Controls Principles

Lessons 9 to 12

Unit 3 Preview

Unit 3 might be best described as a study of “The Little Black Boxes” - those faceless control devices, whose operations are (secretively?) shrouded from view. Invariably it seems, two wires lead in, and two lead out. Between connections, the motionless, mysterious black box performs control wonders. Hopefully, the next four lessons will unravel any mystery that exists for the student, for in this unit you'll be learning about controllers, relays, and electronic devices.

If you go back to the introduction in your textbook, you’ll find that we identified two basic elements in a control system - a controller and a controlled device. The controller is the *brains* of the system; the controlled device is the *slave* or worker. We’ve already learned about two controllers, the room thermostat and room humidistat. Because of their special status, these devices were considered separately in this course. However, by modem control theory, they should also be included in lessons on controllers.

In any event, you’ll now be studying about high-limit/low-limit controllers fan and pump controllers devices (both safety and functional) that ordinarily start and stop equipment and any auxiliaries in unison with or regardless of room thermostat demand. Two lessons are devoted to controllers.

(Note: If it helps, some people think of a room thermostat as a main or master controller, and all others in the system as auxiliary or sub-master controllers.)

The third lesson in the unit deals with the relay. The relay is a real workhorse in a control system, and defies a simple classification. In many instances, the device can be classified as a controlled device (or at least a main component of a controlled device). In other situations, it acts like a transducer.

A low voltage thermostat often triggers a relay to start or stop high voltage equipment. In a year-round system, a control circuit may require a dozen relays. It is a very important device, and because of the numbers used and the operating hours incurred, a relay is a common source of trouble in a control circuit.

Electronics is the division of electricity that deals with electron emission in vacuum tubes and other devices. Electronic controls are not new to the heating and air conditioning industry. Modulating controls using electronic components have been available for years. But new developments in solid state electronics have made more types, and in many cases, better types of controls available.

The lesson on electronics is a primer for the student technician. Because of the newness of solid state devices, more space is devoted to the study of basic principles than to the study of actual solid state control devices. Braced with the basic concepts, however, the student should be well equipped to understand what manufacturers will be offering for some time to come.

As you can well appreciate, Unit 3 contains an important segment of the controls story. It deals with devices that can literally come in a hundred variations. But don't let that worry you. Learn the concepts; learn to recognize the ordinary controllers, relays and electronic devices and their roles in the control circuit, and you'll master the 100 variations as well.

Lesson 9 Overview

The first lesson in Unit 3 is one part of a two-part discussion on the controller. As mentioned previously, a controller is the brain portion of a control system. It senses a change in some condition and orders another device to take action. A room thermostat is a controller.

The controller has two recognizable components - a sensing element and a transducer. The sensing element detects the change in a variable, say, air or water temperature and the transducer converts the action of the sensor into a more useful action to motivate the second device to do something.

Lesson 9 deals only with the sensing elements currently used in ordinary controllers. The following lesson covers the types of transducers that can be encountered.

After studying Lesson 9, you should:

1. Recognize the various forms of bimetal sensors.
2. Understand how a rod and tube and a tube and channel sensor operate.
3. Know the advantages of a bellows over a diaphragm (and vice versa).
4. Know the three “fills” used to produce bellows/diaphragm movement.
5. Be able to explain how a bourdon tube operates.
6. Understand the difference between a CdS cell and a photocell.

Now read Lesson 9 which begins on the next page.

Lesson 9: The Controller Part I – Sensing Elements

A controller is defined by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) as "a device which measures a controlled variable, such as temperature, humidity, and pressure, by means of a sensing element and compares the controlled variable with an input signal to produce a suitable action or impulse for transmission to controlled devices."

The group of control system components known in the industry as controllers is vital to the safe and efficient operation of automatic heating and cooling equipment. The room thermostat which we have discussed in previous lessons is one example of a controller.

As we learned in the introduction to this course, a controller is made up of two basic components – a sensing element and a transducer or energy converter. In this lesson, we'll be concerned only with the common sensing elements used in controllers today. Lesson 10 will take up the discussion of transducers.

Components of the Sensing Element

All controllers contain two basic parts - the *sensing element* and the *transducer.* Sensing elements in common use today include:

1. bimetals
2. rod and tube elements
3. bellows and diaphragms
4. bourdon tubes
5. resistance elements

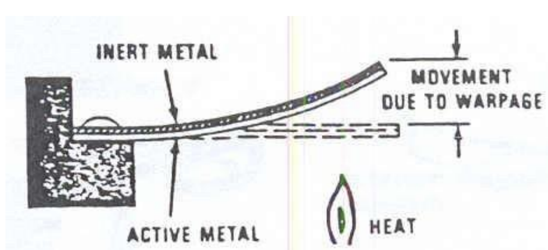


Figure 9-1: Basic bimetal

The sensing element will react to changes in temperature, pressure or liquid level. Sensing element reactions (mechanical movements) will be converted to a useful form by the transducer to control the heating and/or air conditioning system.

