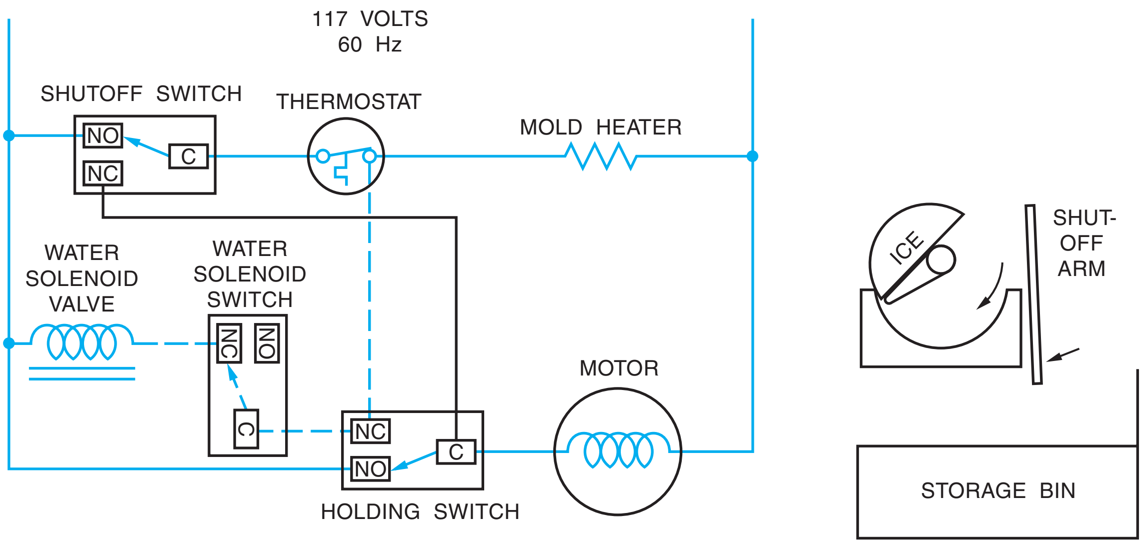


Figure 45–7
The timing cam closes the water solenoid switch. (Source: Delmar/Cengage Learning)

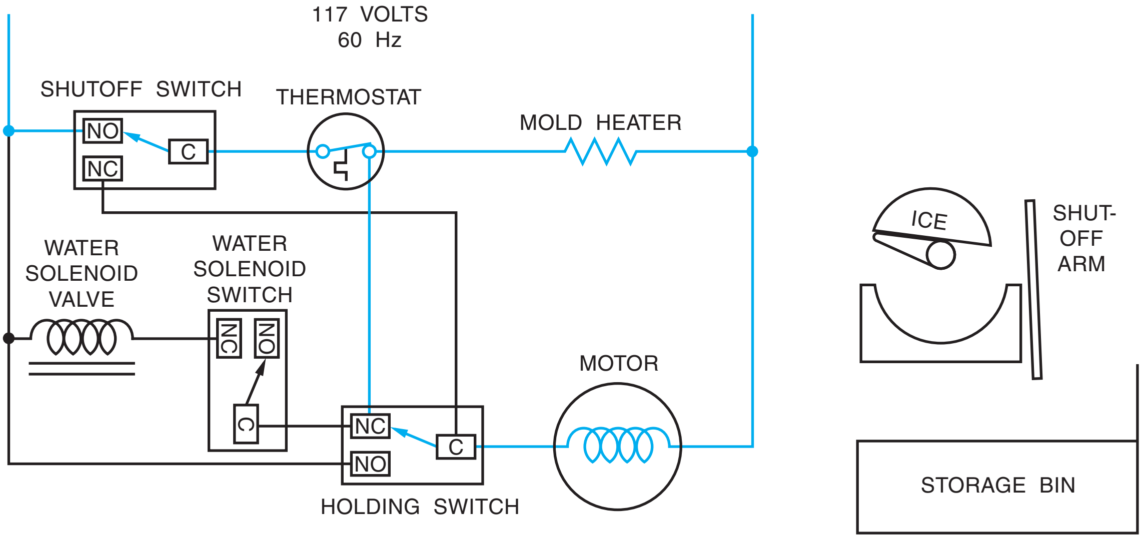


Figure 45–8
End of the first revolution. (Source: Delmar/Cengage Learning)

all cam-operated switches back to their normal position. Notice, however, that the thermostat contact has remained in the closed position, permitting the second revolution to begin.

After the timing cam has rotated a few degrees, the holding switch again closes to maintain a current path to the motor and mold heater, Figure 45–9. The shutoff arm raises and changes the position of the shutoff switch. The continued rotation of the ejector blades dumps the ice into the holding bin.

During the second revolution, the increased temperature from the mold heater causes the thermostat contact to reopen, which deenergizes the heater, Figure 45–10. The holding contact, however, provides a continued current path to the motor. If the storage bin is full, the shutoff arm will not return to its normal position and the shutoff switch will not be reset.

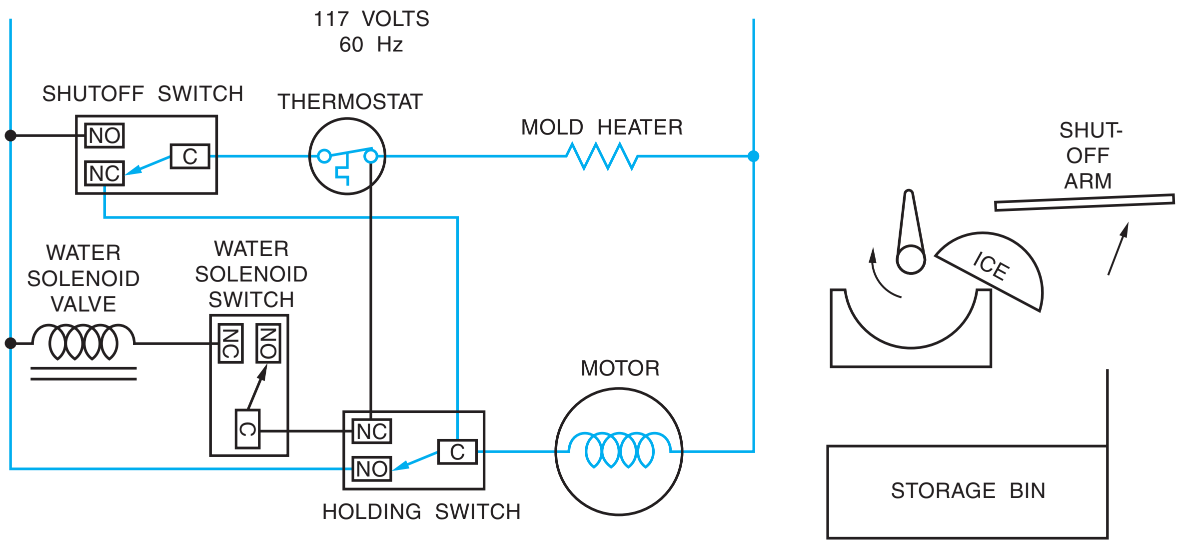


Figure 45–9
Beginning of the second revolution. (Source: Delmar/Cengage Learning)

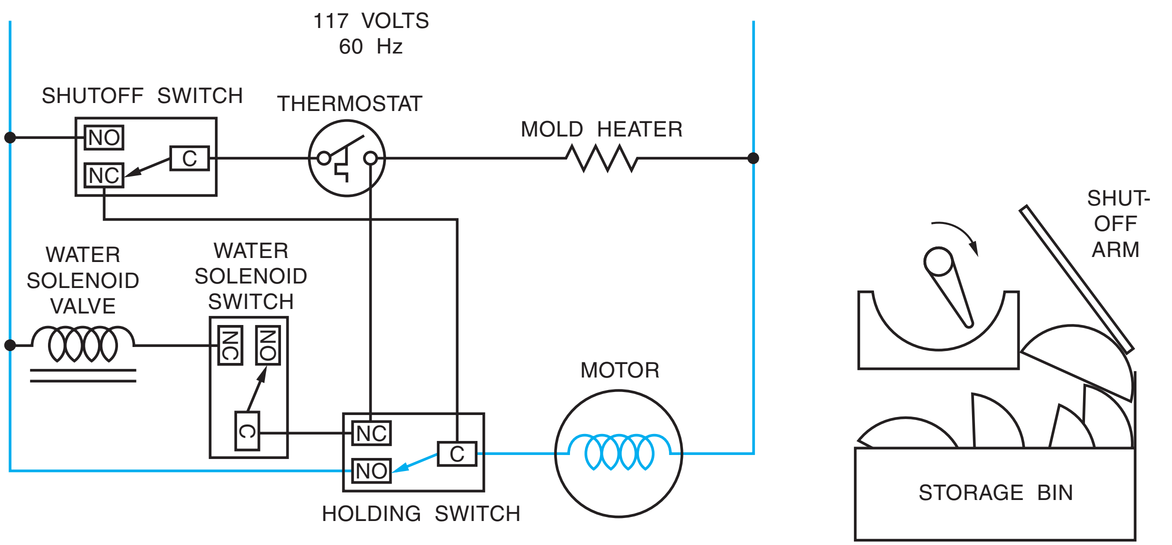


Figure 45–10
Middle of the second revolution. (Source: Delmar/Cengage Learning)

Near the completion of the second revolution, Figure 45–11, the timing cam again closes the water solenoid switch. A current path now exists through the solenoid coil and the mold heater. Although the solenoid coil and mold heater are now connected in series, the impedance of the solenoid coil is much higher than that of the heater. This permits most of the voltage, about 105 to 110 volts, to be applied across the coil causing it to energize and open the water valve.

The cycle ends when the timing cam reopens the water solenoid and holding switch, Figure 45–12. If the storage bin is full as shown in this illustration, a new ejection and refill cycle cannot begin until sufficient ice has been removed from the storage bin to permit the shutoff arm to return to its normal position.

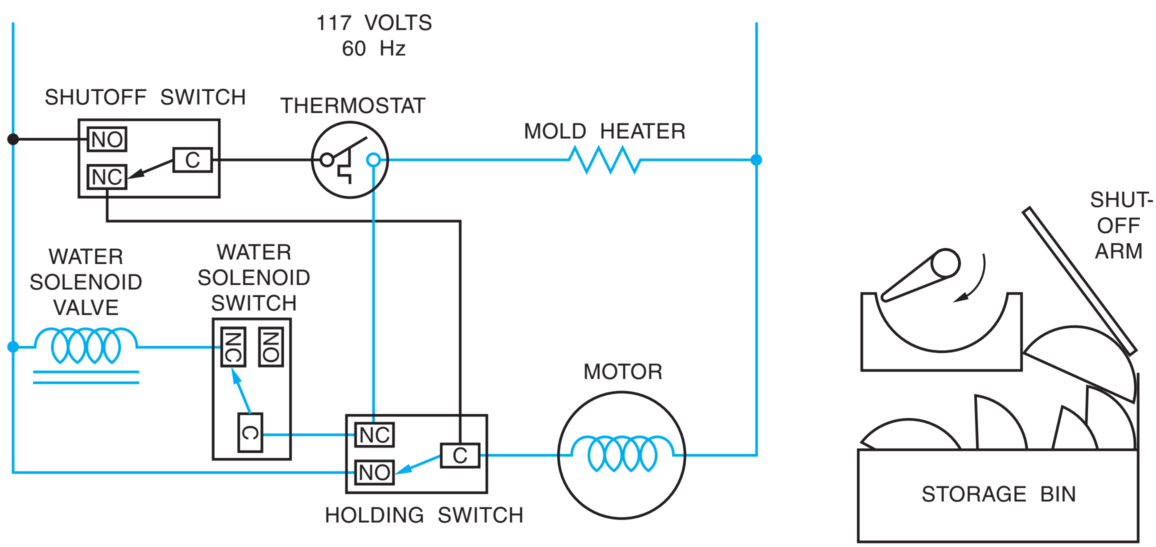


Figure 45–11
End of the second revolution. (Source: Delmar/Cengage Learning)

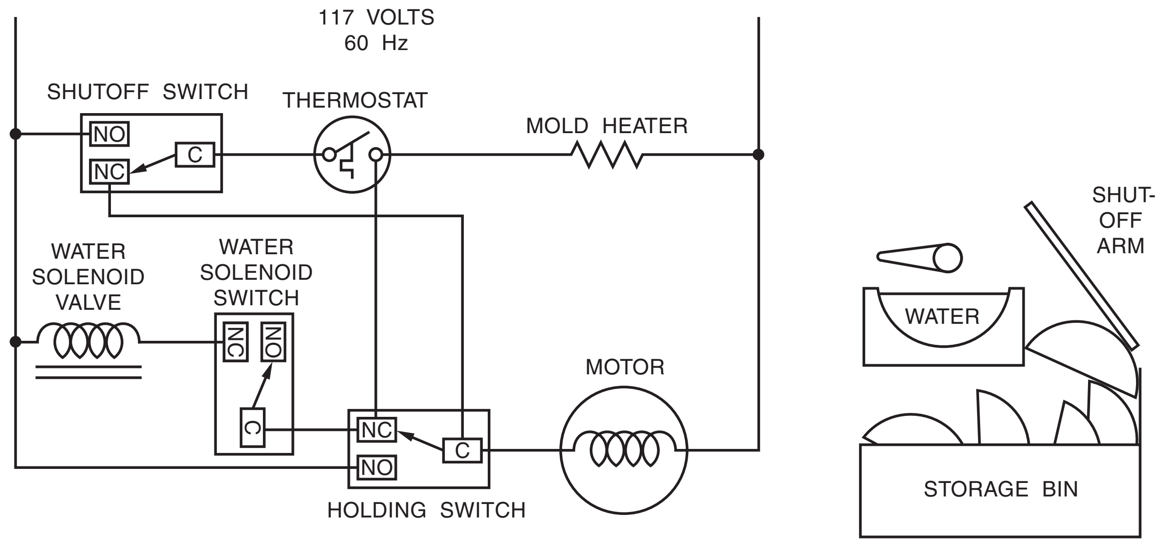


Figure 45–12
End of the cycle. (Source: Delmar/Cengage Learning)

THE NEW MODEL COMPACT ICE MAKER

Although the new model compact ice maker, Figure 45–13, is very similar in design and operating principle to the original version just discussed, there are some significant differences. Some of these differences are listed below:

1. The ejector blades on the newer model stop at a different position, as shown in Figure 45–14. Also shown in Figure 45–14 is the position of the ejector blades when different actions occur during the ejection cycle.
2. The ejector blades make only one revolution instead of two during the ejection cycle.
3. Most of the new models have an external water level adjustment knob, Figure 45–13. Turning the knob moves a set of contacts in relation to its contact ring, permitting the fill time to be longer or shorter.
4. On the original model compact ice maker, the gear located on the front of the unit could be turned manually to advance the ice maker through different parts of the cycle. This gear should *never* be turned on the newer model. To do so will cause damage to the ice maker. The front gears of both the original and newer compact ice makers are shown in Figure 45–15.

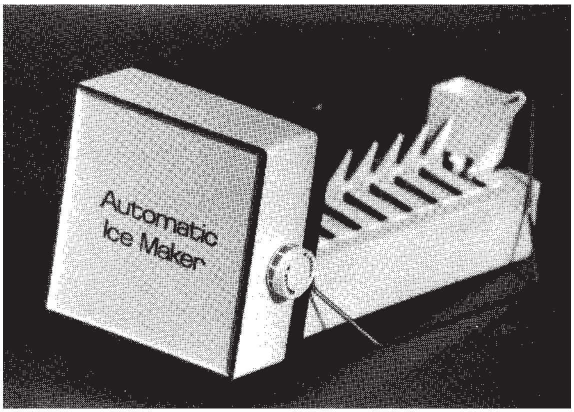


Figure 45–13
New compact ice maker. (Source: Delmar/Cengage Learning)

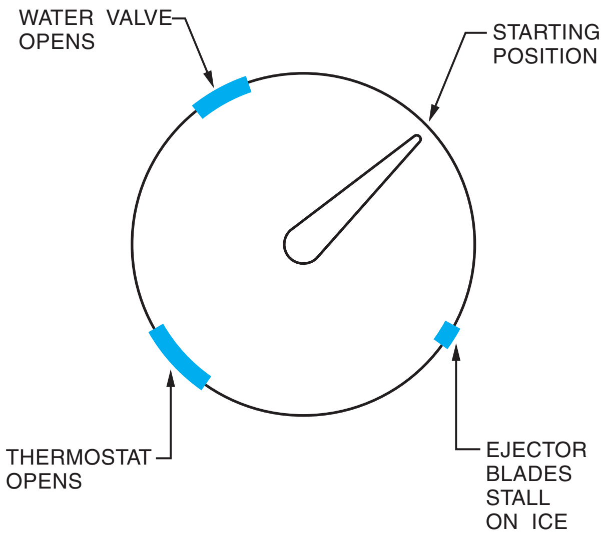


Figure 45–14
Ejector blade positions on new model compact ice maker. (Source: Delmar/Cengage Learning)

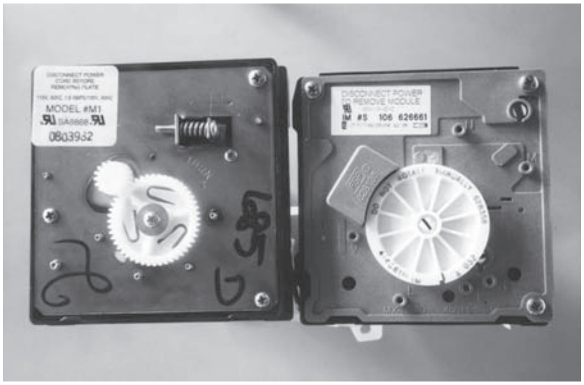


Figure 45–15
Front gears of the original (left) and newer model (right) compact ice makers. (Source: Delmar/Cengage Learning)

5. The new model compact provides **test points** on the plate located behind the front cover, Figure 45–16. It is possible to test different parts of the electrical circuit using a voltmeter and ohmmeter. The letters indicate the following test points:
   - N = Neutral side of the line
   - L = L1 (HOT) side of the line
   - M = Motor connection

- H = Heater connection
- T = Thermostat connection
- V = Water valve connection

6. Probably the greatest difference lies in the electrical circuit itself. In this model, copper strips are laminated on an insulated plate located on the back side of the drive gear. When the motor turns, it turns these copper strips also. Contacts ride against these copper strips and make or break connection to operate the circuit. A diagram of the copper strips and contacts is shown in Figure 45–17.

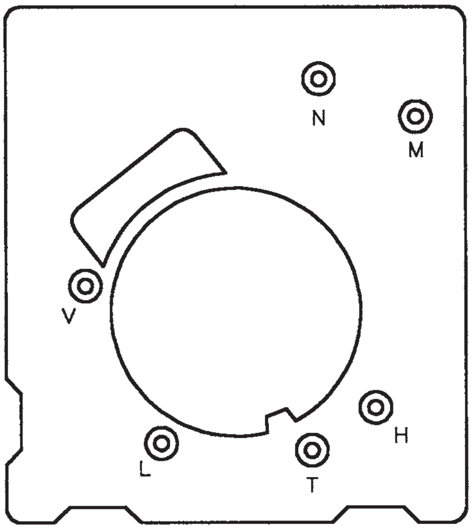


Figure 45–16
Test points. (Source: Delmar/Cengage Learning)

The basic electrical circuit for this unit is shown in Figure 45–18. Please note that the contact points A, B, C, and D correspond to the contacts shown in Figure 45–17. At this point, connection is made between contacts B and C.

When the thermostat reaches approximately 17°F, its contact will close and produce a current path to both the motor and heater as shown in Figure 45–19. The motor begins to turn both the ejector blades and the copper strips located on the back of the main gear. At some point, contact between points B and C is broken and contact between points C and D is made, as shown in Figure 45–20. The ejector blades then stall against the ice. A current path is maintained to the motor between points C and D and a current path is maintained to the heater by the closed thermostat contact.

After the surface of the ice has been thawed by the heater, the ejector blades will begin to turn again. After the ejector blades have rotated approximately 180°, the thermostat contact opens,

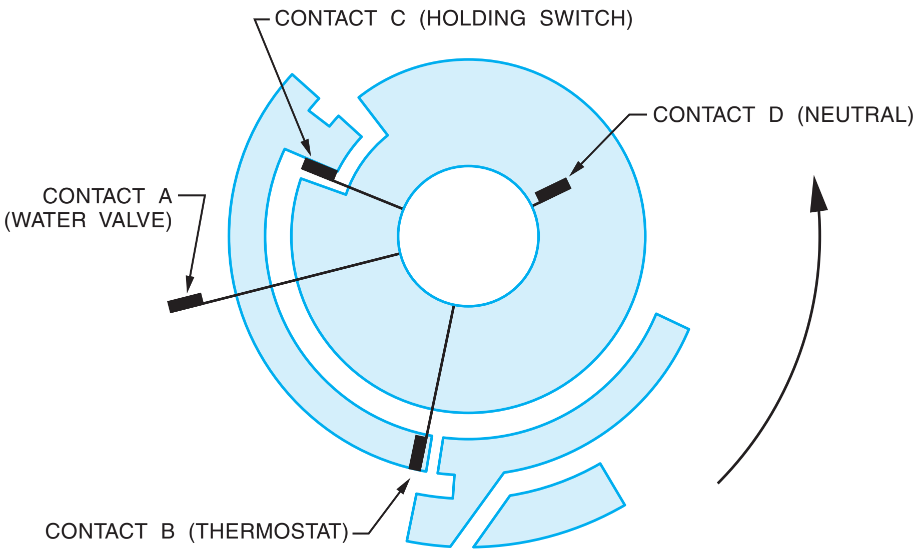


Figure 45–17
Rotary switch located on back of drive gear.
(Source: Delmar/Cengage Learning)

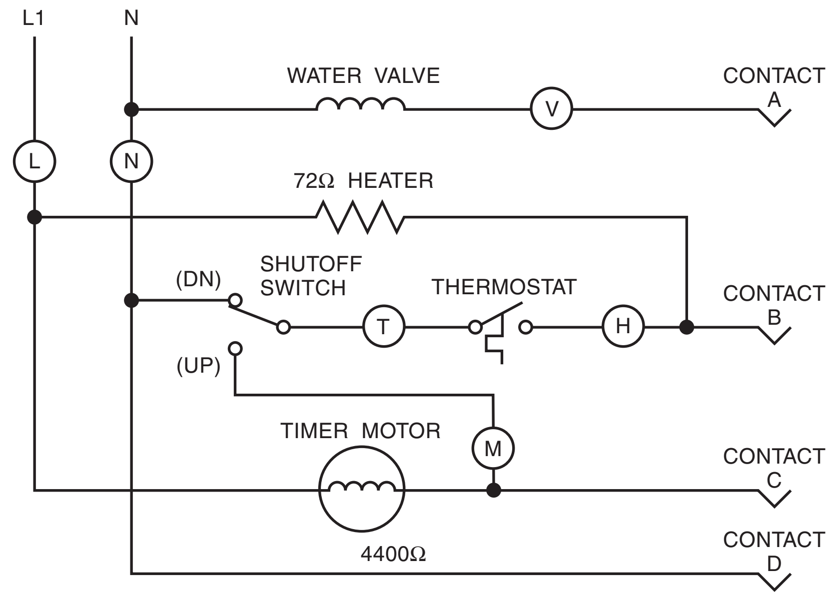


Figure 45–18 Basic schematic diagram for new model of Whirlpool compact ice maker. (Source: Delmar/Cengage Learning)

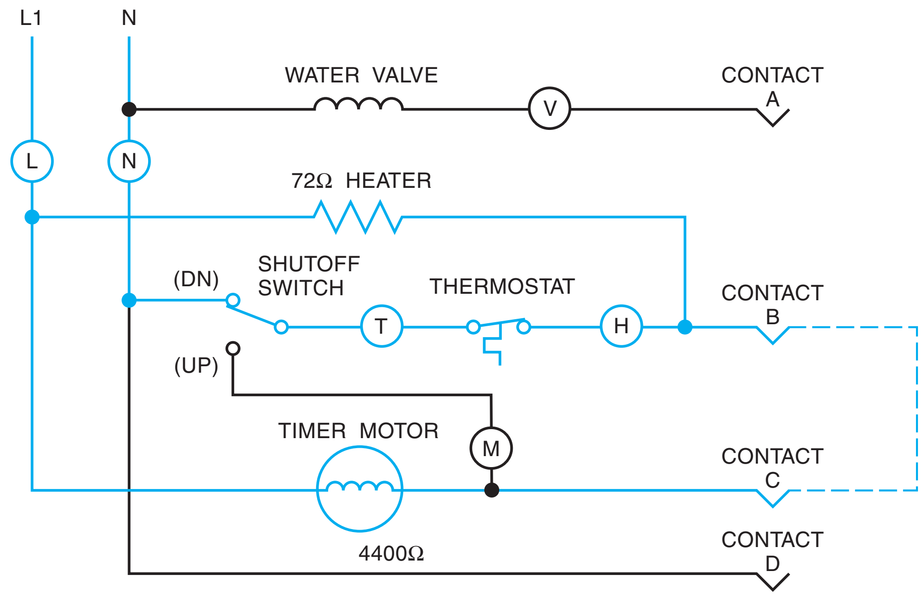


Figure 45–19 A current path is provided through the heater and timer motor. (Source: Delmar/Cengage Learning)

Figure 45–14. As the blades continue to turn, the shutoff arm rises and lowers and the copper strips advance until connection is made between contacts A and B, Figure 45–21. This provides a current path through the mold heater to the water solenoid valve. Because the coil of the solenoid has a much higher impedance than the mold heater, most of the line voltage will be dropped across the valve, causing it to open and refill the mold. The ejector blades will continue to turn until they reach the end of the cycle and the circuit returns to its original condition as shown in Figure 45–18.

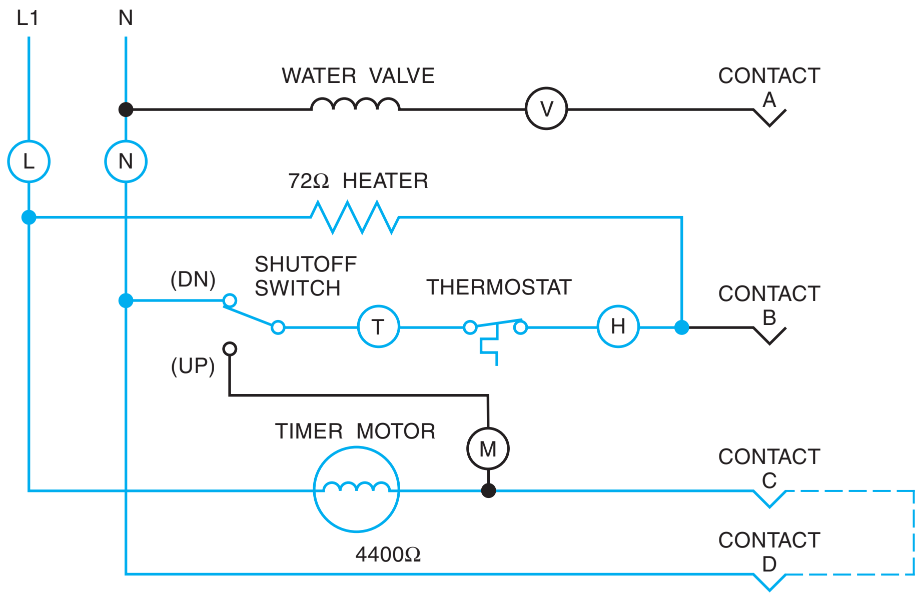


Figure 45–20 The holding contact maintains the timer motor circuit. (Source: Delmar/Cengage Learning)

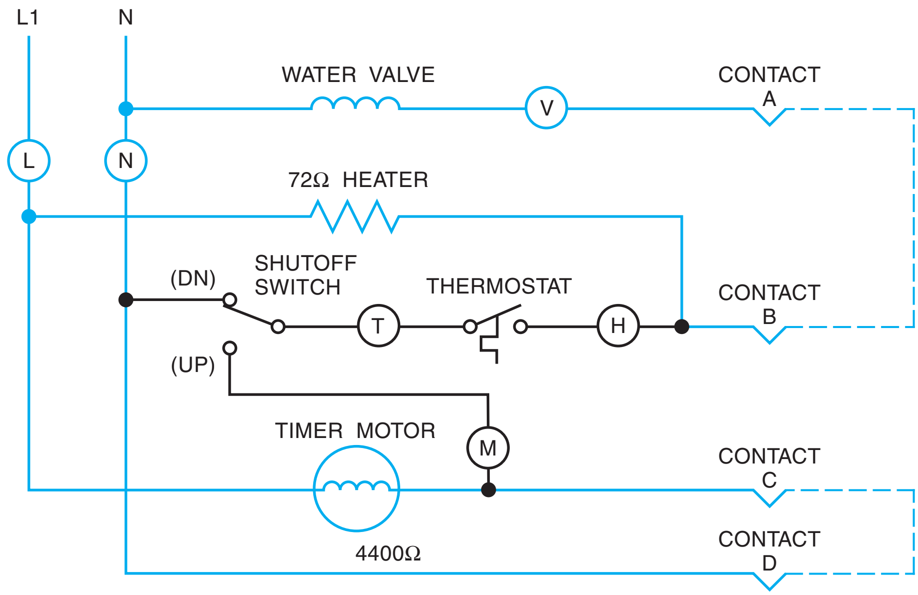


Figure 45–21 Water valve energizes. (Source: Delmar/Cengage Learning)

FLEX TRAY ICE MAKERS

Another type of household ice maker is known as the **flex tray**, Figures 45–22A and 45–22B. Although flex tray type ice makers are no longer manufactured, many are still in service, making it necessary for technicians in the field to understand their operation. Flex tray ice makers differ from the compact ice makers in several ways. Flex tray ice makers fill a tray with water and then, after some

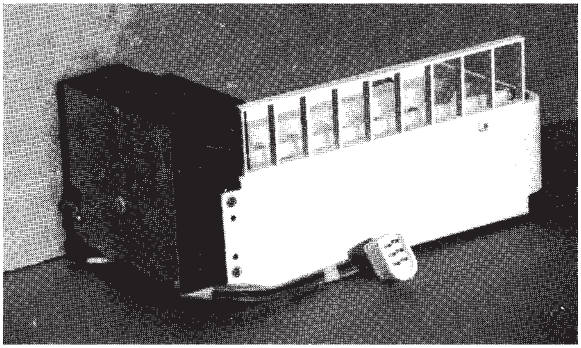


Figure 45–22A
Side view of flex tray ice maker. (Source: Delmar/Cengage Learning)

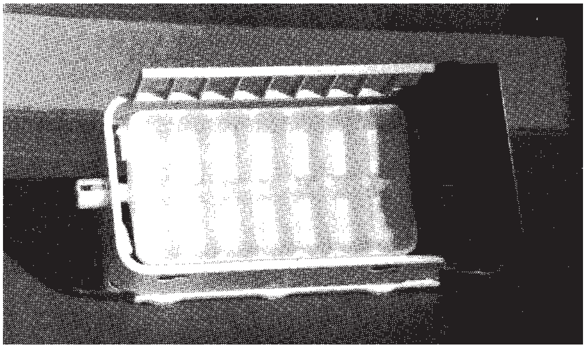


Figure 45–22B
Top view of flex tray ice maker. (Source: Delmar/Cengage Learning)

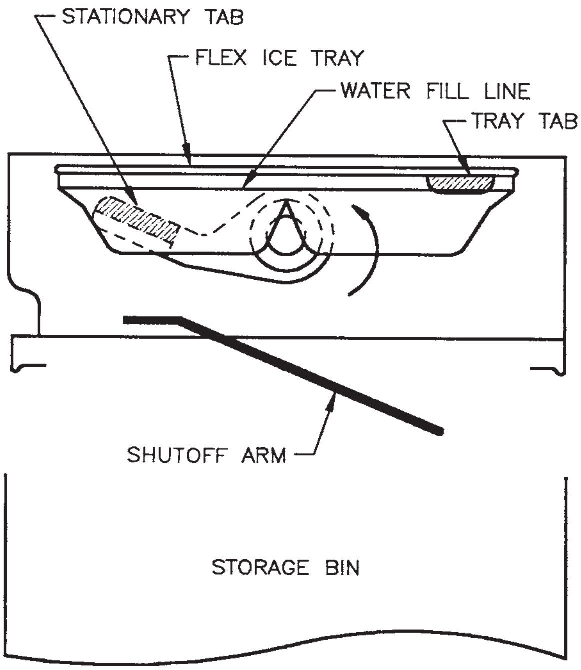


Figure 45–23
Flex tray ice maker. (Source: Delmar/Cengage Learning)

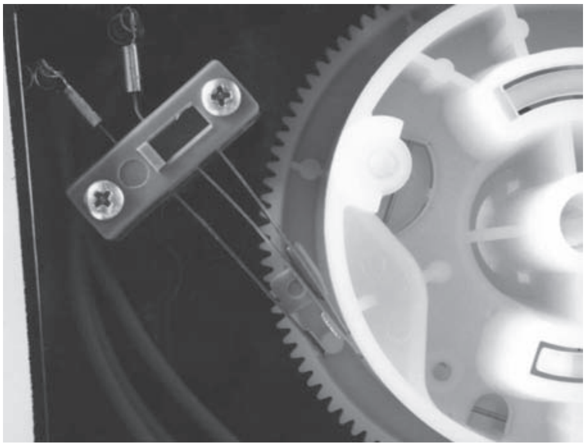


Figure 45–24
Water solenoid switch. (Source: Delmar/Cengage Learning)

length of time, turn the tray to dump the cubes into a storage bin, Figure 45-23. At a point during the ejection cycle, a tab located on one side of the rear of the tray contacts a stationary stop. The front of the tray continues to turn, causing the tray to flex or bend at about a 20° angle. This flexing action causes the cubes to dump into the storage bin. Notice that the time necessary to complete one cycle is about 13.3 minutes. When the turning tray approaches the upright position again, a cam operated switch energizes a water solenoid valve for a period of about 13 seconds and refills the tray with approximately 8 ounces of water, Figure 45–24.

Note that replacement motors for this type of ice maker operate at a higher rate of speed than the original motors supplied with the unit. The new motors cause an ejection cycle to occur every 90 minutes instead of 120 minutes. For this reason, the water fill switch should be changed with the motor to prevent short cycling of the fill cycle.

The principle of operation of the flex tray ice maker is different than that of the compact type. The flex tray ice maker is incorporated in the same circuit with the defrost timer, Figure 45–25. Because this type of ice maker does not need a mold heater or separate thermostat, it contains only three electrical components:

1. A timer motor, which operates both the defrost timer and the ice maker, Figure 45–26. This motor contains a two-stage output gear. One gear operates the time cycle for the defrost heater, and the other gear operates the ice maker. The defrost cycle operates every 9.6 hours of timer motor running time, and the ice maker operates every 2 hours of timer motor running time. When the appliance is in the freeze cycle, the timer motor can operate only when both the **cabinet thermostat** and the **defrost heater thermostat** are closed. During the defrost cycle, however, the timer motor will continue to operate regardless of the condition of either thermostat.
2. Defrost timer switch, Figure 45–27.
3. Water fill switch, Figure 45–24.

Another operating difference is that the flex tray ice maker is more dependent on mechanical control

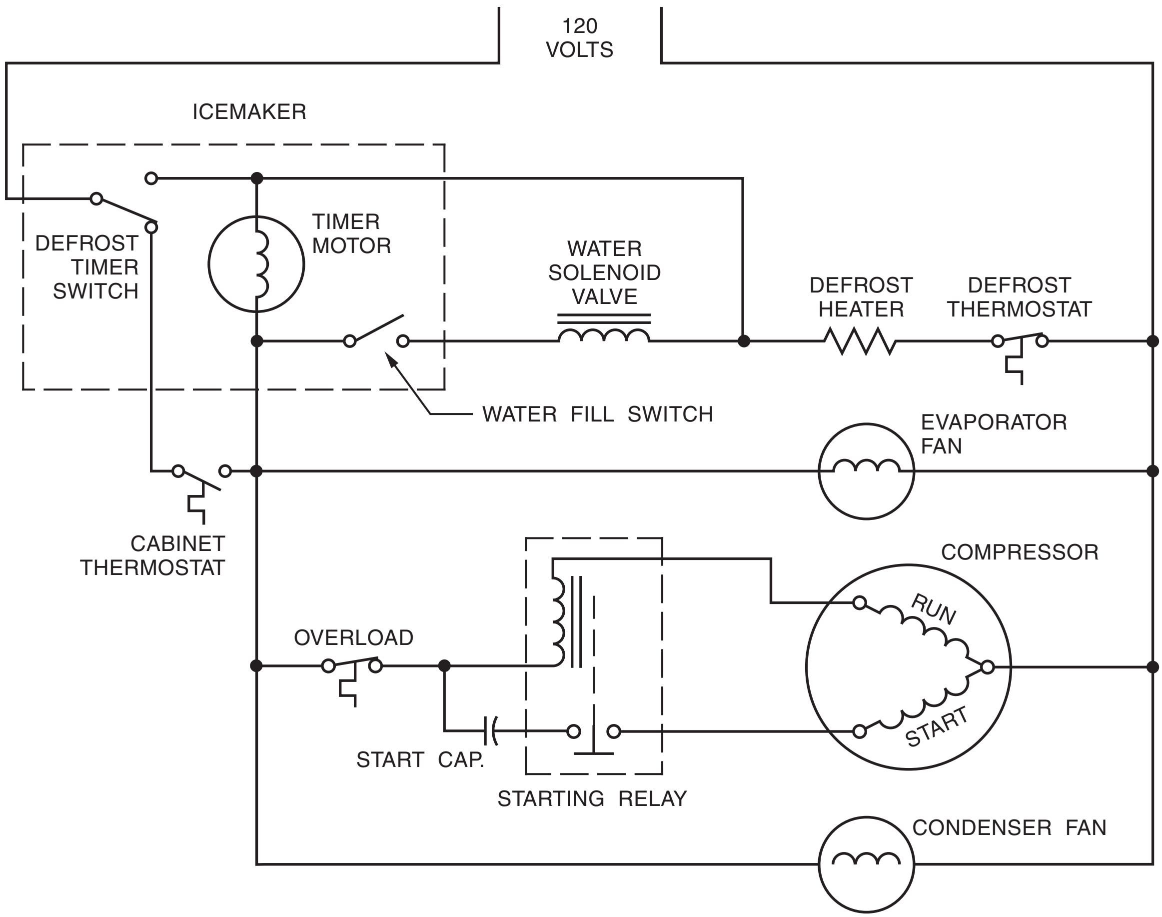


Figure 45–25
Schematic of flex tray ice maker. (Source: Delmar/Cengage Learning)

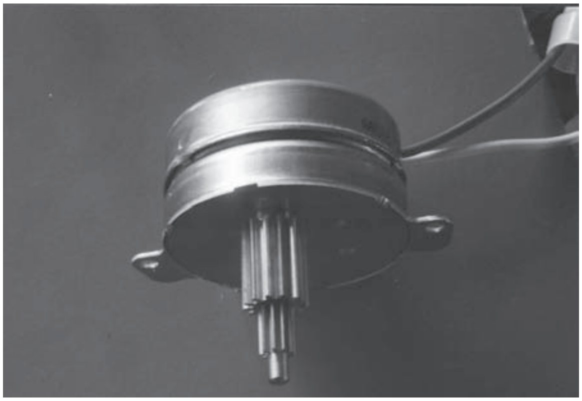


Figure 45–26
Timer motor. (Source: Delmar/Cengage Learning)

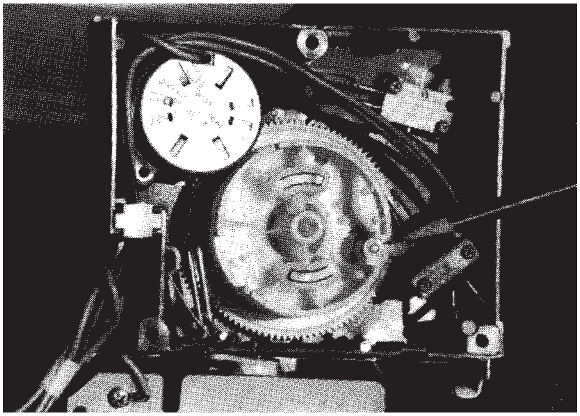


Figure 45–28
Locking pin. (Source: Delmar/Cengage Learning)

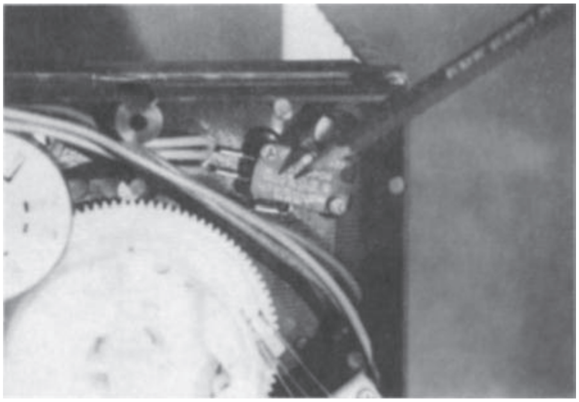


Figure 45–27
Defrost timer switch. (Source: Delmar/Cengage Learning)

than electrical control. The shutoff arm located at the bottom of the ice maker senses the level of ice in the storage bin. When this arm is in the down position, it permits a spring-loaded pin to move forward and lock a gear in place, Figure 45–28. This locked gear permits the timing motor to turn the tray through one revolution and eject the ice into the storage bin. The pin is mechanically reset at the end of each ejection cycle.

When the shutoff arm is held up, the pin will not be released and the tray will not enter into an ejection cycle. The operation of the ice maker can be manually stopped by lifting the arm above its normal turnoff position.

CIRCUIT OPERATION

In the first stage of operation, the circuit is shown during the freeze cycle, Figure 45–29. The cabinet thermostat and defrost heater thermostat are both closed. At this point, several circuit paths exist. One circuit is completed through the timer motor, defrost heater, and defrost thermostat. A circuit is completed through the evaporator fan, condenser fan, and the run winding of the compressor. If the cabinet thermostat should open, as shown in Figure 45–30, the timer motor also stops.