Bimetals

Bimetals, which were discussed briefly in Lesson 4, are composed of two or more metallic alloys that are welded together (Figure 9-1). Since the metallic alloys used in the bimetal have different coefficients of expansion, a change in temperature will cause a warping action. This warping, or change in curvature, occurs because the metal with a high coefficient of expansion -- the active metal - will, when exposed to heat, elongate more rapidly than the metal with the low coefficient of expansion - the inert metal. However, since the metals are fused together, the bimetal will warp. The bimetal, therefore, converts a change in temperature into a mechanical motion.

Bimetals are constructed in various forms (Figure 9-2) and are commonly used in room air thermostats, warm air insertion controllers, and liquid immersion temperature controllers. Bimetals are extremely sensitive - a small change in temperature can produce relatively large mechanical movement.

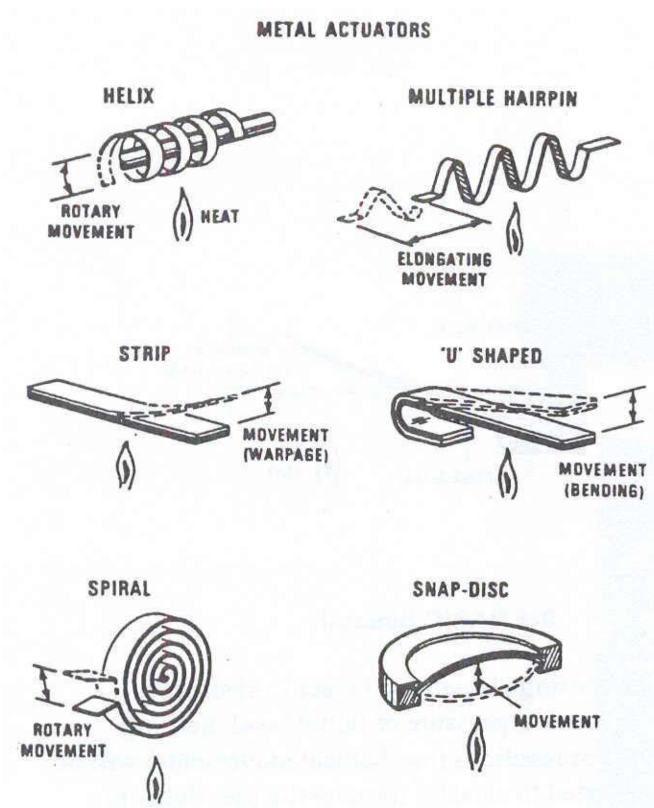


Figure 9-2: COMMON bimetal configurations used in thermostats, warm air controllers and some water immersion controllers.

Rod and Tube

The rod and tube sensing element is constructed by placing an inert rod in an active tube (Figure 9-3). Since the rod is anchored to one end of the tube, a temperature change will cause a pushing or pulling movement.

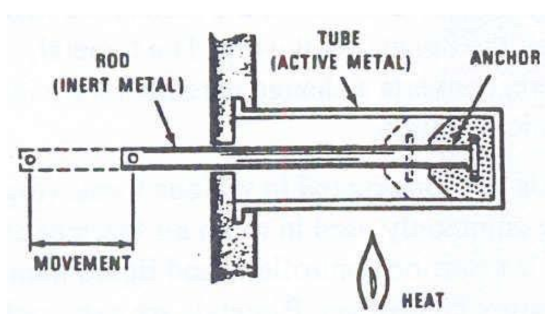


Figure 9-3: Rod and tube sensors are used in some controllers.

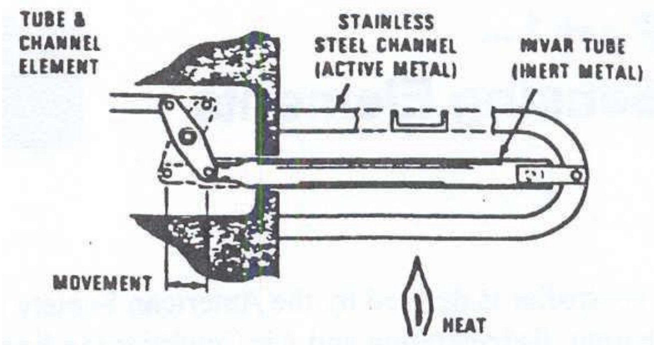


Figure 9-4: Tube and channel sensors are not as sensitive as bimetals but are still very useful.