After 9.6 hours of timer motor operation, the defrost timer switch changes position and completes the circuits shown in Figure 45–31. The defrost heater is now connected directly to the power line, which permits it to warm the evaporator and melt accumulations of frost. A current path also exists through the timer motor to the evaporator fan, compressor run winding, and condenser fan. It is this circuit path that permits the timer motor to continue operation if the defrost thermostat should open its contacts. The timer motor must continue to run, or the defrost cycle cannot be completed. Note that

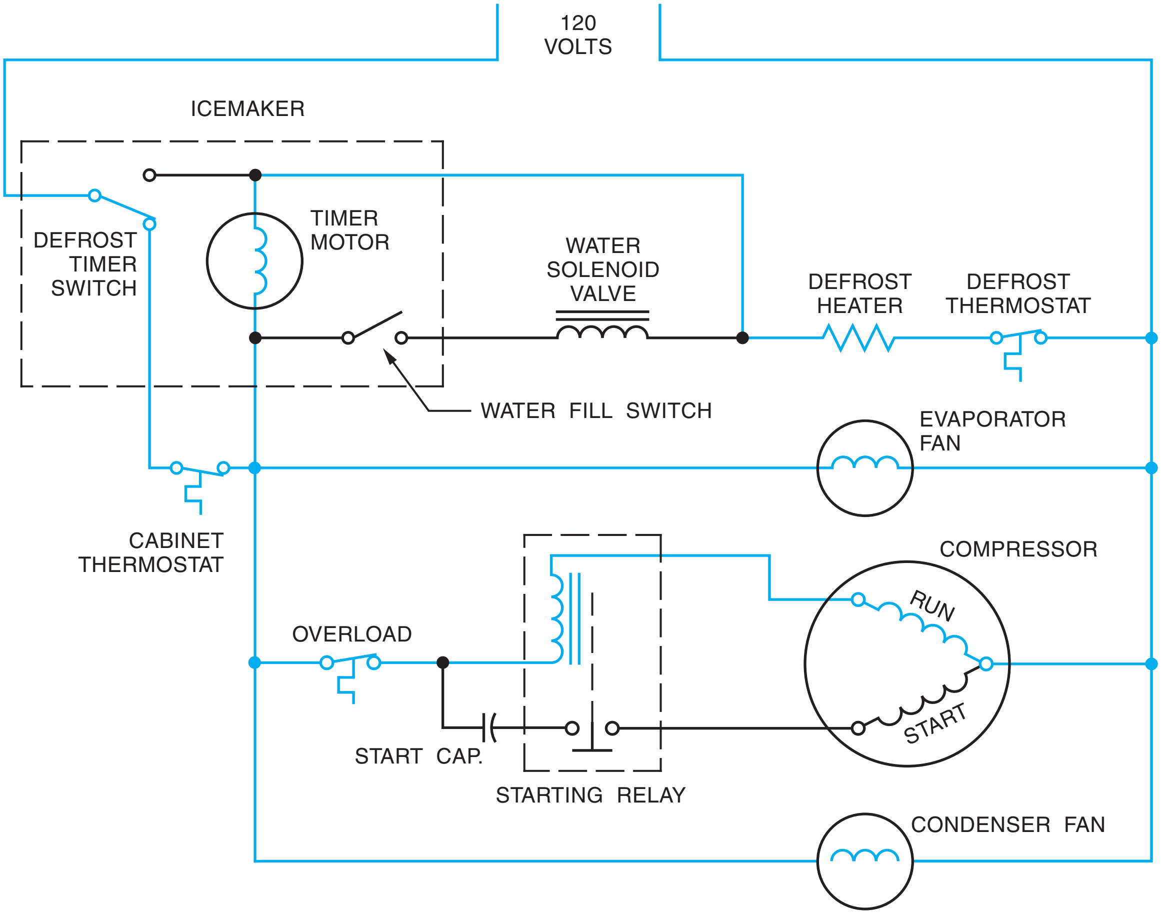


Figure 45–29
First stage of operation. (Source: Delmar/Cengage Learning)

the winding of the timer motor has a much higher impedance than the run winding of the compressor. This permits almost all the voltage to be dropped across the timer motor and very little to be dropped across the evaporator fan, compressor run winding, and condenser fan. At this time, the timer motor will operate, but the other motors will not. The defrost cycle lasts for approximately 21.5 minutes.

At the end of the defrost cycle, the defrost timer switch changes back to its normal position. Because

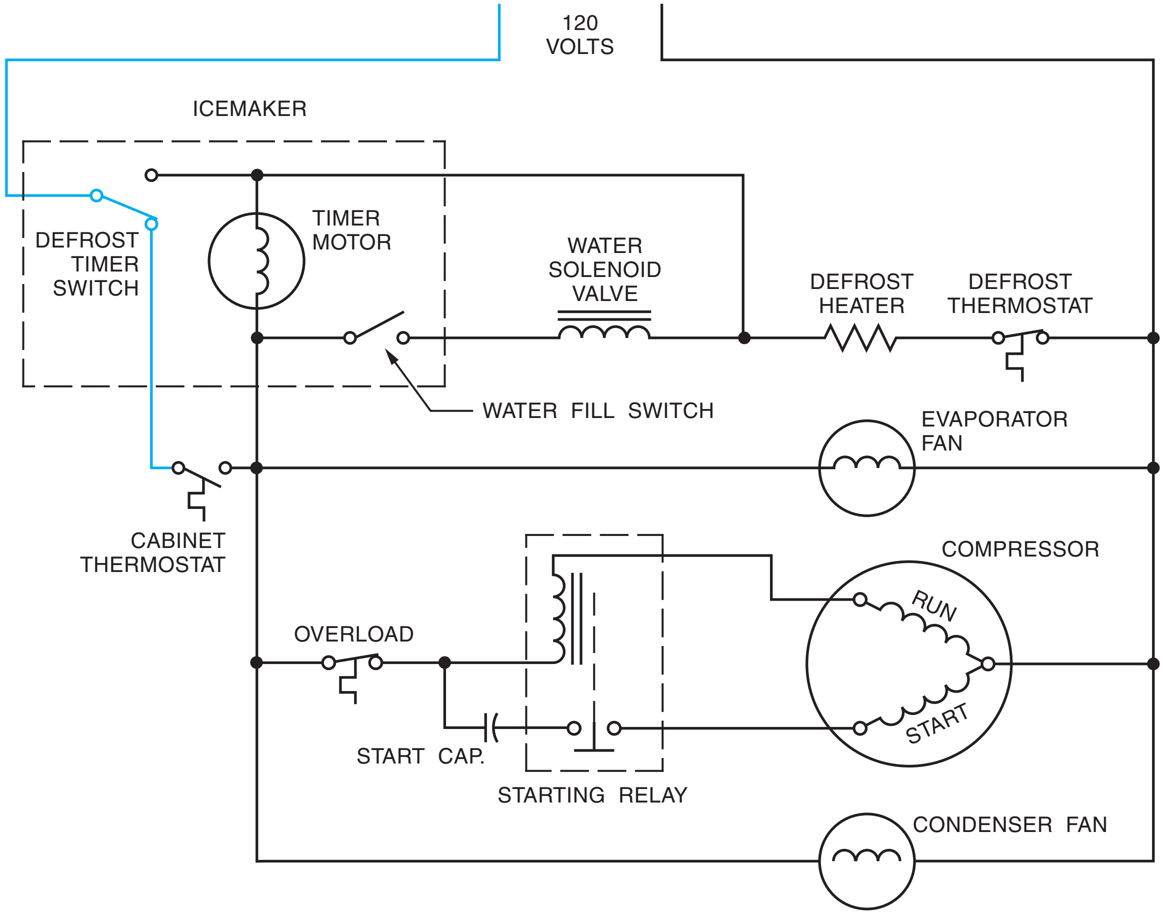


Figure 45–30
Cabinet thermostat opens. (Source: Delmar/Cengage Learning)

the defrost thermostat opens its contacts at approximately 70°F and does not reclose them until the evaporator reaches about 2°F, it is normal for these contacts to be open at the end of the defrost cycle, Figure 45–32. During this time, the timer motor is turned off.

Under normal conditions, the ice maker activates after 2 hours of timer motor running time. Figure 45–33 shows the condition of the circuit near the end of the ejection cycle. The cam-operated water fill switch has closed and now completes a circuit through the water solenoid valve, defrost

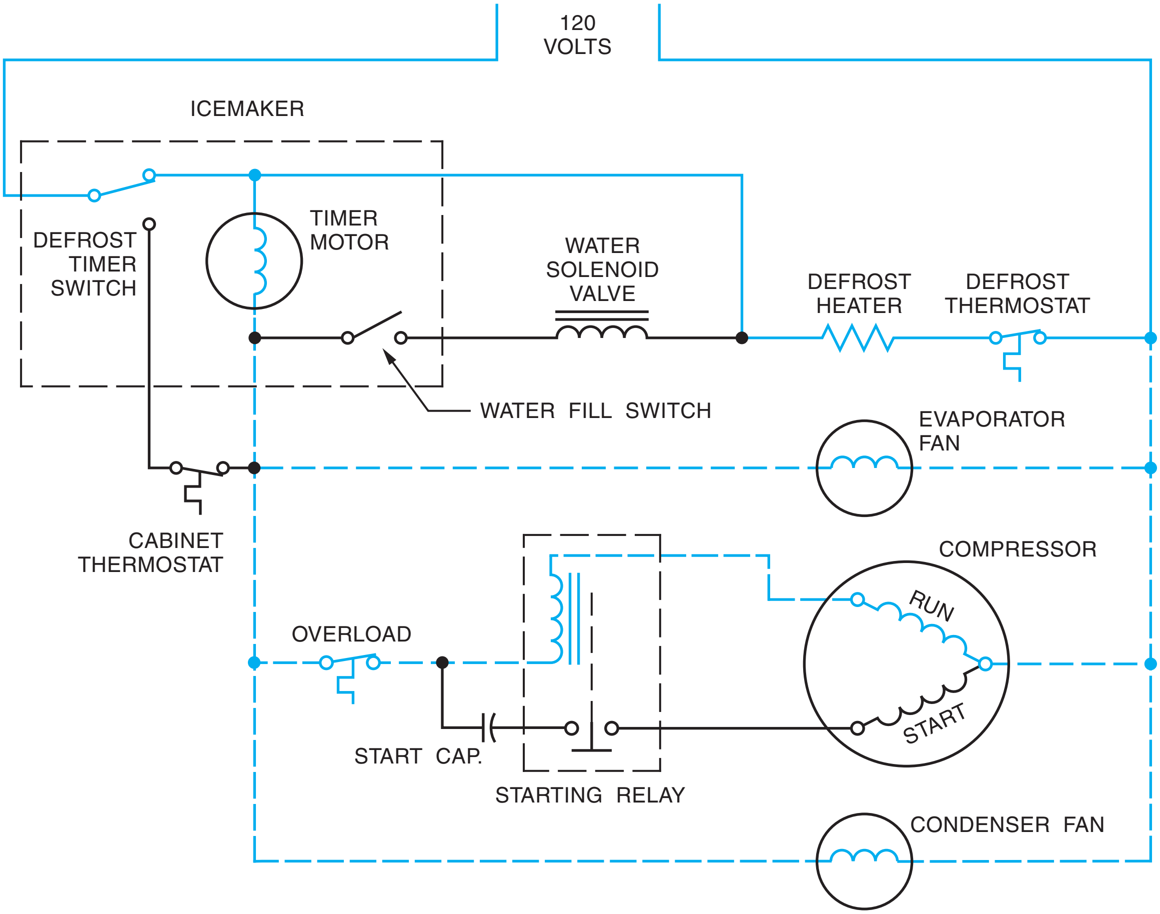


Figure 45–31
Defrost thermostat closes. (Source: Delmar/Cengage Learning)

heater, and defrost thermostat. Note that if the cabinet thermostat should open during the water fill cycle, the cycle will be interrupted until the cabinet thermostat again closes.

Because the timer motor is used to operate both the ice maker and defrost cycle, it is possible for the ice ejection cycle to occur during the defrost cycle, Figure 45–34. Notice that a parallel current path exists through both the timer motor and water solenoid valve. If the defrost thermostat should open while the water valve switch is closed, the same current path is provided through the evaporator fan, compressor run winding, and condenser fan for both the timer motor and water solenoid valve. This permits the tray to dump the ice and refill with water.

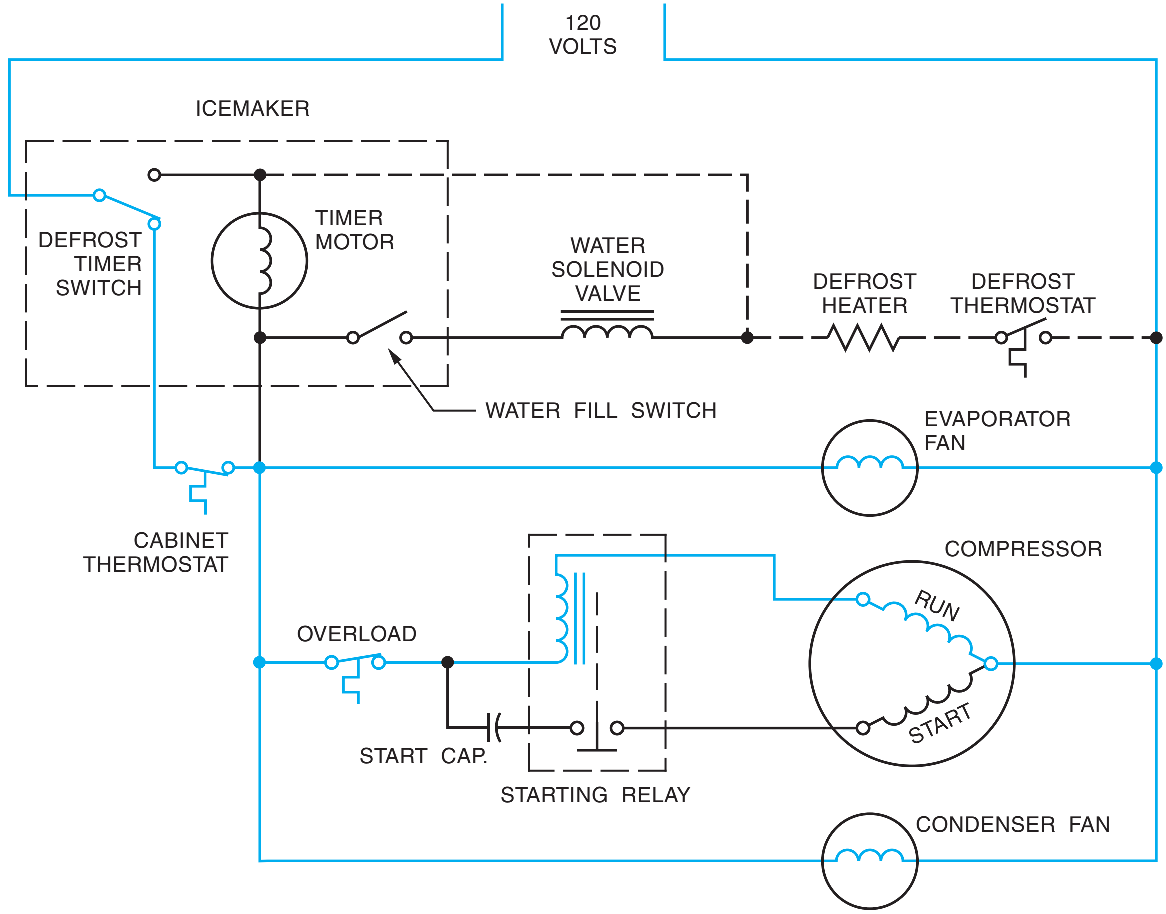


Figure 45–32
The defrost thermostat remains open until the temperature drops to 2°F. (Source: Delmar/Cengage Learning)

PROBLEMS AND PRECAUTIONS WITH THE FLEX TRAY ICE MAKER

When servicing the flex tray ice maker, there are several conditions the serviceperson should be aware of:

1. Before disconnecting the ice maker, turn the cabinet thermostat to the OFF position or unplug the appliance. This is done to prevent arcing at the terminal connector block.
2. If the ice maker should jam, it will prevent the defrost timer from operating.
3. The flex tray type of ice maker permits no adjustment of the water fill switch.
4. One of the most common problems is that the surface of the ice tray becomes rough because of mineral deposits in the water. This causes the ice cubes to stick in the tray and not be ejected. When ice cubes are not ejected, the tray becomes too full during the fill cycle and

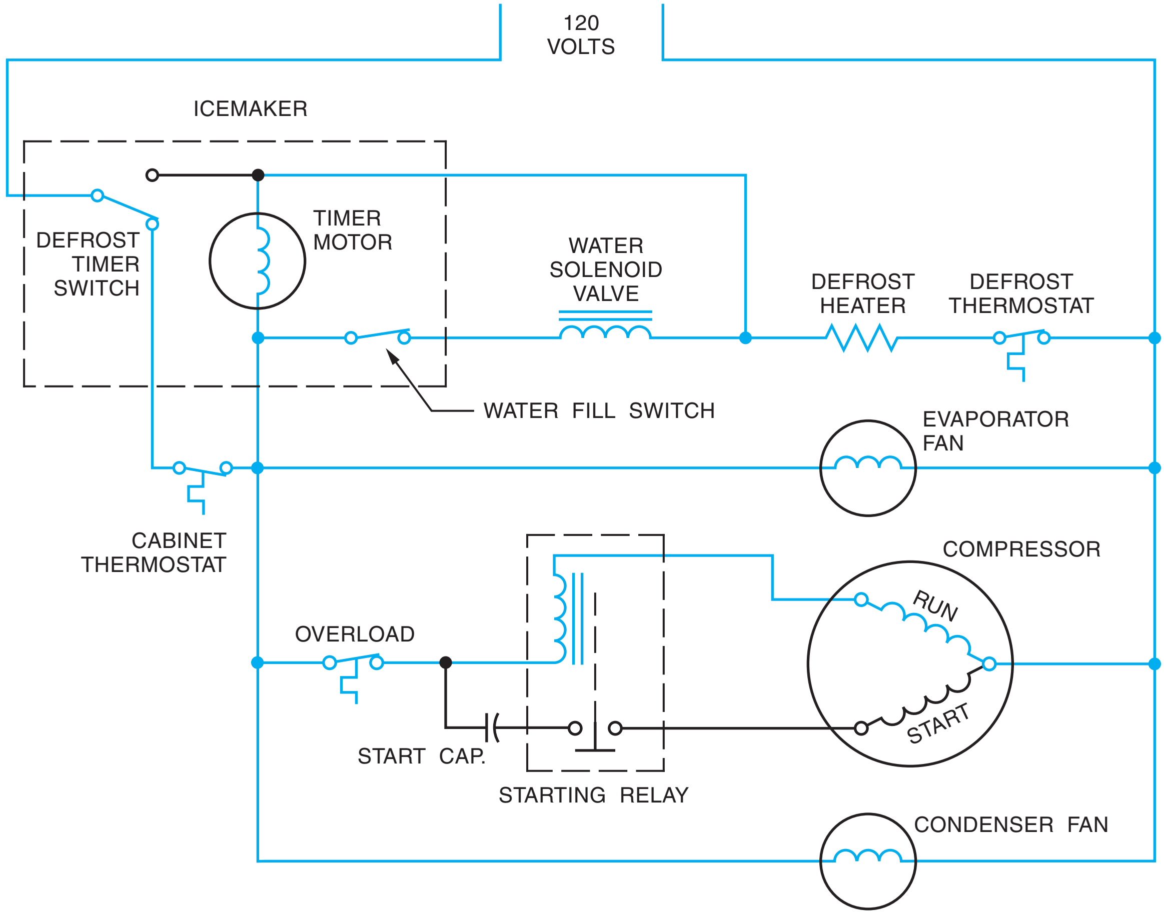


Figure 45–33
The water fill switch closes. (Source: Delmar/Cengage Learning)

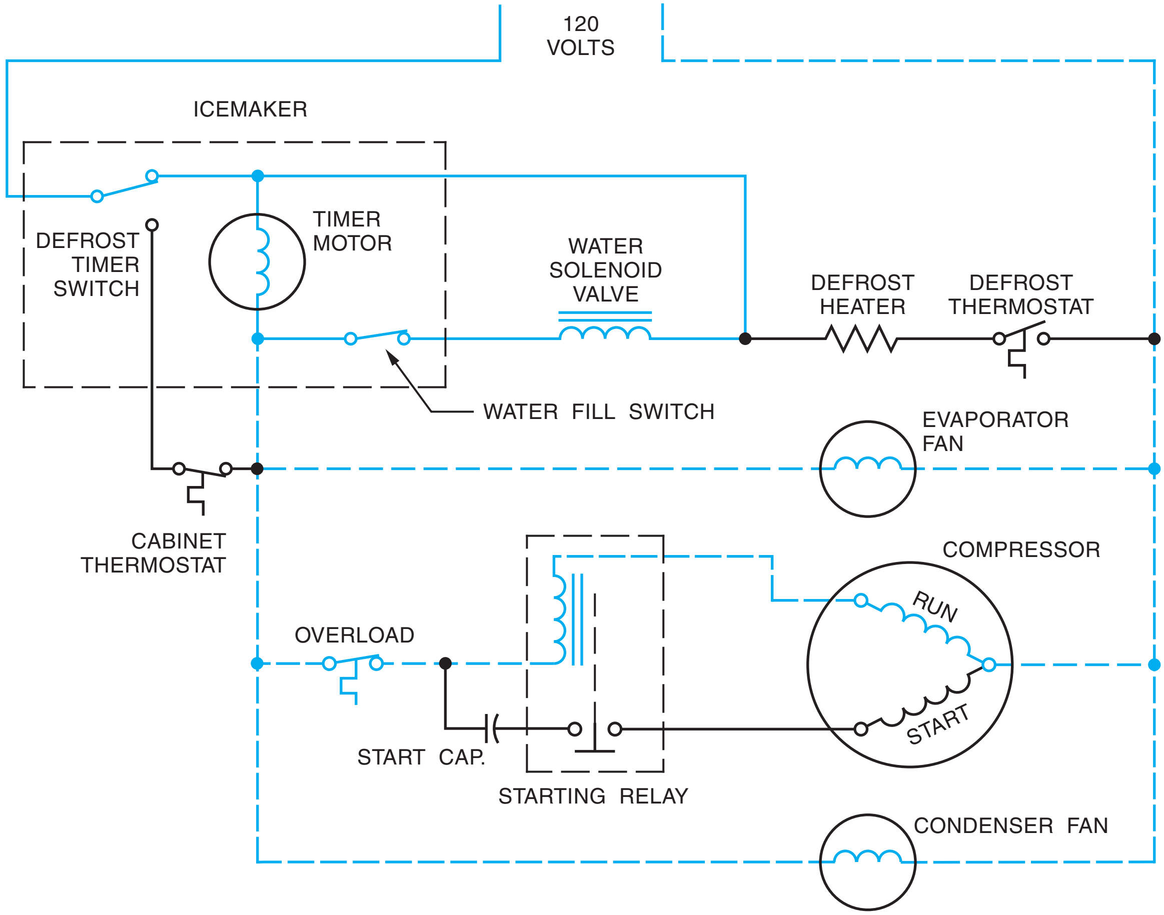


Figure 45–34
The ice ejection cycle can occur during the defrost cycle. (Source: Delmar/Cengage Learning)

causes a slab of ice to form. This slab can cause damage to the pin, gears, and/or timer motor. The ice tray should be replaced at the first sign of slabbing. A set of drive gears and pin are shown in Figure 45–35.

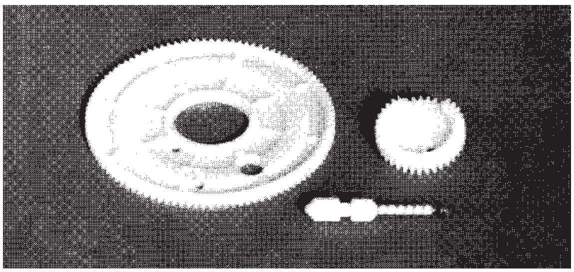


Figure 45–35
Drive gear and pins for the flex tray ice maker.
(Source: Delmar/Cengage Learning)

SUMMARY

- Ice makers can be divided into two major categories: household and commercial.
- An electric solenoid valve permits the tray to be filled with water at the proper time.
- A flow washer is used to meter the amount of water flow to the tray.
- The flow control washer is designed to operate with pressures that range between 15 and 100 psi.
- The amount of water needed to fill the mold or tray is approximately 135 cc or 4 oz.
- A thermostat mounted to the mold senses when the water is frozen.
- A mold heater is used to slightly melt the cubes so the ejector blades can push them out of the mold.
- The shutoff arm senses when the storage bin is full of cubes.
- The shutoff arm can be used to manually prevent starting another cycle.
- Flex tray ice makers operate by filling a flexible tray with water. When the water freezes, the entire tray rotates and dumps the ice in the storage bin.
- The motors of flex tray ice makers are generally used to operate the defrost timer circuit.

KEY TERMS

cabinet thermostat
compact
defrost heater thermostat
ejector blades
flex tray
flow washer
holding switch
mold heater
test points

REVIEW QUESTIONS

1. Ice makers are divided into what two major categories?
2. What is the advantage of continually recirculating the water during the ice-making process?
3. What component controls the amount of water flow into the original compact ice maker?
4. Does the flex tray ice maker require a mold heater to thaw the ice cubes before they can be dumped into the storage bin?
5. In the original compact ice maker, what method is used to sense when the water has been frozen?
6. In the original compact ice maker, what controls the start of the ejection and refill cycle?
7. In the flex tray ice maker, what controls the start of the ejection and refill cycle?
8. How can the original compact ice maker be manually turned off?

9. How many revolutions will the ejector blades of the original compact ice maker normally make during the ejection cycle?
10. What is the function of the holding switch in the original compact ice maker circuit?
11. Concerning the flex tray ice maker, what two separate tasks are performed by the timer motor?
12. What is the function of the spring loaded pin in the flex tray ice maker?
13. Concerning the flex tray ice maker, is it possible for the timer motor to operate during the defrost cycle?
14. Concerning the new type compact ice maker, what method is used to change the contacts labeled A, B, C, and D in the schematic diagram shown in Figure 45–18?
15. Can the gear of the new type compact ice maker be rotated to manually advance the operation of the ice maker?
16. How many revolutions do the ejector blades of the new type compact ice maker make during the ejection cycle?

UNIT 46

Commercial Ice Makers

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the basic design of different types of commercial ice makers
- Discuss the operation of a cube-type and flaker-type ice maker
- Discuss the control system of a cube-type and flaker-type ice maker

Commercial ice makers are designed to produce large quantities of ice and are generally found in restaurants, cafeterias, motels, and hotels. Some ice makers produce cubes and others produce flaked ice. The first commercial type ice maker to be discussed is manufactured by Scotsman Company. The basic components of this unit are shown in Figure 46–1. Notice that this unit can be equipped with either an air-cooled or a water-cooled condenser. The water-cooled unit operates much more quietly.

This unit produces ice by cascading water over a metal plate used as the evaporator, Figure 46–2. A water pump provides continuous circulation of water when the compressor is operating. A water distributor, located at the top of the plate, provides an even flow of water over the entire surface of the plate. Excess water is caught by a trough at the bottom of the plate and is returned to a sump where

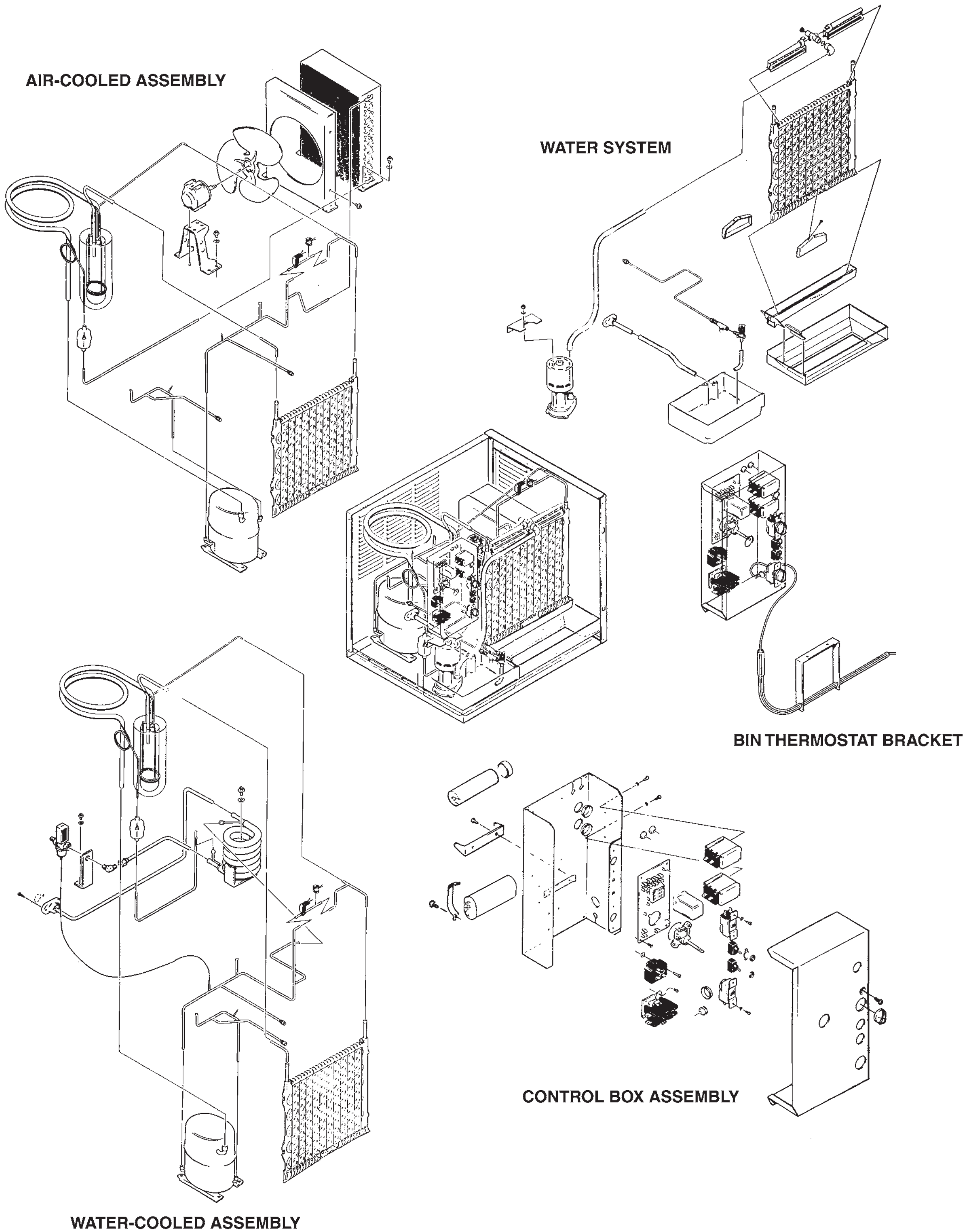


Figure 46–1
Scotsman cube-type ice maker. (Courtesy of Scotsman Ice Systems).

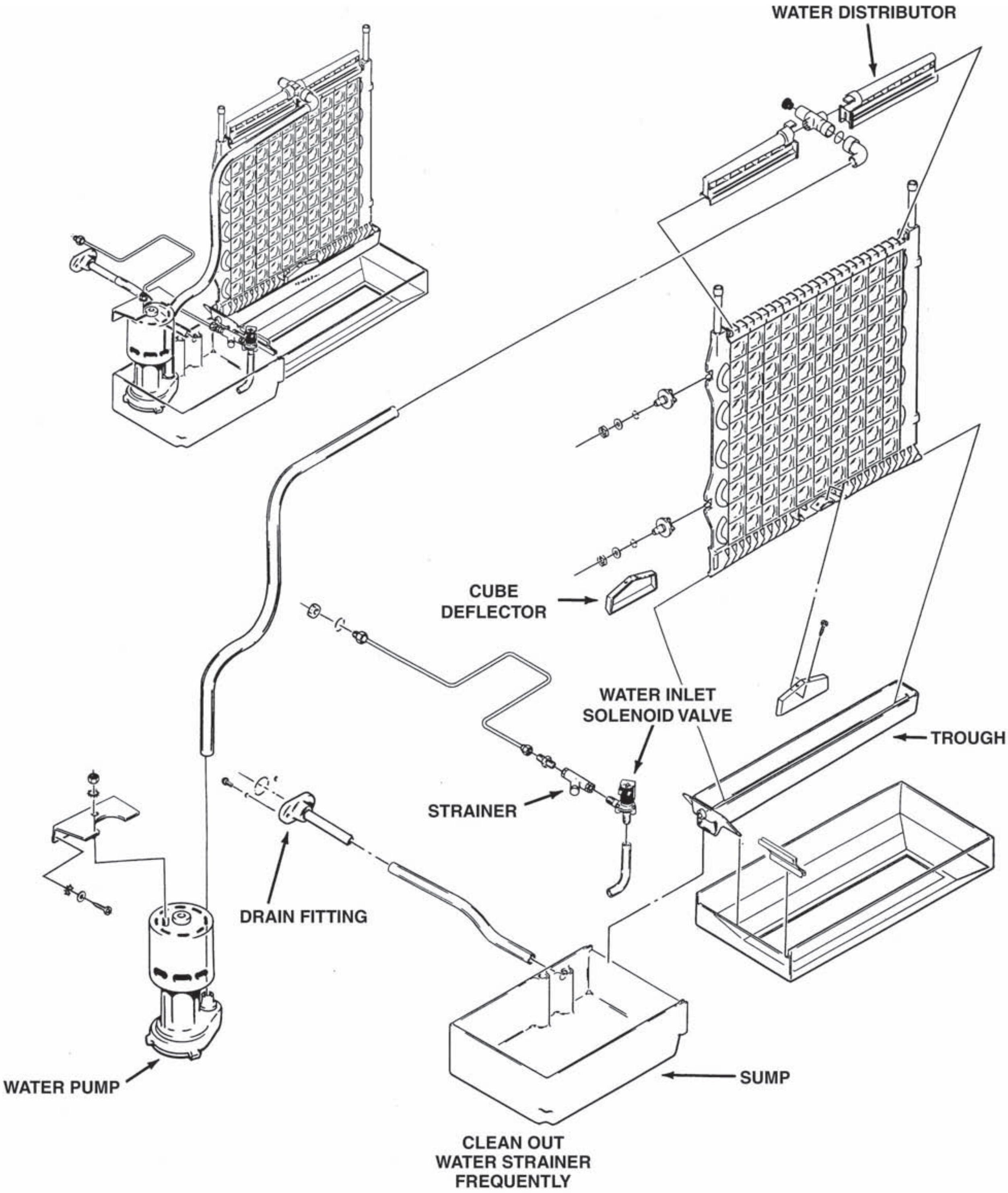


Figure 46–2
Water cascades over a metal plate to produce ice. (Courtesy of Scotsman Ice Systems).

it is recirculated by the pump. Continuous circulation of water produces a clearer ice because pure water freezes faster than impure water. This is not to say that water can be purified by circulating it. The purification is a result of the freezing process. Basically, the water freezes before the impurities and minerals have a chance to freeze. The water, minus the impurities and minerals, is frozen to the evaporator plate and the impurities and minerals are returned to the sump.

After the ice has formed, the harvest cycle begins. At the beginning of this cycle, a **hot-gas solenoid valve** opens and permits high pressure hot gas to be diverted to the evaporator plate. This high pressure gas warms the plate, and thaws the surface of the ice that is in contact with it. The combination of the warm plate and the cascading water loosens the ice cubes so that they drop away from the plate and fall into the storage bin below. During the harvest cycle, a **water solenoid valve** opens and permits fresh water to flow into the sump. This not only refills the sump, but also flushes impurities out the overflow drain.

The basic electrical schematic diagram for this machine is shown in Figure 46–3. There are two manual switches in this circuit. One is the master

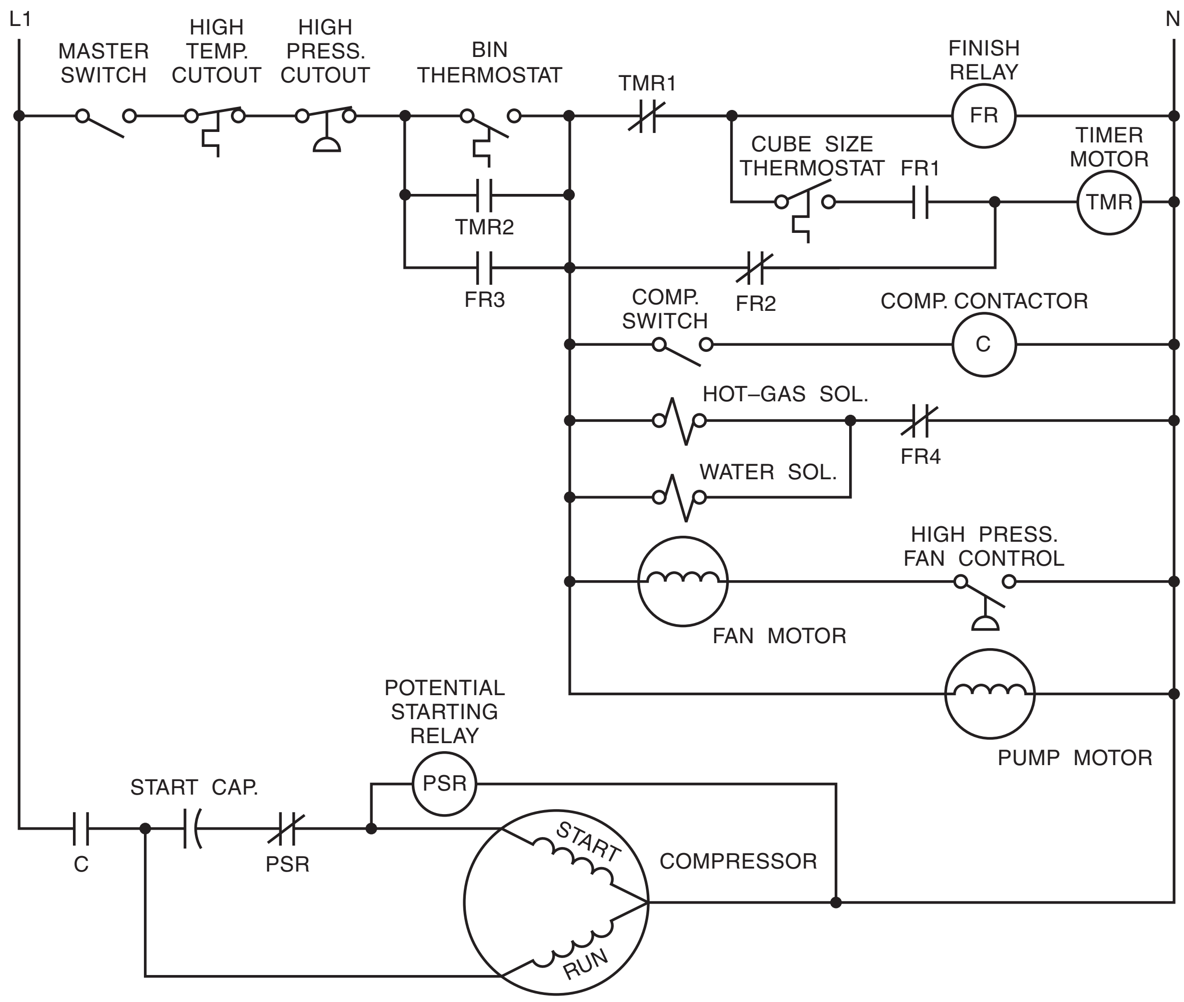


Figure 46–3
Basic schematic diagram of a commercial ice cube maker. (Source: Delmar/Cengage Learning)

switch, and can be used to disconnect power to the entire control circuit. The second is connected in series with the compressor contactor relay coil. This switch can be used to turn off the compressor separately. Two safety switches, the high temperature cutout and the high pressure cutout, are connected in series with the master switch. If either of these switches opens, they will disconnect power to the control circuit.

This circuit also contains two thermostats, the **bin thermostat** and the **cube-size thermostat**. The sensor for the bin thermostat is located in the ice storage bin and senses the level of ice. When the ice reaches a high enough level, it touches the sensor and causes the contact to open. This stops the operation of the ice maker at the end of the harvest cycle. The sensor for the cube-size thermostat is mounted on the evaporator plate. When the evaporator plate reaches a low enough temperature, the thermostat contact closes and completes a circuit to the timer motor. The timer contains a set of cam-operated contacts and is used to complete the freeze and harvest cycle.

This circuit also contains a fan motor controlled by a pressure switch that senses the pressure on the high side of the compressor. This fan motor is used only on units with an air-cooled condenser. Because this fan motor is controlled by a pressure switch, it may cycle on and off during the unit's operation.

For a better understanding of this circuit, it is shown at the beginning of the freeze cycle, Figure 46–4. It is assumed that the master switch and the compressor switch have been closed, and that the bin thermostat contact is closed. A circuit is now completed to the finish relay, FR, causing all FR contacts to change position. The FR3 contact serves as a holding contact to permit completion of the cycle in the event the bin thermostat contact should open. The FR1 contact has closed to permit a current path to the timer motor when the cube size thermostat closes. The compressor contactor coil is energized, which closes its contact and connects the compressor to the line. The pump motor is energized causing water to flow over the evaporator plate. It is also assumed that the high-pressure fan control switch is closed, permitting the condenser fan motor to operate. Notice, however, that the FR4 contact has opened to prevent the hot-gas solenoid and the water solenoid from operating.

After the circuit has operated in this condition for some period of time, the evaporator plate becomes cold enough to permit the cube-size thermostat to close as shown in Figure 46–5. This completes a circuit to the timer motor. The timer is used to complete the cycle in the event the bin thermostat should open.

After the timer has operated for some length of time, the timer contacts will change position as shown in Figure 46–6, starting the harvest cycle. The TMR2 contact closes to maintain a current path around the bin thermostat contact, and the TMR1 contact opens and deenergizes coil FR. When coil FR deenergizes, all of its contacts return to their normal position. The FR2 contact recloses and maintains a current path to the timer motor, permitting it to complete the cycle. When the FR4 contact recloses, the hot-gas solenoid and water solenoid valves open. As hot gas is circulated through the evaporator plate, it warms and permits the cube size thermostat contact to reopen. The circuit will continue to operate in this condition until the timer completes the cycle and resets both TMR contacts. At this point, the freeze cycle will begin again if the bin thermostat is still closed.

FLAKER-TYPE ICE MAKERS

Flaker-type ice makers produce ice continuously as opposed to harvesting ice cubes at certain intervals. Flaked ice has a soft, flaky texture and is often preferred by restaurants. A basic diagram of a flaker-type ice maker is shown in Figure 46–7. The water supply from the building enters the water reservoir. A float valve maintains a constant water level in the reservoir.

Water from the reservoir enters the bottom of the **freezer assembly**. The freezer assembly is the evaporator of the refrigeration unit. The freezer assembly is basically a hollow tube surrounded by a cylindrical container. Refrigerant is used to cool the hollow tube. A stainless steel **auger** is placed inside the hollow tube. The motor drive assembly turns the auger. As water enters the bottom of the freezer assembly, it is frozen into ice and carried upward by the auger. When the ice reaches the top, the flared end of the auger presses excess water out of the ice before it is extruded or flaked out through

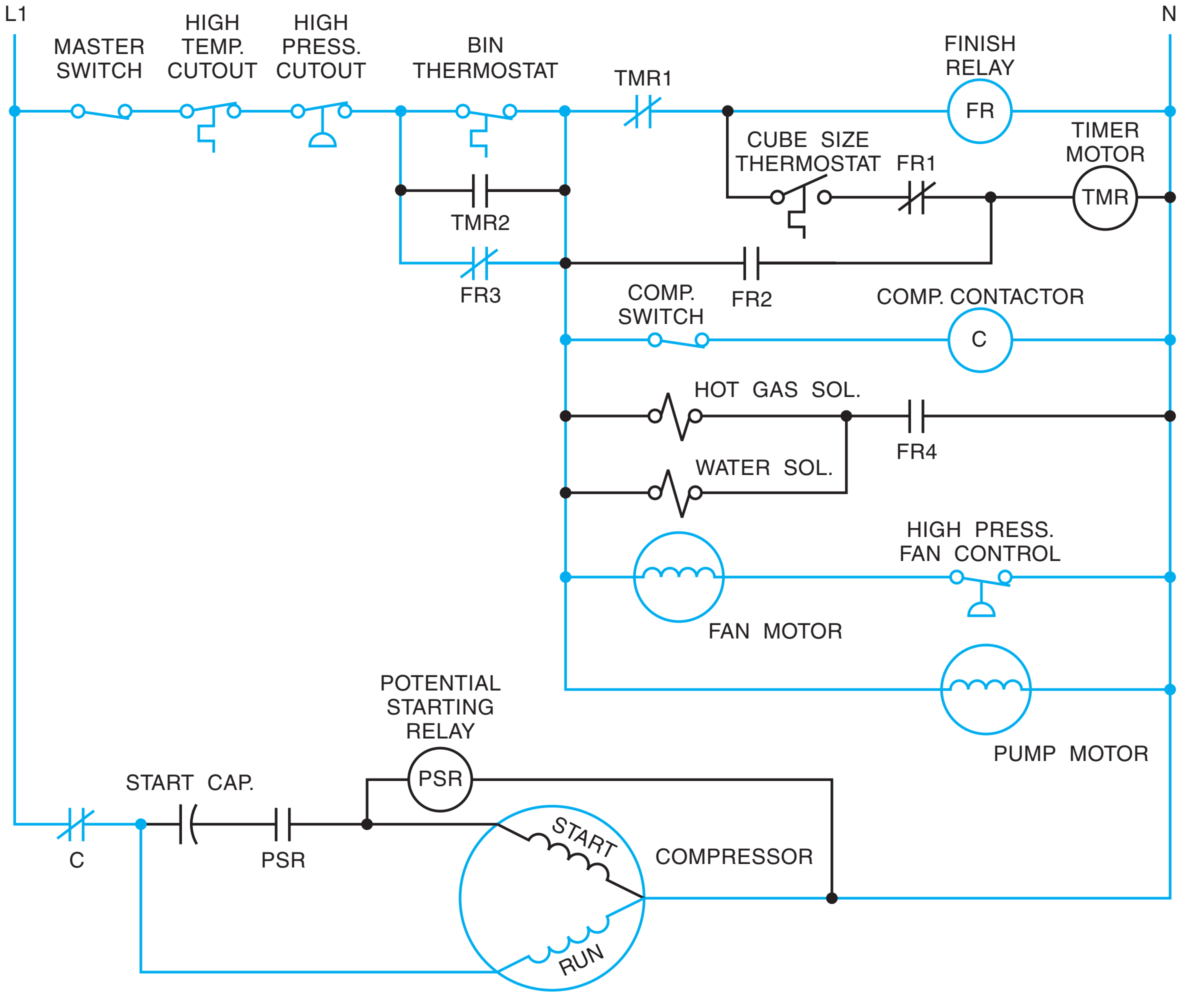


Figure 46–4
Beginning of freezing cycle. (Source: Delmar/Cengage Learning)

the ice spout. A **nylobraid tube** carries the ice to the ice storage bin. When enough ice accumulates, it touches the sensor bulb of the bin thermostat. The bin thermostat contact then opens and the compressor is disconnected from the line, but the auger drive motor continues to operate for approximately 1 to 2 minutes. This permits the auger to clear the ice out of the freezer unit before it stops operating.

The basic schematic diagram for the flaker-type ice maker is shown in Figure 46–8. Notice that the auger drive motor contains two separate centrifugal switches, one normally closed and the other normally open. The normally closed switch connects the motor start winding to the line when the motor is started. The normally open centrifugal switch controls the coil of the compressor contactor. The compressor contactor can be energized only when the auger drive motor operates within a certain speed range. If ice becomes compacted in the freezer unit, it will cause the auger drive motor to slow down. If the speed of the auger drive motor is reduced below a certain point, the centrifugal switch connected in

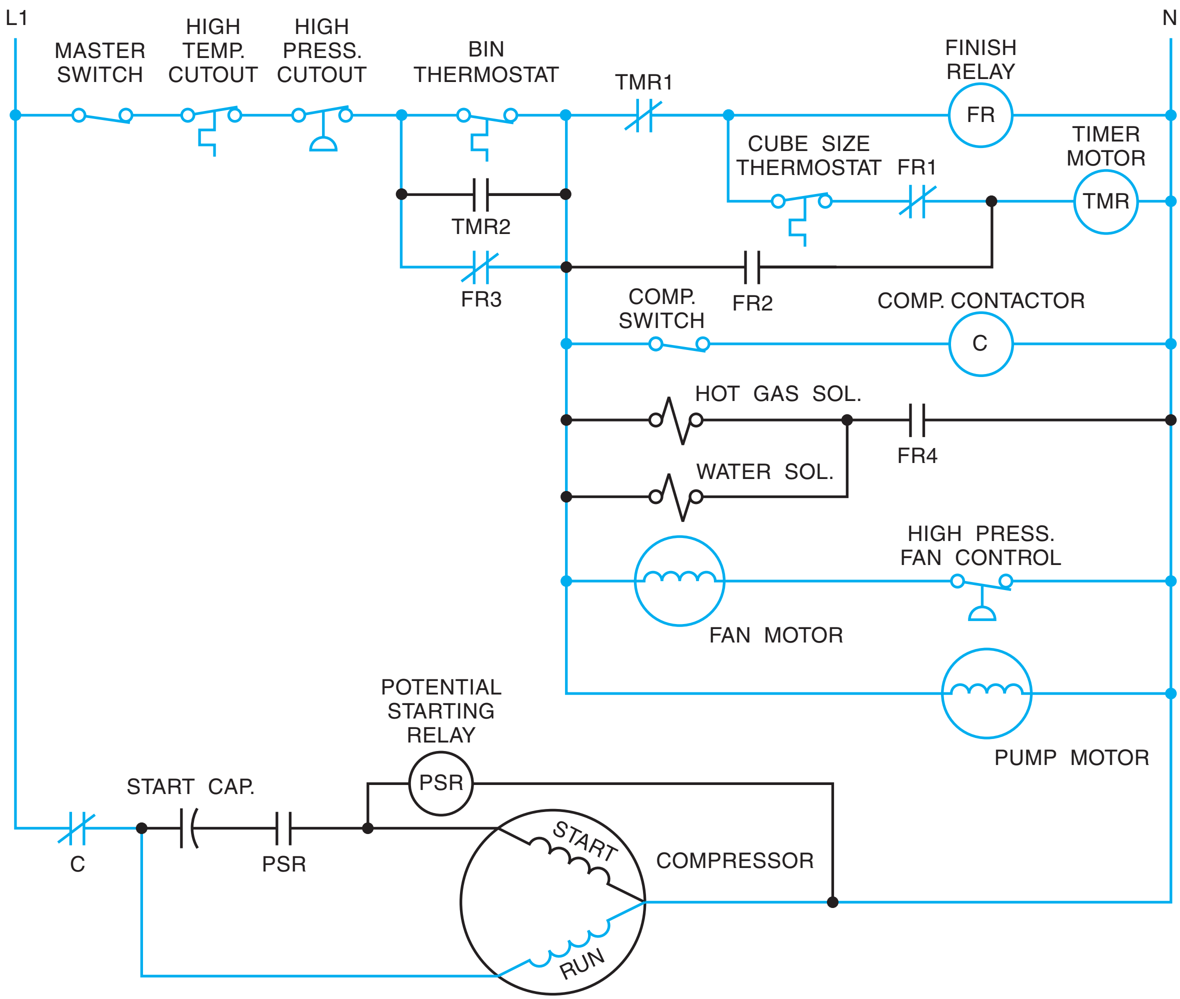


Figure 46–5
The cube-size thermostat closes to complete a circuit to the timer motor. (Source: Delmar/Cengage Learning)

series with the compressor contactor coil will open. If this should happen, the compressor turns off, but the auger delay pressure control switch permits the auger to continue operating for approximately one and a half minutes. If the ice is cleared sufficiently in that length of time, the auger drive motor speed will increase and permit the centrifugal switch to reclose and start the compressor.

The auger delay pressure control switch is a single-pole double-throw pressure switch connected in the low side of the refrigeration system. When the system is turned off, and the pressures have equalized in the system, the low-side pressure is high enough to hold the switch in the position shown in Figure 46–8. When the compressor starts, the low-side pressure begins to decrease. When it has decreased to 20 **psig (pounds per square inch gauge)**, the contacts change position. They will remain in the changed position until the low-side pressure increases to 32 psig.

The bin thermostat senses the level of ice in the storage bin and normally controls the operation of

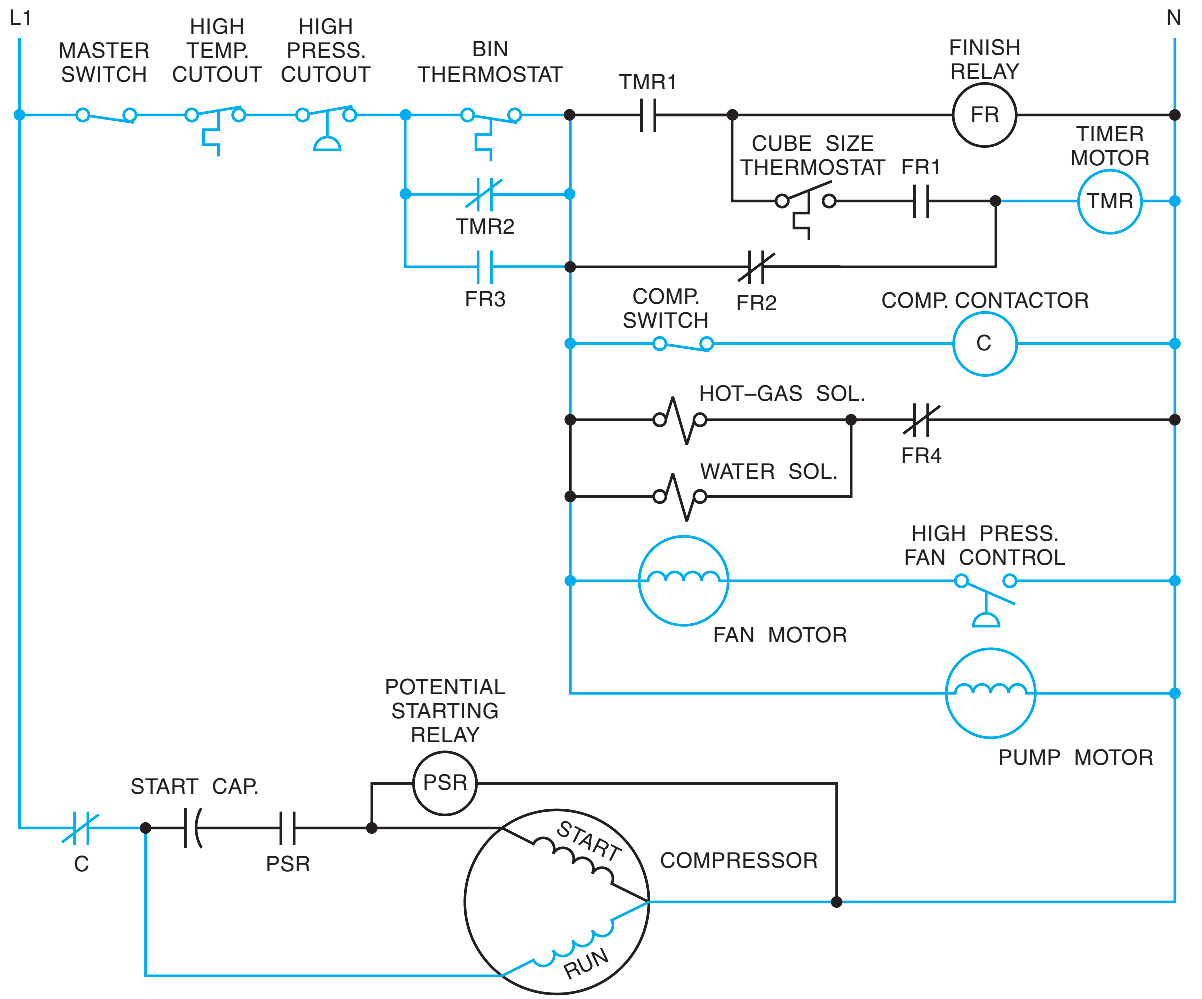


Figure 46–6
Harvest cycle. (Source: Delmar/Cengage Learning)

the ice maker. A low water-pressure switch is connected to the water supply line. If the water pressure drops below 5 psig, the switch contacts will open. They will reclose when the water pressure reaches 20 psig. The low head-pressure switch can interrupt operation of the compressor if the head pressure should become too low.

A master switch disconnects power to the entire control circuit. The spout switch can also disconnect power to the entire circuit in case the ice becomes compacted in the nylobraid tube and spout. If the spout switch becomes tripped, it must be manually reset.

This unit utilizes two condenser fan motors. One motor is mounted at the bottom of the condenser and the other is mounted at the top. The bottom fan motor is connected in parallel with the compressor and will operate any time the compressor is in operation. The top fan motor is controlled by a pressure switch that senses the high side of the refrigeration system. If the pressure becomes high enough, the

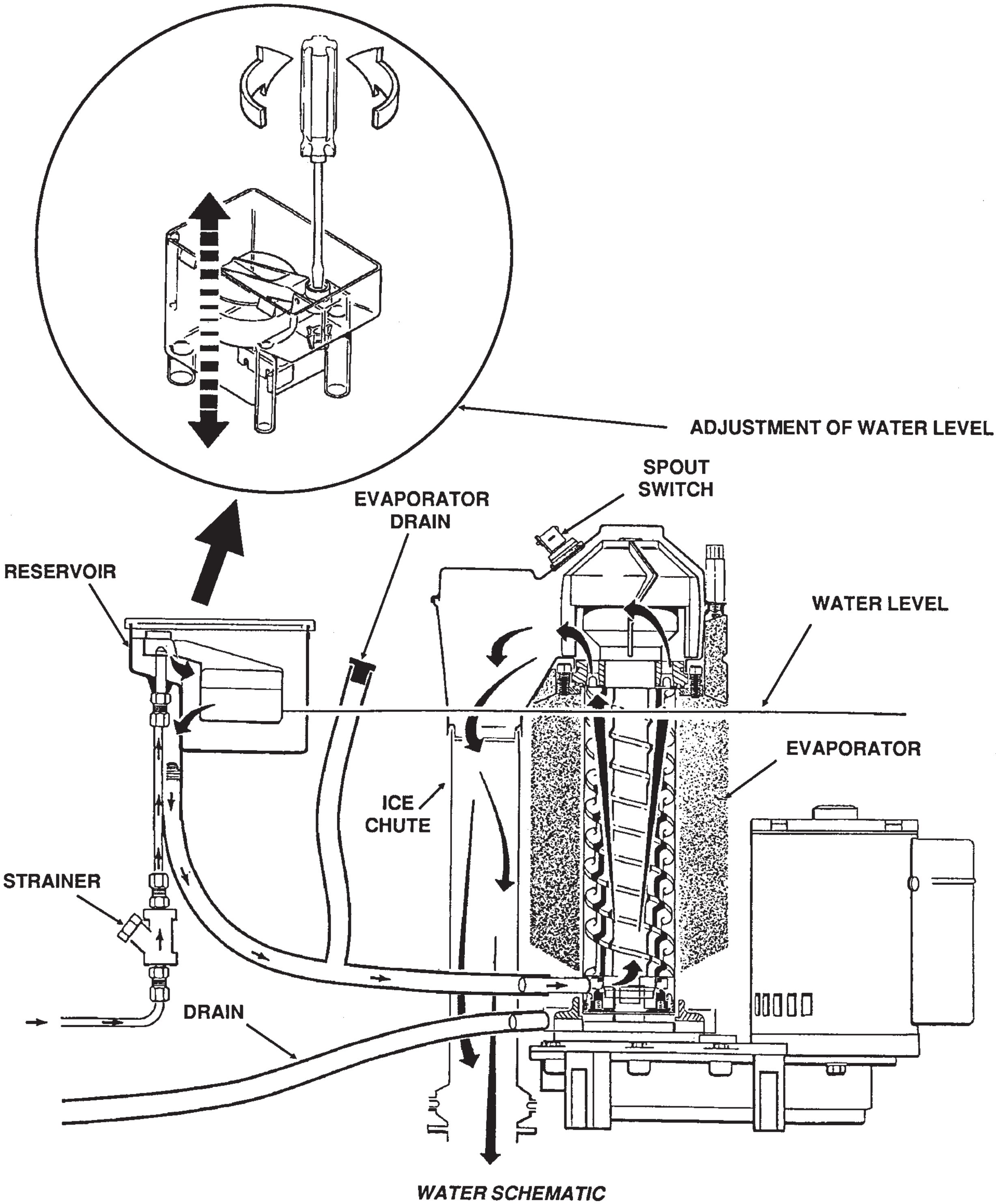


Figure 46–7
Water schematic. (Courtesy of Scotsman Ice Systems).

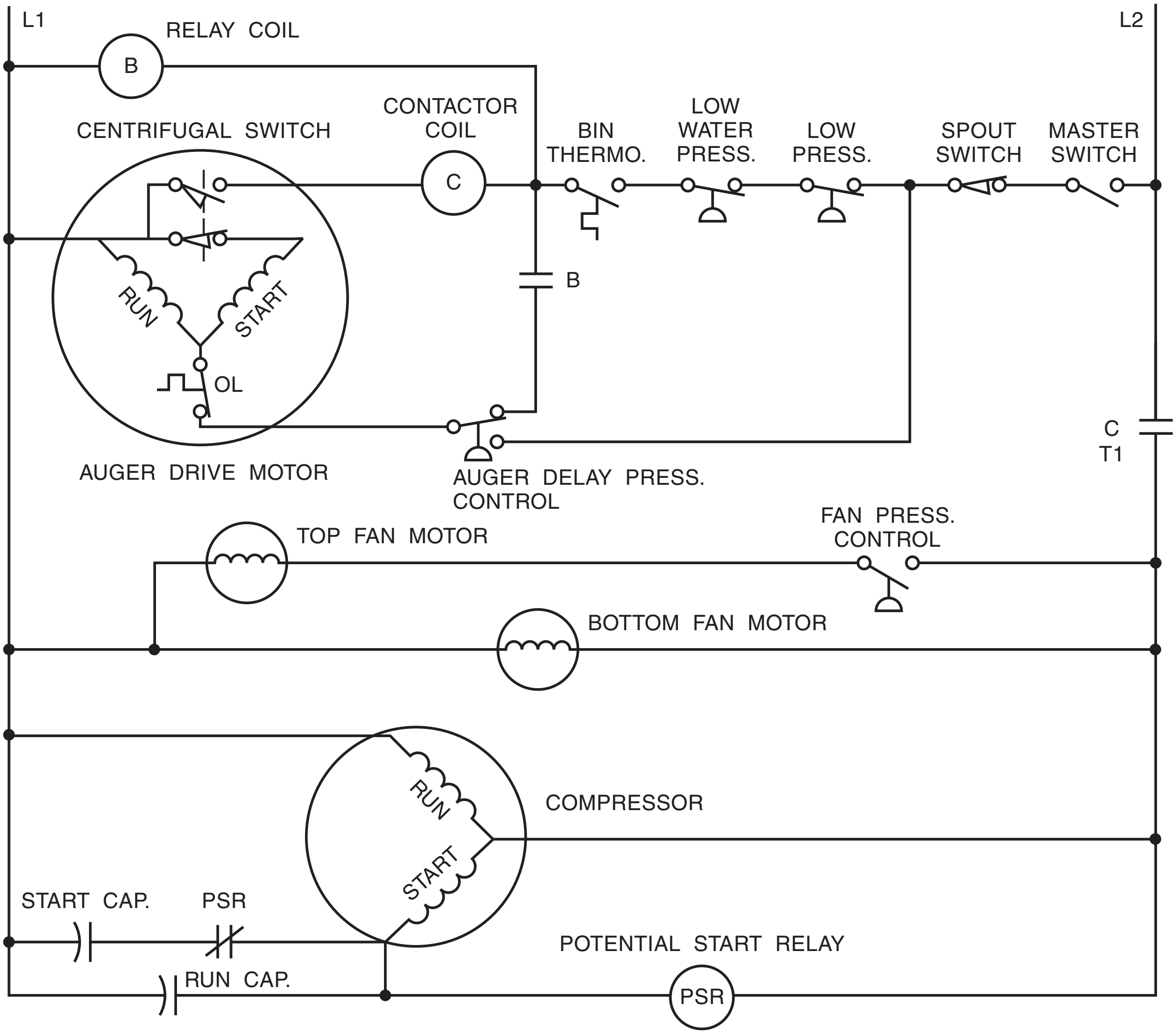


Figure 46–8
Basic schematic of flaker-type ice maker. (Source: Delmar/Cengage Learning)

switch contact will close and start the top condenser fan motor.

OPERATION OF THE CIRCUIT

The circuit in Figure 46–9 shows the initial start up of the ice maker. It is assumed that the master switch and the bin thermostat switch are closed. A circuit is first completed through coil B. This closes contact B and completes a circuit through the auger delay pressure control switch to the auger drive motor. The normally closed centrifugal switch contact completes a circuit to the start winding and permits the auger drive motor to start.

The normal running mode of the circuit is shown in Figure 46–10. In this phase of operation, it is assumed that the auger drive motor is operating at the proper speed and the centrifugal switch

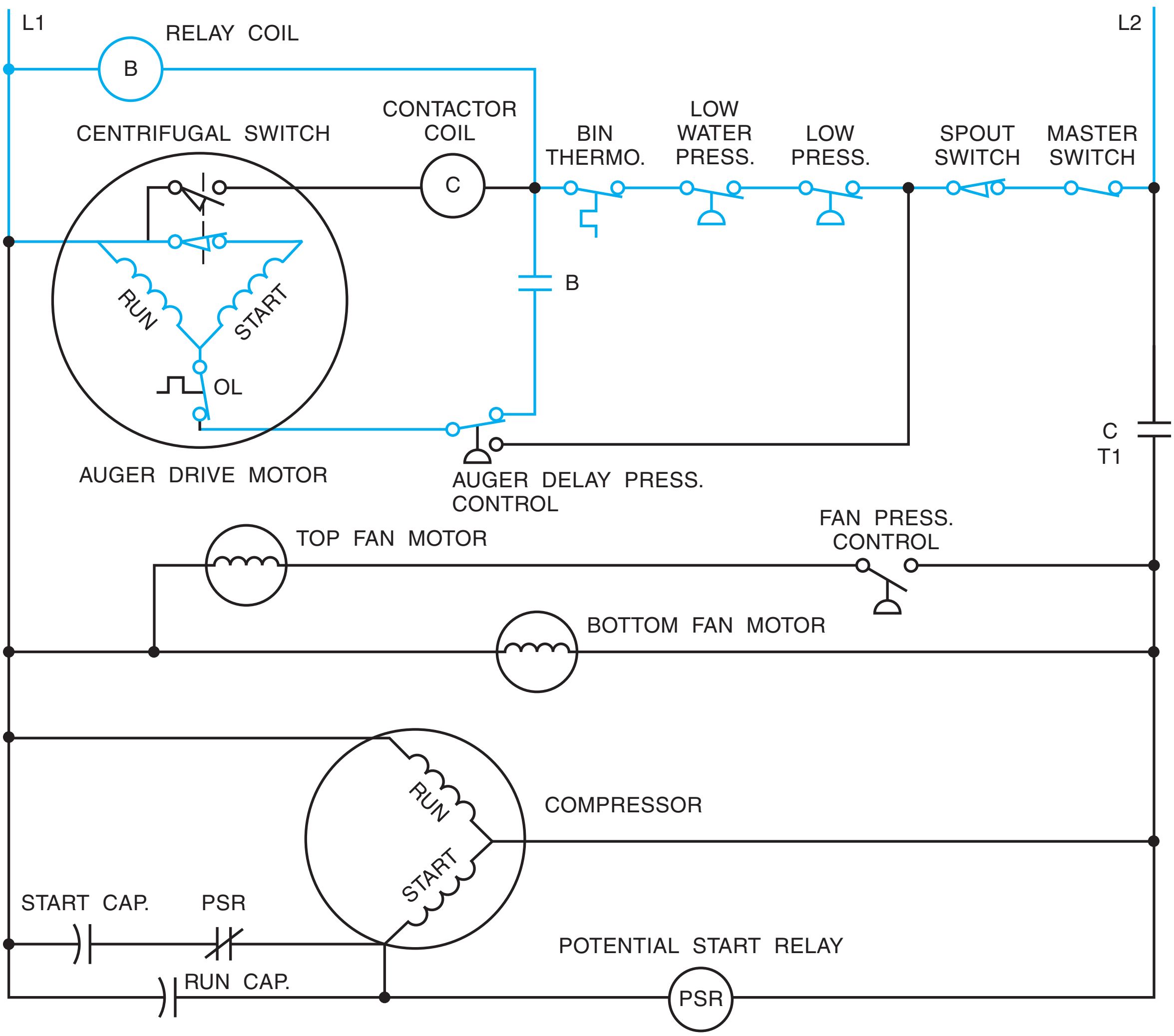


Figure 46–9
Initial start sequence. (Source: Delmar/Cengage Learning)

connected in series with the compressor contactor has closed and permitted the compressor to start. The suction pressure has dropped low enough to permit the auger delay pressure control switch contacts to change position. The bottom condenser fan motor is in operation and the top fan motor may or may not be operating depending on the pressure on the high side of the refrigeration system.

In the schematic shown in Figure 46–11, it is assumed that the bin thermostat has been satisfied and has opened its contact. This opens the circuit to coils B and C and stops the operation of the compressor. The auger drive motor will continue to operate until the pressure on the low side of the refrigeration system increases enough to reset the auger delay pressure switch. The circuit will then be back in its original, deenergized position.

The circuit in Figure 46–12 shows the operation of the circuit when the auger drive motor slows down enough to cause the centrifugal switch in

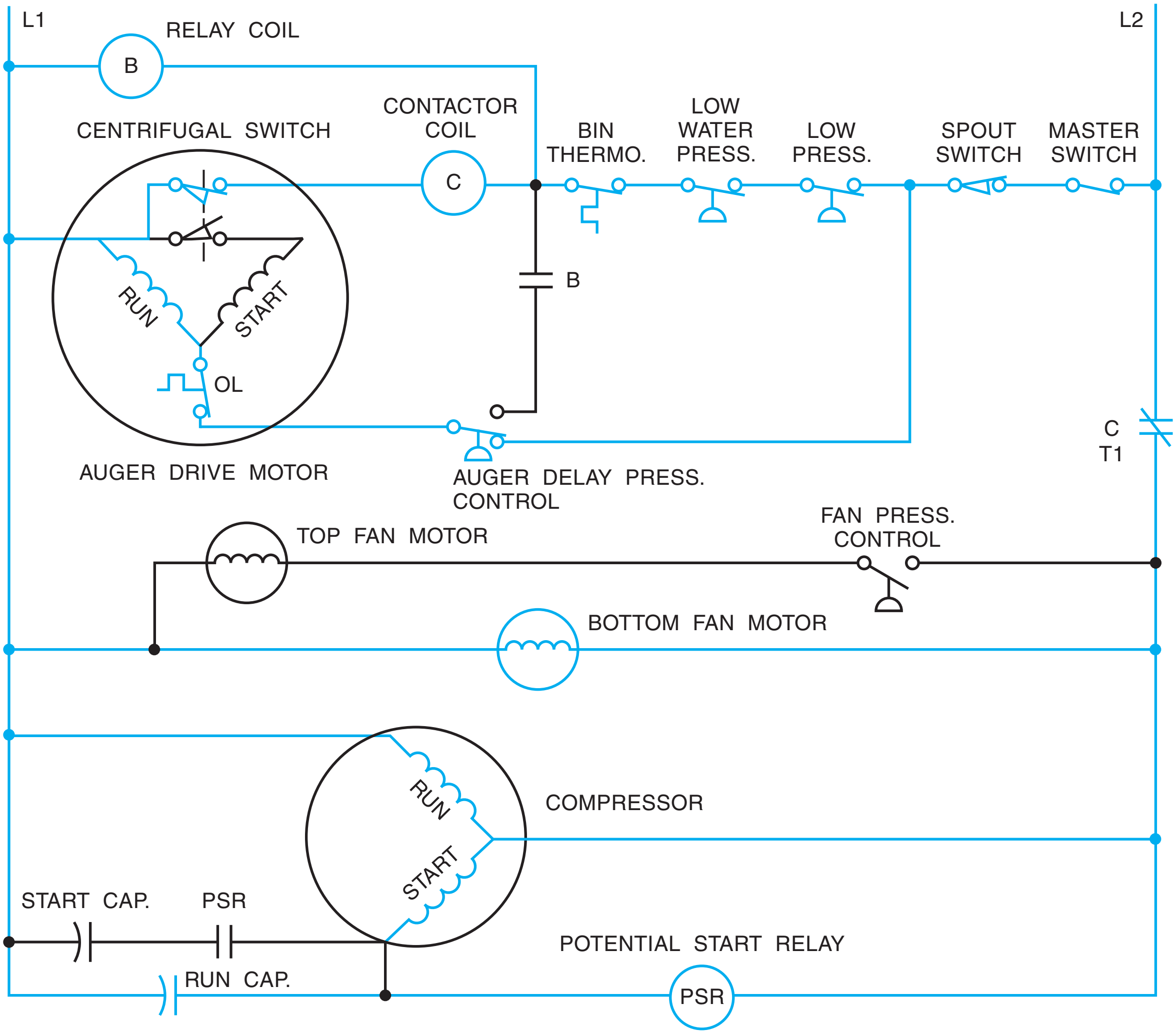


Figure 46–10
Normal ice-making mode. (Source: Delmar/Cengage Learning)

series with the compressor contactor to open. If this occurs, the compressor will be disconnected from the line and stop operating. A current path is maintained through the auger drive motor and auger delay pressure switch. Notice also that a current path is maintained through relay coil B. If the auger drive motor speed does not increase sufficiently before the auger delay switch changes position, the closed B contact will provide a current path through the reset auger delay switch and permit the auger drive motor to continue operation.

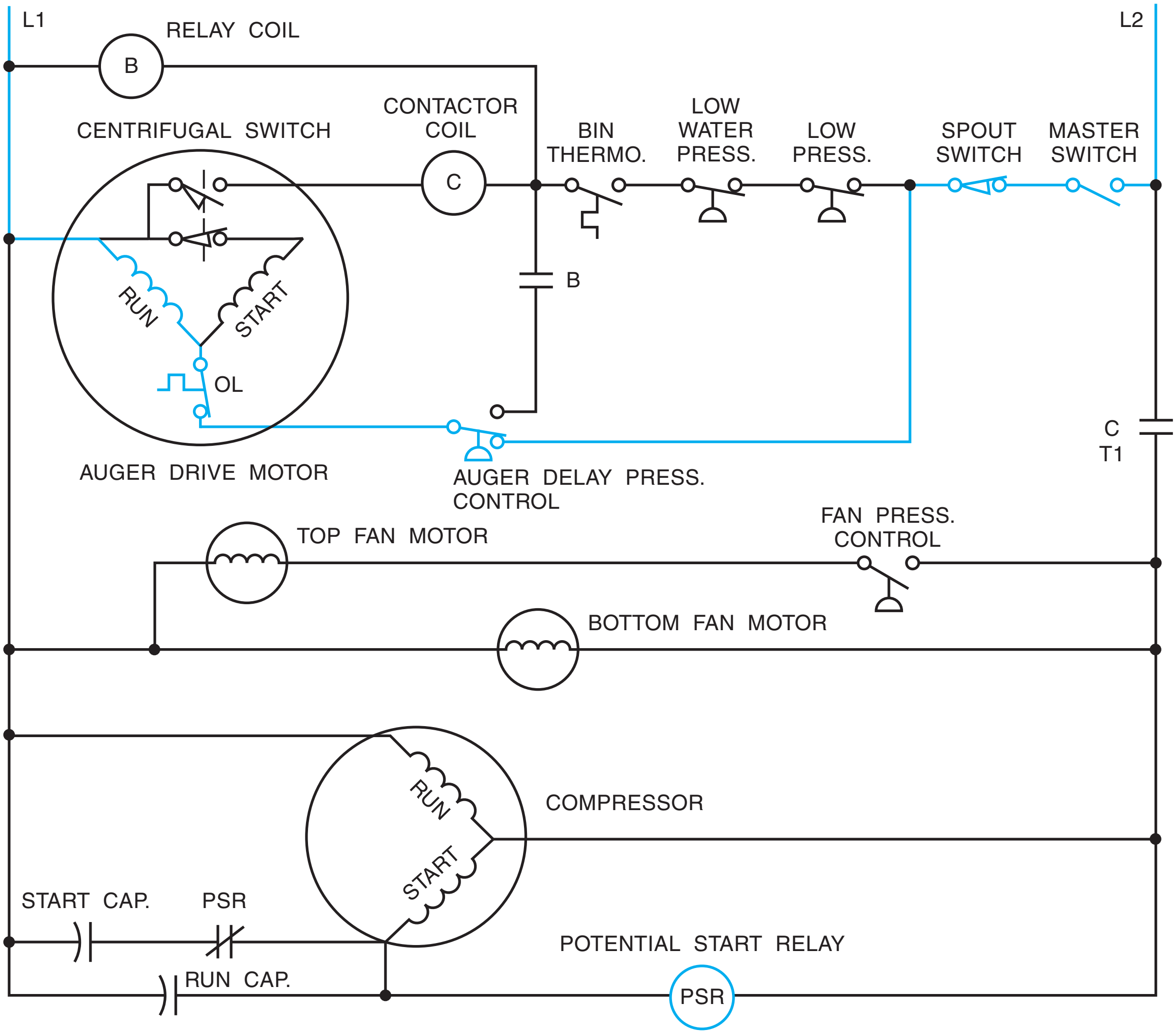


Figure 46–11
The bin thermostat stops the ice-making process. (Source: Delmar/Cengage Learning)

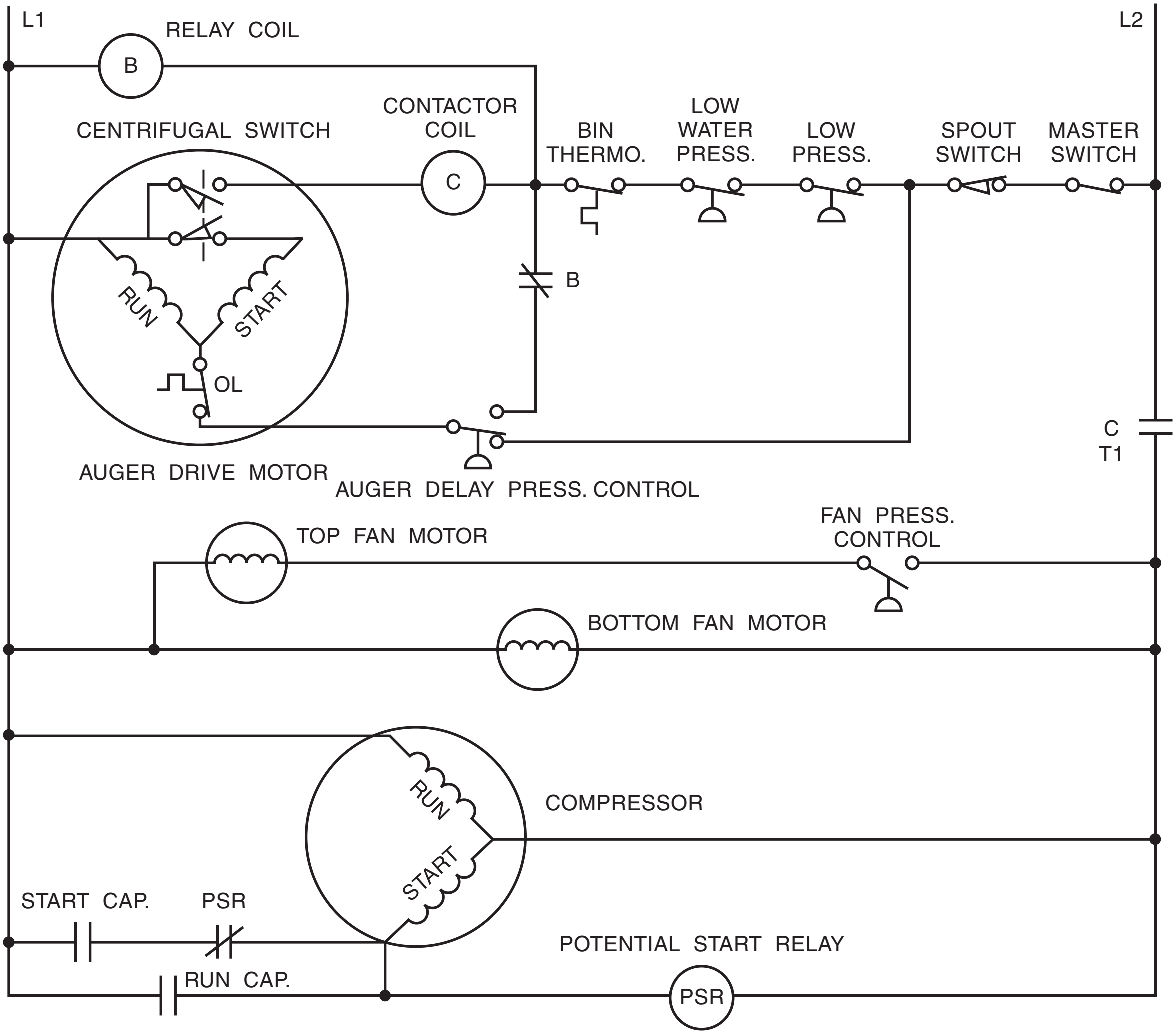


Figure 46–12
Auger becomes overloaded and disconnects the compressor. (Source: Delmar/Cengage Learning)

SUMMARY

- Commercial ice makers are designed to produce large quantities of ice.
- Continuous circulation of water produces a clearer ice because pure water freezes faster than impure water.
- At the beginning of the harvest cycle of the cube-type ice maker, a hot-gas solenoid valve permits high pressure gas to be diverted to the evaporator plate. This warms the plate and thaws the surface of the ice.

- During the harvest cycle, a water solenoid valve opens and permits fresh water to flow into the sump.
- The cube-type ice maker contains two thermostats: the bin thermostat and the cube-size thermostat.
- Flaker-type ice makers produce ice continuously.
- In the flaker-type ice maker, a float valve maintains a constant water level in the water reservoir.
- The flaker-type ice maker uses a hollow tube as the evaporator.
- An auger is used to carry ice up the freezer assembly.
- A thermostat located inside the bin of a flaker-type ice maker senses when the bin is full.
- The auger motor of the flaker-type ice maker contains two centrifugal switches.

KEY TERMS

auger
bin thermostat
cube-size thermostat
flaker-type
freezer assembly
hot-gas solenoid valve
nylobraid tube
psig (pounds per square inch gauge)
water solenoid valve

REVIEW QUESTIONS

1. Concerning the Scotsman cube-type ice maker, what device is used to cause the water to flow evenly over the surface of the evaporator plate?
2. Concerning the Scotsman cube-type ice maker, what method is used to thaw the surface of the ice in contact with the evaporator plate during the harvest cycle?
3. Concerning the Scotsman cube-type ice maker, what are the two safety switches used to disconnect power from the control circuit?
4. What device is used to sense the level of ice cubes in the storage bin of the Scotsman cube-type ice maker?
5. What electrical component starts the operation of the timer motor in the Scotsman cube-type ice maker?
6. Concerning the Scotsman flaker-type ice maker, what device is used to carry the ice to the top of the evaporator tube?
7. How is excess water pressed out of the ice before it is ejected into the storage bin of the flaker-type ice maker?
8. Explain the operation of the auger delay switch used in the flaker-type ice maker.
9. Concerning the flaker-type ice maker, why is it desirable to have the auger drive motor continue to operate for some period of time after the compressor has stopped operation?

10. What controls the operation of the bottom condenser fan motor in the flaker-type ice maker?
11. What electrical component is used to stop the operation of the compressor if the auger should become overloaded?
12. Concerning the Scotsman flaker-type ice maker, which safety switch must be manually reset if it trips?

UNIT 47

Refrigeration Controls

OBJECTIVES

After studying this unit the student should be able to:

- Discuss differences between refrigeration and air conditioning control systems
- Discuss problems of low head pressures in a refrigeration system
- Discuss ways of improving the operation of refrigeration systems
- Explain condenser flooding
- Discuss the use of shutters and dampers
- Discuss fan cycling

Refrigeration and air conditioning systems are essentially the same in that they both involve removing heat from the surrounding air. The differences that occur are in the amount of heat removed and the operating environment. Air conditioning systems operate at a higher temperature and are used for comfort cooling and humidity control. They generally operate only in the warmer months and the condenser units are located outside the structure being cooled.

Refrigeration systems are intended to produce colder temperatures and generally operate throughout the year. Some are intended to produce temperatures that range from 35°F to 45°F for food storage and others produce temperatures of 0°F or lower for hard freezing. Probably the greatest difference between air conditioning and refrigeration, as far as controls are concerned, lies in the fact that refrigeration systems operate at lower temperatures and must employ some method for defrosting the evaporator.

Many refrigeration systems, such as open freezers in supermarkets, are intended to operate inside an air conditioned building. It is this operating environment that can create some special problems. The cold ambient air temperature in winter or the cool air inside an air conditioned building can cause the compressor head pressure to drop below a point such that the pressure differential between the high and low side of the system is insufficient for the unit to operate efficiently. When this is the case, some method must be employed to raise the temperature of the condenser and permit the compressor head pressure to increase. Some common ways of accomplishing this are fan cycle control, shutters, and condenser flooding. Refrigeration and air conditioning units that employ water-cooled condensers control the flow of cooling water to maintain head pressure.

CONDENSER FLOODING

Condenser flooding is accomplished by placing a pressure operated valve in the refrigerant line between the condenser and metering valve. More than one method can be employed to accomplish this. Flooding the condenser with liquid refrigerant has the effect of covering the condenser with a plastic blanket. This causes an increase in condenser temperature and a corresponding increase in head pressure. To accomplish condenser flooding, the unit must contain enough liquid refrigerant to flood the condenser. This calls for a large charge of refrigerant and some means of storing it. Units intended to use condenser flooding contain a receiver to hold the excess refrigerant.

Nonadjustable Head Pressure Valve

Figure 47–1 illustrates the connection of a nonadjustable head pressure control valve. A line drawing of the valve is shown in Figure 47–2. The valve's main port is between the condenser and receiver. As long as receiver pressure remains above a certain level the bypass between discharge and receiver portions of the valve are closed. If the receiver pressure should drop, such as would be the case with low ambient temperature, the spring loaded valve overcomes the receiver pressure and hot gas begins to flow through the discharge portion of the valve. Low receiver pressure also causes the valve to decrease the flow from the condenser, causing refrigerant to backup in the condenser. This has the effect of decreasing the surface area of the condenser causing an increase in temperature and a corresponding

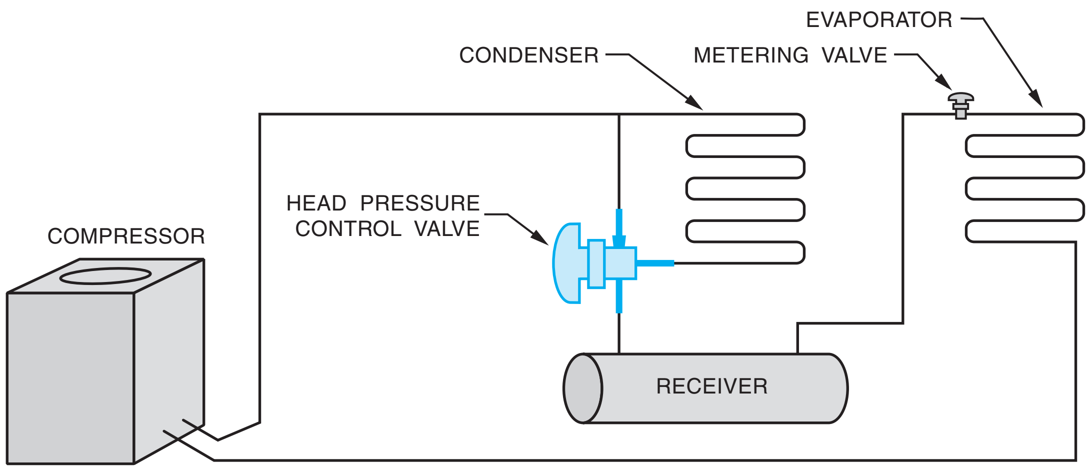


Figure 47–1
The head pressure control valve meters the flow of refrigerant through the condenser. (Source: Delmar/Cengage Learning)

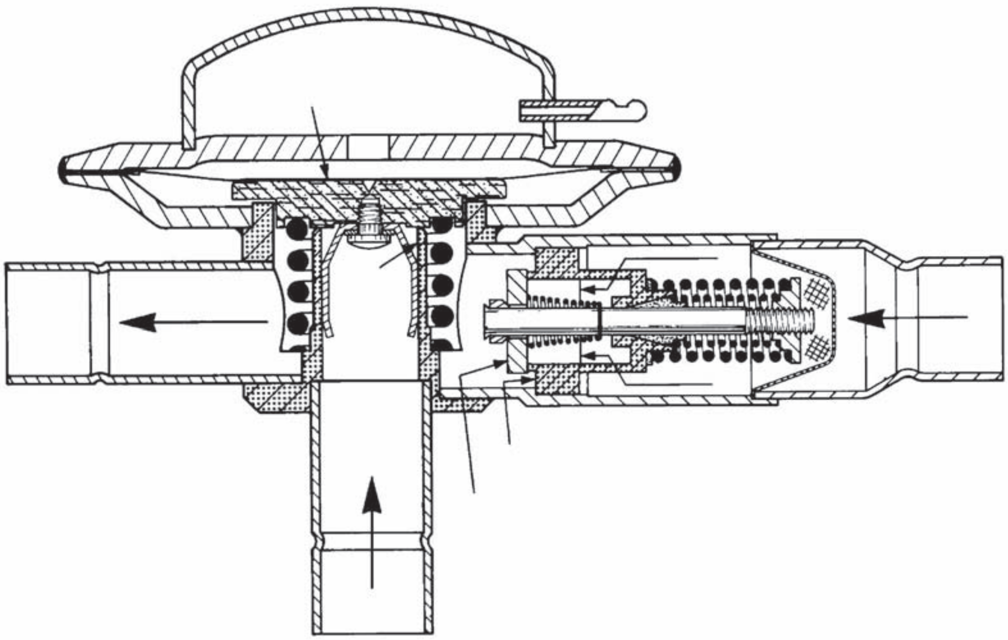


Figure 47–2
Operation of a nonadjustable head pressure control valve. (Courtesy of Sporlan Valve Company).

increase in pressure. This valve maintains an almost constant pressure and function well in temperatures of up to about –40°F. A nonadjustable head pressure control valve is shown in Figure 47–3.

Figure 47–3
A nonadjustable head pressure valve. (Courtesy of Sporlan Valve Company).

Adjustable Head Pressure Valve

Adjustable head pressure systems generally require the use of two valves. One valve **opens on rise of inlet** pressure (ORI) and the other **opens on rise of differential** pressure (ORD). A basic piping connection for the adjustable head pressure system is shown in Figure 47–4. An illustration of the ORI valve is shown in Figure 47–5. The ORI valve is an inlet pressure regulating valve that responds to changes in the condenser pressure. Note that both the inlet and outlet pressures are against the seat disc. One tends to cancel the effects of the other. In warm weather the condenser pressure is greater than the receiver pressure, which causes the valve to open and permit refrigerant to flow through the condenser.

The ORD valve provides a bypass around the condenser. An illustration of the ORD valve is shown in Figure 47–6. The compressor head pressure acts to open the ORD valve and the receiver pressure and

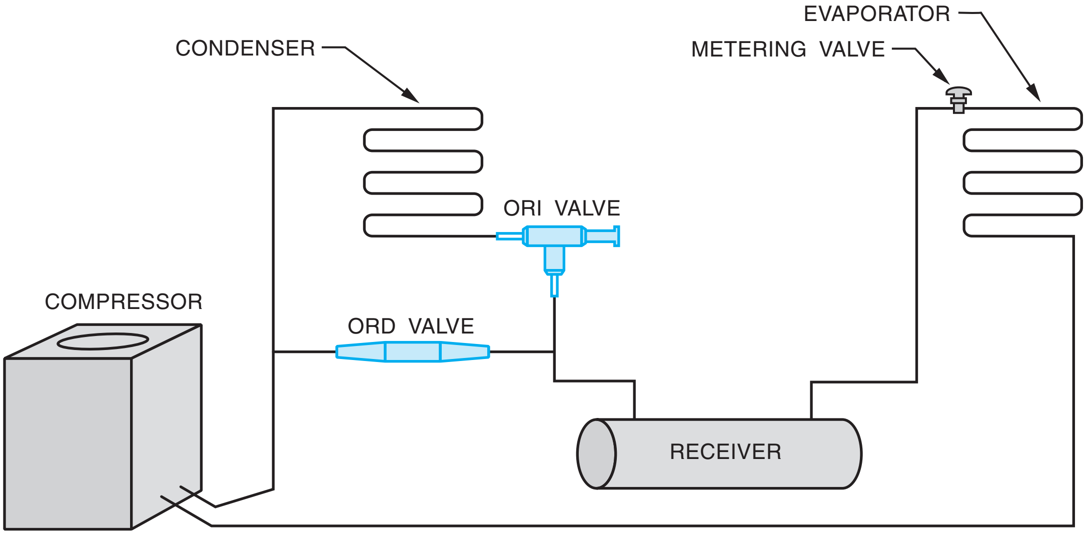


Figure 47–4
An adjustable head pressure system requires two valves. (Source: Delmar/Cengage Learning)

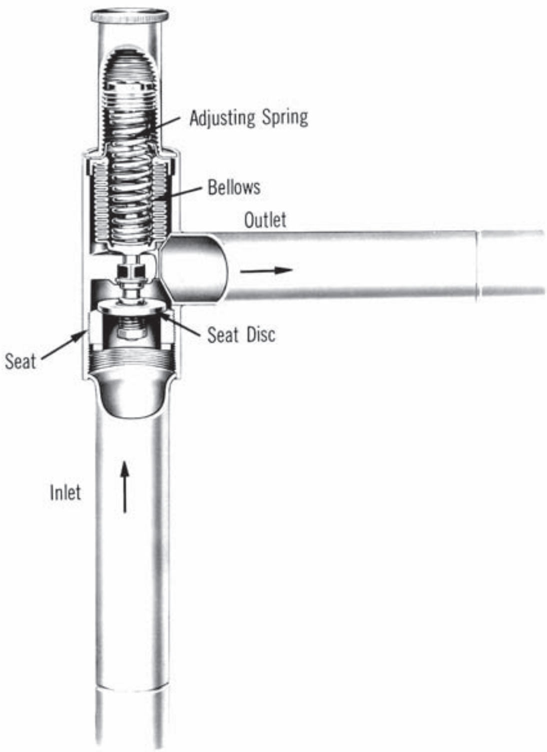


Figure 47–5
The open on rise of inlet pressure (ORI) valve can be adjusted. (Courtesy of Sporlan Valve Company).

spring tend to keep the valve closed. If the receiver pressure should drop due to low ambient temperature, two actions take place.

1. The ORI valve begins to close and reduce the flow of refrigerant through the condenser.
2. The ORD valve begins to open and permit the hot gas to bypass the condenser and flow to the receiver.

The reduced flow of refrigerant through the condenser causes an increase in temperature and pressure. An ORI valve is shown in Figure 47–7 and an ORD valve is shown in Figure 47–8.

FAN CYCLE CONTROL

Another common method of increasing head pressure is by controlling the amount of air across the condenser. Air-cooled condensers of large refrigeration units and air conditioners employ a fan to increase airflow across them. The increased airflow permits a greater amount of heat to be removed. During periods that the ambient temperature is so low that the head pressure drops below a certain amount, a fan cycle switch can be used to disconnect power to the condenser fan, Figure 47–9. The switch shown in Figure 47–9 is pressure

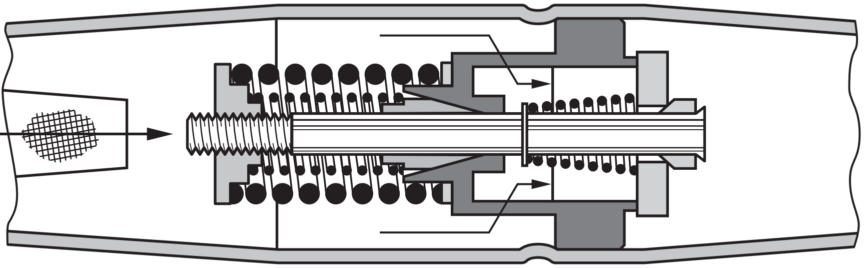


Figure 47–6
The open on rise of differential (ORD) valve operates on the difference in pressure between the compressor head pressure and receiver pressure.
(Courtesy of Sporlan Valve Company).

Figure 47–7
An open on rise of inlet pressure (ORI) valve. (Courtesy of Sporlan Valve Company).

Figure 47–8
An open on rise of differential pressure (ORD) valve.
(Courtesy of Sporlan Valve Company).

operated. It is connected in the high side of the unit, Figure 47–10. The switch can be adjusted for the amount of pressure required to turn the fan on and off. A typical setting for refrigerant R12 is 125 psi turn off and 175 psi turn on. At pressures greater than 175 psi a set of electrical contacts inside the switch close and connect the condenser fan to the power line. If the high side pressure should drop below 125 psi, the contacts will open and turn off the condenser fan. The pressure differential prevents rapid cycling of the condenser fan motor. The fan cycle switch will not hinder operation during warm months and will provide good operation during cold months.

The fan cycle switch is relatively inexpensive and can be added to an existing system with very little trouble. Generally no alterations to the piping system are required. There is one potential problem

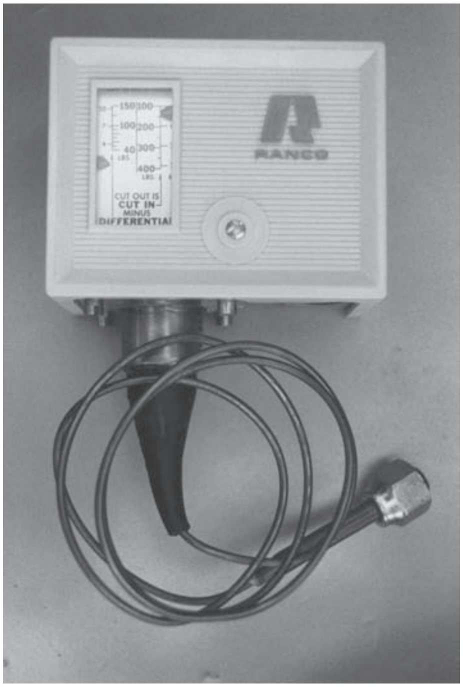


Figure 47–9
Pressure operated fan cycle switch. (Source: Delmar/Cengage Learning)

with this type of head pressure control. The pressure differential between fan turn on and turn off can cause erratic operation of the expansion valve.

Units that employ more than one condenser fan will often have one fan controlled by pressure and the others controlled by temperature-sensitive switches. The fans will be set to turn on or off in stages. One temperature switch, for example, may turn a fan off at 75°F and another switch may turn a fan off at 65°F. This helps maintain a more constant head pressure. When temperature switches are used, the temperature sensing element is generally connected to the liquid line.

Variable Speed Control

Another type of fan cycle control employs a solid state device called a triac to control motor speed, Figure 47–11. The triac has the ability to control the output voltage applied to the motor. Refer to Unit 56 for more information concerning the operation of a triac. Some controls vary the output voltage applied to the condenser fan in accord with the temperature of the liquid refrigerant line, and others sense ambient

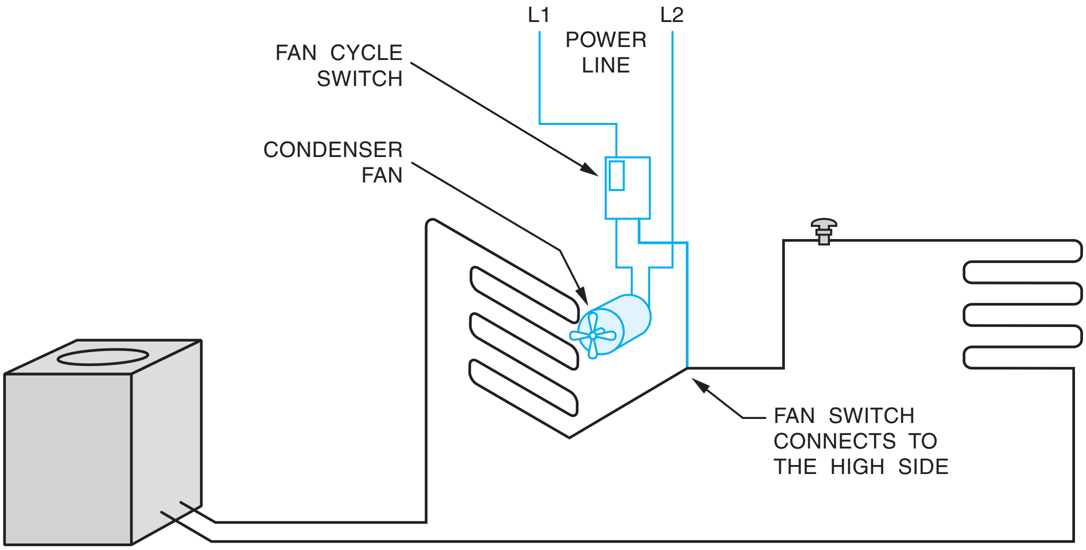


Figure 47–10
A pressure-operated fan cycle switch controls the condenser fan to control head pressure. (Source: Delmar/Cengage Learning)

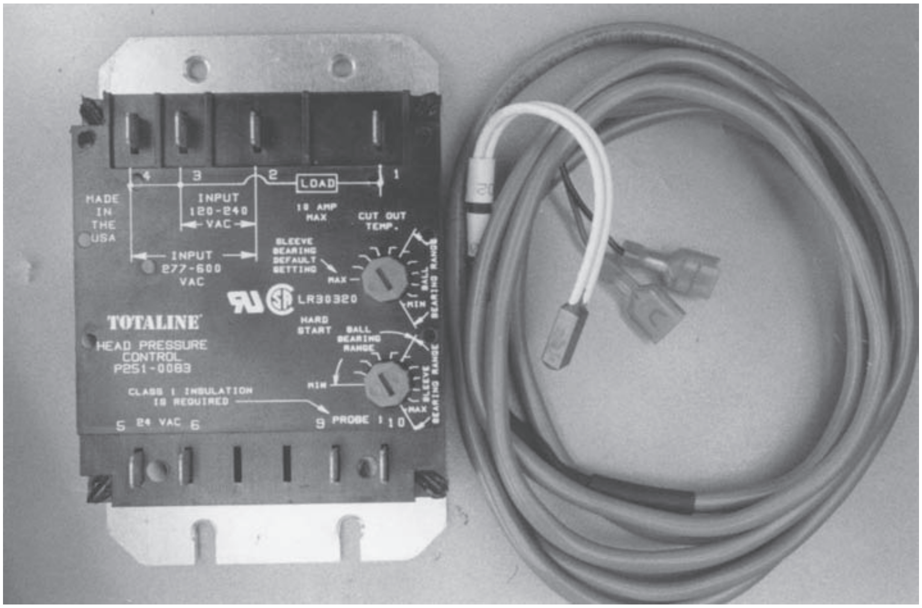


Figure 47–11
Variable-speed fan cycle control. (Source: Delmar/Cengage Learning)

temperature. A thermistor is used to sense the temperature. A decrease of temperature causes the unit to reduce the voltage applied to the condenser fan motor causing it to slow down. As the temperature increases the output voltage increases permitting the motor to increase speed. A chart illustrating typical voltage and temperature relationships for a control that senses liquid line temperature is shown in Figure 47–12. The voltage/temperature relationship can be changed to some degree by changing the type thermistor used to sense the temperature. Notice on the chart that at temperatures below about 75°F the motor is turned off and at temperatures above about 115°F full output voltage is applied to the motor. The variable speed control helps eliminate some of the pressure differential problems encountered with fan cycle controls that simply turn on or off. A typical connection diagram for this type control is shown in Figure 47–13.

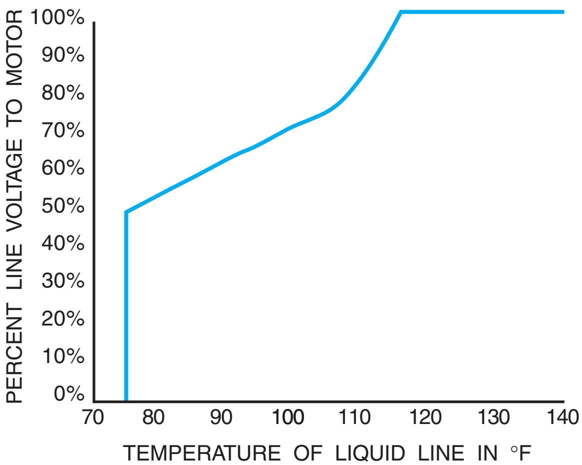


Figure 47–12
Typical output voltage and temperature curve for a variable-speed fan cycle control. (Source: Delmar/Cengage Learning)

SHUTTERS

Another method for controlling head pressure is with the use of shutters. Shutters can be opened or closed to control the airflow across the condenser. They can be installed on the inlet or outlet side of the condenser fan. A pressure-operated piston is used to open the shutters and permit more air to flow. The piston is connected to the high side of the system in

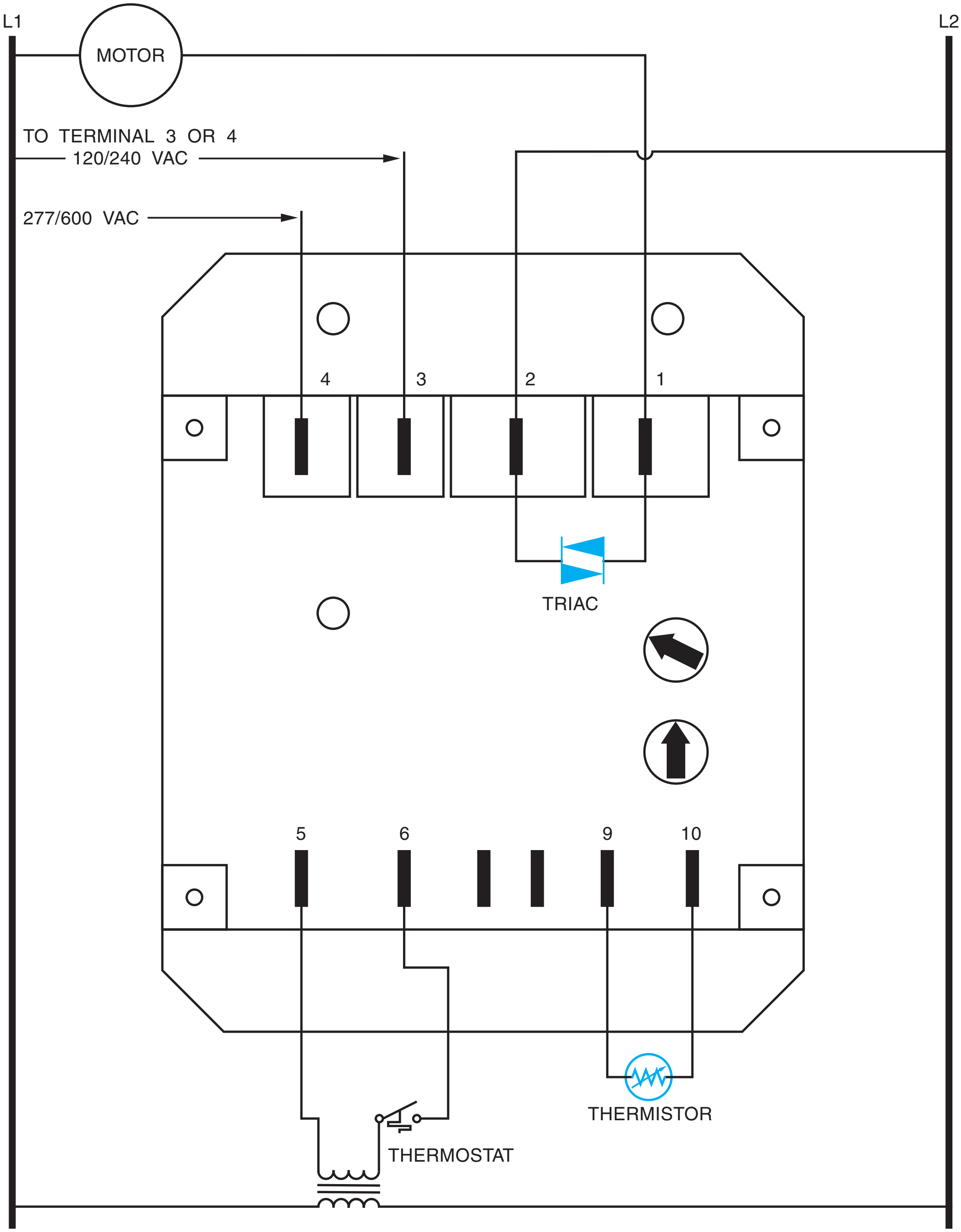


Figure 47–13
Basic connection for a variable-speed fan control. (Source: Delmar/Cengage Learning)

much the same way as the pressure-operated fan cycle switch. If pressure decreases, the shutters close to restrict airflow. If the pressure rises, the piston pushes against a mechanical rod causing the shutters to open and permit more airflow.

An advantage of shutters is that they open and close slowly maintaining an even head pressure. If a condenser contains multiple fans, one fan is generally equipped with a shutter and the other fans will be cycled on or off with pressure-activated or temperature-activated switches.

SUMMARY

- Refrigeration systems differ from air conditioning systems in the temperature ranges in which they operate, and refrigeration systems require some method of defrosting the evaporator.
- Refrigeration systems can experience difficulties due to low head pressure in cold weather.
- Head pressure can be increased by limiting the airflow across the condenser.
- Condenser flooding has the effect of covering the condenser with a plastic blanket.
- To employ condenser flooding, the unit must have a large charge of refrigerant and a place to store it.
- Condenser flooding is generally accomplished by connecting a pressure-operated valve between the condenser and the expansion valve.
- Fan cycle control is accomplished by turning the condenser fan on or off in relation to pressure or temperature.
- Variable-speed fan cycle controls reduce the voltage applied to the motor if the liquid line temperature or ambient air temperature decreases below a certain point.
- Shutters can be used to decrease airflow across the condenser.
- Shutters generally employ a pressure-operated piston to control the opening and closing of the shutters.

KEY TERMS

opens on rise of differential (ORD)
opens on rise of inlet (ORI)

REVIEW QUESTIONS

1. Explain why low ambient temperatures can cause problems with refrigeration systems.
2. What can be done to make the unit act as if the condenser has been covered with a plastic blanket?

3. Referring to the chart in Figure 47–12, what is the approximate percent of output voltage at a temperature of 100°F?
4. Referring to the chart in Figure 47–12, at about what temperature does the control turn the condenser fan off?
5. Name two requirements that must be met to use condenser flooding to control head pressure.
6. What device is used to operate the shutters on most shutter systems?
7. Does an increase in pressure cause the shutters to open or close?
8. What problem can be caused by cycling the condenser fan on and off to control head pressure?
9. What device is used to sense liquid line temperature with the variable-speed fan cycle control described in this unit?
10. What solid state device does the variable-speed control unit employ to control the voltage to the condenser fan motor?

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SECTION 8

Solid-State Devices

UNIT 48

Resistors and Color Codes

OBJECTIVES

After studying this unit the student should be able to:

- Discuss different types of resistors
- Determine the resistance of a resistor using the color code
- Test a resistor to determine if it is within its rated tolerance

Resistors are among the most common components found in electrical circuits. It is sometimes necessary for a technician to be able to determine the value of a resistor in a circuit. Some resistors are intended to carry large amounts of current and produce heat, such as the resistors in electric heating systems, small space heaters, and the burners of an electric range, Figure 48–1. These resistors are generally made from a special type of wire called nichrome. **Nichrome** wire is about 65 times more resistive than copper and can be operated at very high temperatures.

Wire wound resistors are made from nichrome wire also. These resistors are often made by winding nichrome wire on a hollow porcelain tube, Figure 48–2. Wire wound resistors of this type should be mounted vertically and not horizontally. The hollow portion of the resistor acts as a chimney

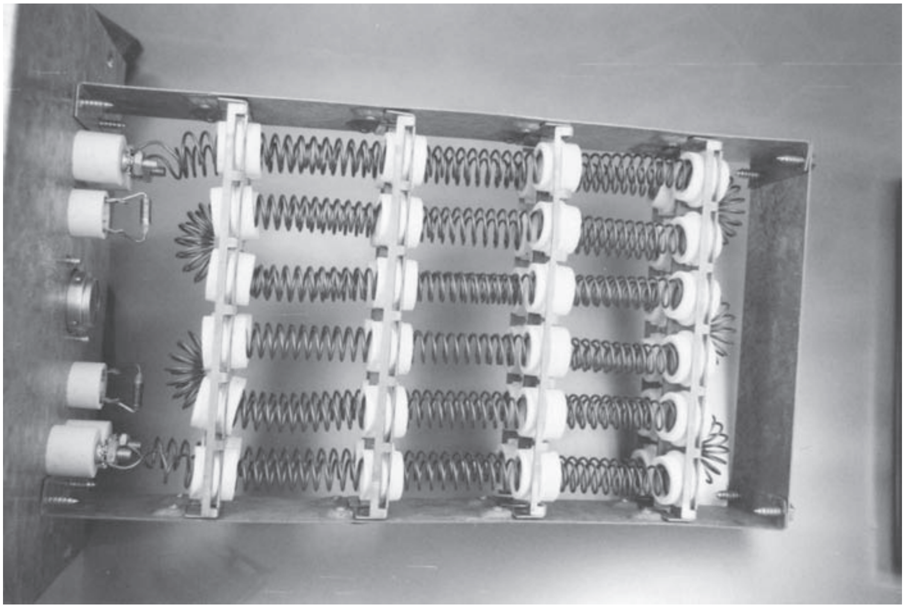

Figure 48–1
Electric heating element.
(Source: Delmar/Cengage Learning)

Figure 48–2
Wire wound resistor. (Source: Delmar/Cengage Learning)

to permit air to circulate through the resistor, Figure 47–3. People often employ light bulbs as small heaters to protect well pumps during periods of cold weather. The problem with light bulbs is that they have a bad habit of burning out during the coldest nights of the year. A better solution is to use a wire wound resistor instead of a light bulb. A resistor with a value of 120 ohms would produce 120 watts of heat when connected to 120 volts. If the resistor were rated at 150 watts or more, it would probably never burn out.

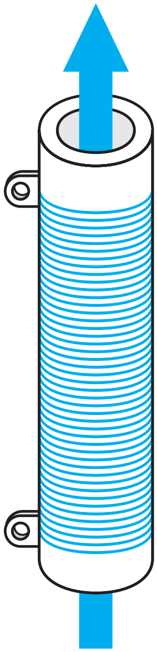

Figure 48–3
Mounting the resistor vertically permits air to flow through the hollow opening. (Source: Delmar/Cengage Learning)

Wire wound resistors generally have the ohmic value and power rating written on the resistor. If the ohmic value is not written on the resistor, an ohmmeter can be used to determine its value.

Color Code

Small **fixed resistors** with ratings of 1/8 to 2 watts are generally marked with **bands of color** to indicate their ohmic value and tolerance. The size of the resistor indicates its **wattage rating**, Figure 48–4. Resistors can have from three to five bands of color. Most have four bands. The colors are used to indicate a numeric value. The chart in Figure 48–5 lists the colors and their corresponding number value. Resistors with a tolerance of ±20% will contain three bands of color. Resistors with a tolerance of ±10%, ±5%, and ±2% will contain four bands of color, and resistors with a tolerance of ±1% and some special purpose resistors will contain five bands of color. When determining the ohmic value and tolerance of a resistor with three or four bands of color, the first two bands represent numbers, the third band is the multiplier, and the fourth band indicates the tolerance, Figure 48–6. If the resistor has a tolerance of ±10%, the fourth band will be silver. The fourth band will be gold for a resistor with a tolerance of ±5%, and red for a resistor with a tolerance of ±2%.

Assume a resistor has color bands of yellow, violet, orange, and gold, Figure 48–7. The first two

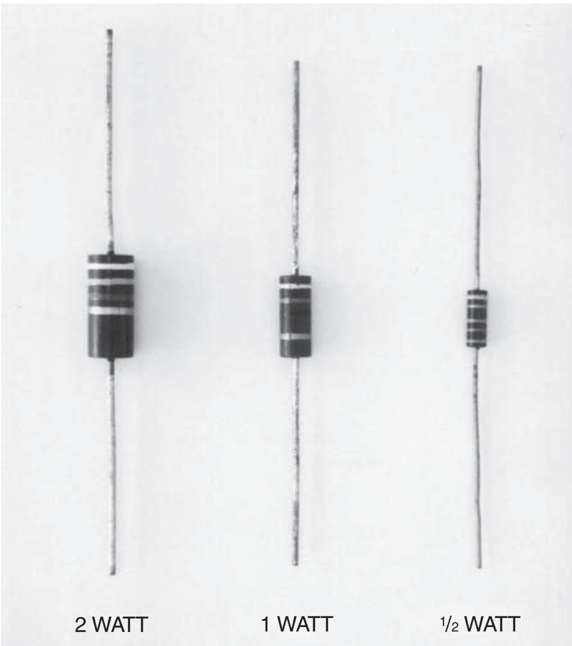

Figure 48–4
The size of a fixed resistor indicates its wattage value. (Source: Delmar/Cengage Learning)

COLOR	NUMBER VALUE
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9
Tolerance	
No fourth band	20%
Silver fourth band	10%
Gold fourth band	5%
Red fourth band	2%
Brown fifth band	1%
Special Multipliers	
Gold third band	0.10
Silver third band	0.01

Figure 48–5
Colors represent numeric values. (Source: Delmar/Cengage Learning)

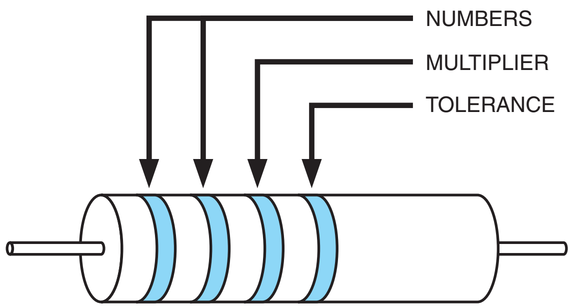

Figure 48–6
Four band resistor. (Source: Delmar/Cengage Learning)

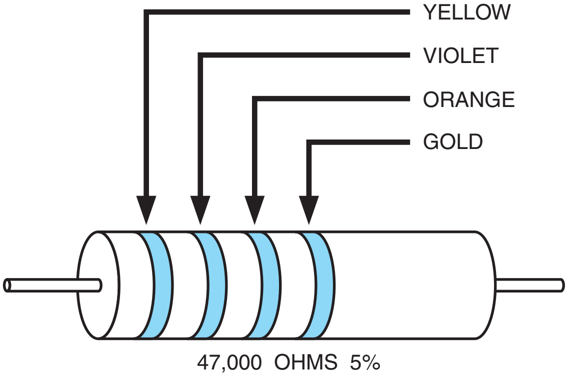

Figure 48–7
The resistor has a value of 47,000 ohms with a tolerance of 5%. (Source: Delmar/Cengage Learning)

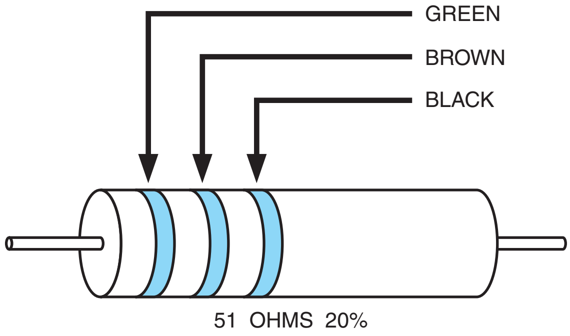

Figure 48–8
The resistor has a value of 51 ohms and a tolerance of 20%. (Source: Delmar/Cengage Learning)

bands represent numbers. Yellow is 4 and violet is 7. The third band is the multiplier. Add the number of zeros indicated by the color. Orange is three, so add 3 zeros. The number becomes 47000. The resistor has a value of 47,000 ohms with a tolerance of ±5%.

Now assume that a resistor has color bands of green, brown, black, Figure 48–8. Green is 5, brown is 1, and black is 0. The first two colors are numbers 51 and the third band color is black which is zero. This means there is no multiplier. The resistor has an ohmic value of 51 ohms. Since there is no third band the resistor has a tolerance of ±20%.

Resistors that have a value less than 10 ohms use gold and silver in the third band as multipliers. When a resistor has a third band of gold it means to multiply the first two numbers by 0.1 or divide the first two numbers by 10. If the third band is silver, multiply the first two numbers by 0.01 or divide the first two numbers by 100. Assume a resistor has colors of blue, gray, gold, and red, Figure 48–9. Blue is 6, gray is 8 and gold means to divide by 10. The resistor has an ohmic value of 6.8 ohms. The red fourth band indicates a tolerance of ±2%.

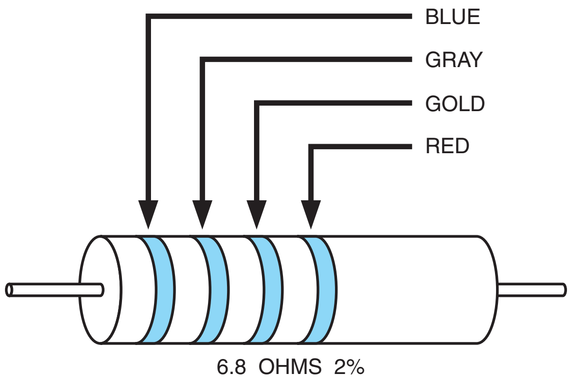

Figure 48–9
The resistor has a value of 6.8 ohms with a tolerance of 2%. (Source: Delmar/Cengage Learning)

Tolerance

The **tolerance** indicates the limits of ohmic value. Assume that a resistor is marked 1,000 ohms with a tolerance of ±10%. To determine if this resistor is within its tolerance rating, find 10% of the rated value (1,000 × 0.10 = 100 Ω. The resistor will be in tolerance if its value is between 1,100 and 900 ohms (1,000 + 100 = 1,100 and 1,000 – 100 = 900).

Standard Resistance Values

Fixed resistors are generally manufactured in standard values. The higher the tolerance value, the fewer resistance values available. Standard resistor values for different tolerances are listed in the chart shown in Figure 48–10. In the column under 10% only 12 values of resistance are listed. These standard values, however, can be multiplied by factors of 10. Notice that one of the standard values listed is 33 Ω. There are also standard values in

STANDARD RESISTANCE VALUES							
.1%, .25%, .5%	1%	.1%, .25%, .5%	1%	.1%, .25%, .5%	1%	.1%, .25%, .5%	1%
10.0	10.0	17.8	17.8	31.6	31.6	56.2	56.2
10.1	–	18.0	–	32.0	–	56.9	–
10.2	10.2	18.2	18.2	32.4	32.4	57.6	57.6
10.4	–	18.4	–	32.8	–	58.3	–
10.5	10.5	18.7	18.7	33.2	33.2	59.0	59.0
10.6	–	18.9	–	33.6	–	59.7	–
10.7	10.7	19.1	19.1	34.0	34.0	60.4	60.4
10.9	–	19.3	–	34.4	–	61.2	–
11.0	11.0	19.6	19.6	34.8	34.8	61.9	61.9
11.1	–	19.8	–	35.2	–	62.6	–
11.3	11.3	20.0	20.0	35.7	35.7	63.4	63.4
11.4	–	20.3	–	36.1	–	64.2	–
11.5	11.5	20.5	20.5	36.5	36.5	64.9	64.9
11.7	–	20.8	–	37.0	–	65.7	–
11.8	11.8	21.0	21.0	37.4	37.4	66.5	66.5
12.0	–	21.3	–	37.9	–	67.3	–
12.1	12.1	21.5	21.5	38.3	38.3	68.1	68.1
12.3	–	21.8	–	38.8	–	69.0	–
12.4	12.4	22.1	22.1	39.2	39.2	69.8	69.8
12.6	–	22.3	–	39.7	–	70.6	–
12.7	12.7	22.6	22.6	40.2	40.2	71.5	71.5
12.9	–	22.9	–	40.7	–	72.3	–
13.0	13.0	23.2	23.2	41.2	41.2	73.2	73.2
13.2	–	23.4	–	41.7	–	74.1	–
13.3	13.3	23.7	23.7	42.2	42.2	75.0	75.0
13.5	–	24.0	–	42.7	–	75.9	–
13.7	13.7	24.3	24.3	43.2	43.2	76.8	76.8
13.8	–	24.6	–	43.7	–	77.7	–
14.0	14.0	24.9	24.9	44.2	44.2	78.7	78.7
14.2	–	25.2	–	44.8	–	79.6	–
14.3	14.3	25.5	25.5	45.3	45.3	80.6	80.6
14.5	–	25.8	–	45.9	–	81.6	–
14.7	14.7	26.1	26.1	46.4	46.4	82.5	82.5
14.9	–	26.4	–	47.0	–	83.5	–
15.0	15.0	26.7	26.7	47.5	47.5	84.5	84.5
15.2	–	27.1	–	48.1	–	85.6	–
15.4	15.4	27.4	27.4	48.7	48.7	86.6	86.6
15.6	–	27.7	–	49.3	–	87.6	–
15.8	15.8	28.0	28.0	49.9	49.9	88.7	88.7
16.0	–	28.4	–	50.5	–	89.8	–
16.2	16.2	28.7	28.7	51.1	51.1	90.9	90.9
16.4	–	29.1	–	51.7	–	92.0	–
16.5	16.5	29.4	29.4	52.3	52.3	93.1	93.1
16.7	–	29.8	–	53.0	–	94.2	–
16.9	16.9	30.1	30.1	53.6	53.6	95.3	95.3
17.2	–	30.5	–	54.2	–	96.5	–
17.4	17.4	30.9	30.9	54.9	54.9	97.6	97.6
17.6	–	31.2	–	55.6	–	98.8	–

STANDARD RESISTANCE VALUES *continued*							
2%, 5%	10%	2%, 5%	10%	2%, 5%	10%	2%, 5%	10%
10	10	18	18	33	33	56	56
11	–	20	–	36	–	62	–
12	12	22	22	39	39	68	68
13	–	24	–	43	–	75	–
15	15	27	27	47	47	82	82
16	–	30	–	51	–	91	–

Figure 48–10
Standard resistance values. (Source: Delmar/Cengage Learning)

10% resistors of 0.33; 3.3; 330; 3300; 33,000; and 330,000, 3,300,00 Ω. Notice there is no listing for a value 32 or 34 ohms. They do not exist as a standard value. The 2% and 5% column lists 24 standard values and the 1% column lists 96 values. All of the values listed can be multiplied by factors of 10 to obtain other resistance values. Resistors with tolerance ratings of 0.1%, 0.25%, and 0.5% generally have the resistance value printed on the resistor.

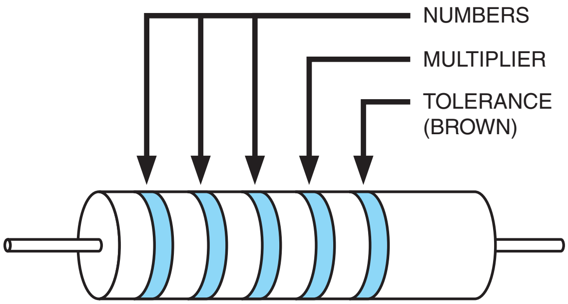

Figure 48–11
Five-band resistor. (Source: Delmar/Cengage Learning)

1% Value Resistors

Notice in the chart shown in Figure 48–10 that the resistor values listed in the 1% column have three numeric numbers instead of two as is the case with 2%, 5%, and 10% values. Because resistors with a tolerance of 1% use three numbers instead of two, a five band resistor must be used to indicate their value, Figure 48–11. Assume a five band resistor has color bands of brown, blue, yellow, orange, and brown, Figure 48–12. The first three bands represent numbers: brown = 1, blue = 6, and yellow = 4. The fourth band is orange, which means that you would multiply by 1,000 or move the decimal three places; 16.4 becomes 16,400 ohms. The fifth band is brown, which indicates a tolerance value of ±1%.

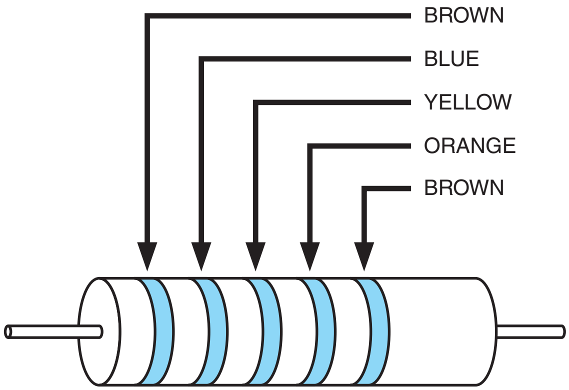

Figure 48–12
A 1% resistor has five color bands. (Source: Delmar/Cengage Learning)

Other Fifth-Band Colors

Some resistors have five bands of color that are not 1% resistors. These are generally military markings. A resistor with a fifth band of yellow or orange is a reliability rating. The military often needs resistors that have been tested for reliability. It has long been known that if a resistor can operate within its tolerance for some number of hours without failure that the chances of failure become much smaller. The military often employs companies to test resistors for some period of time by operating them in a circuit and then checking the value to see if the resistor has remained within its tolerance rating. Resistors with a fifth band of yellow are rated reliable enough for space flight equipment. An orange fifth band indicates the resistor is reliable enough for use in missile systems. A white fifth band indicates the leads are solderable.

SUMMARY

- Wire wound resistors are generally used for applications requiring a high power rating.
- Nichrome wire is generally employed in the construction of wire wound resistors.
- Electric heating elements are generally made of nichrome wire.
- Resistors in sizes ranging from 1/8 to 2 watts generally have their values marked with bands of color.
- The size of a resistor is generally an indication of its power rating.
- A resistor color code is generally used to indicate a resistor's ohmic value and tolerance.
- Resistors that have only three bands of color are rated at ±20%.
- Resistors with a tolerance rating of ±2%, ±5%, and ±10% have four color bands.
- Resistors with a tolerance rating ±1% have a brown fifth band.
- The fifth band of some military resistors indicates reliability.

KEY TERMS

bands of color
fixed resistors
nichrome
tolerance
wattage rating
wire wound

REVIEW QUESTIONS

1. What type of resistor is generally used when a high power rating is needed?
2. What type of wire is generally used in the construction of resistors intended to be operated at high temperatures?
3. A resistor is marked orange, orange, orange, and gold. An ohmmeter indicates that the resistor value is 34,700 ohms. Is this resistor within its tolerance rating?
4. What would be the color bands for a 1,000-ohm resistor with a tolerance of ±2%?
5. What would be the color bands for a resistor valued at 365,000 ohms?
6. A resistor has color bands of yellow, orange, gold, gold. What is the value and tolerance of this resistor?

7. What color bands would be found on a resistor with an ohmic value of 510 Ω and a tolerance of ±10%?
8. Should a wire wound resistor with a hollow core be mounted vertically or horizontally?
9. A wire wound resistor has a value of 100 Ω and a power rating of 150 watts. If this resistor is connected to 120 volts, will its power rating be exceeded?
10. A circuit requires a resistor with a value of 5,000 ohms. What is the closest standard value of a 5% resistor that can be used in this circuit?

UNIT 49 Semiconductor Materials

OBJECTIVES

After studying this unit the student should be able to:

- Discuss the atomic structure of conductors, insulators, and semiconductors
- Discuss how a P-type material is produced
- Discuss how an N-type material is produced

Many of the air conditioning controls are operated by solid-state devices as well as magnetic and mechanical devices. If a service technician is to install and troubleshoot control systems, he or she must have an understanding of electronic devices as well as relays.

Solid-state devices, such as diodes and transistors, are often referred to as **semiconductors**. The word *semiconductor* refers to the type of material solid-state devices are made of. To understand how solid-state devices operate, one must study the atomic structure of conductors, insulators, and semi conductors.

CONDUCTORS

Conductors are materials that provide an easy path for electron flow. Conductors are generally made from materials that have large, heavy atoms. This is why