A tube and channel sensing element (Figure 9-4) is similar to the rod and tube. The U-shaped channel is usually made of stainless steel, an active metal, while the tube is made of invar steel, an inactive metal. Both ends of the channel are anchored to the base of the control. One end of the tube is fastened to the "U" of the channel while the other end is linked to the switch mechanism. A change in temperature will, again, cause a pushing or pulling reaction.

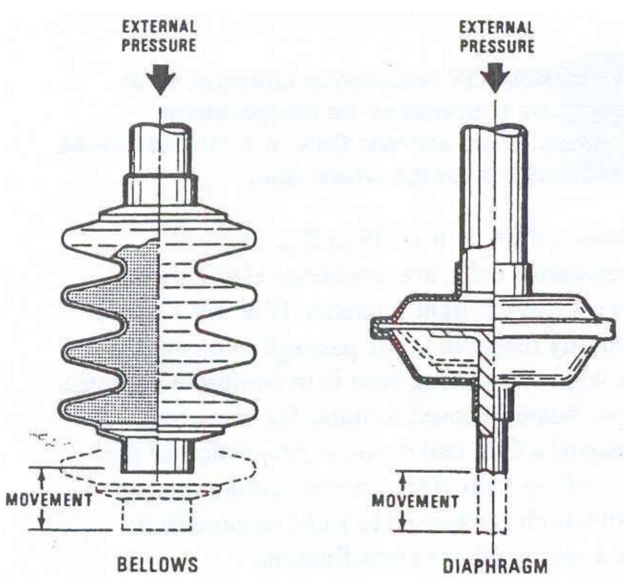
Rod and tube or tube and channel sensing elements are not normally as sensitive as bimetals; however, if properly constructed, these elements will produce relative large amounts of mechanical power.

Before you continue, can you name the five common sensing elements used in modern controls?

Bellows and Diaphragms

Bellows and diaphragms react to changes in pressure. Bellows are produced by forming a flexible metal into successive convolutions (Figure 9-5). Because of its relatively large internal volume, the bellows will produce a greater mechanical movement than the diaphragm for given changes in pressure.

Figure 5: Bellows and diaphragms react to pressure changes and are often used in pressure controllers.



The flexible section of the diaphragm is made of metal, rubber, or plastic. The diaphragm is considered to be more accurate than the bellows and is normally used where frequent cycling is likely to occur or when high pressures must be contained. Both bellows and diaphragms are used in controllers, depending on the amount of movement required, the sensitivity desired and the working pressures that must be contained to operate a transducer.

Although bellows and diaphragms react to pressure, they may be used in closed systems to control temperature. To accomplish this, an enclosed reservoir element which is connected to the sensing element by a flexible tube, is exposed to the temperature to be controlled (Figure 9-6). Temperature changes imposed on the reservoir element cause mechanical movement of the bellows or diaphragm by one of three methods, depending on the type and amount of fill used in the system.

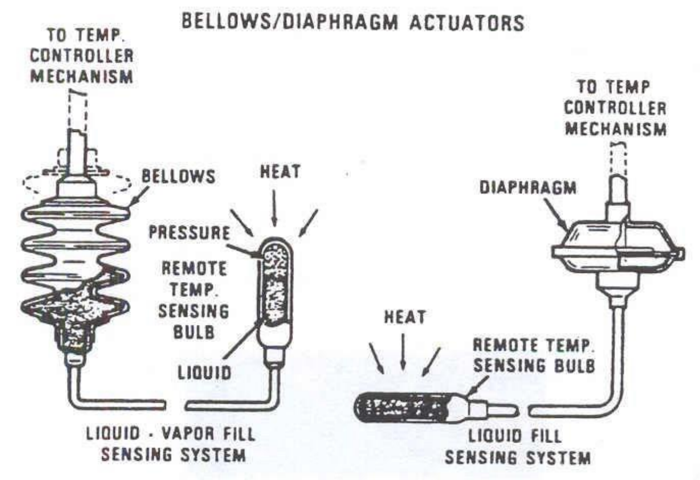


Figure 9-6: Filled actuators attached to bellows and diaphragms permit these devices to be used to sense temperature as well as pressure.

1. Vapor Fill: If the reservoir element is filled with a vapor, an increase in temperature will expand the vapor and cause the bellows to move. (Vapor reservoir elements are usually used only with a bellows because the vapor itself is compressible.) Vapor fill systems will produce good mechanical movements for a small change in temperature.

2. Liquid/Vapor Fill: In the liquid-vapor system, the reservoir element is partially filled with a liquid which will vaporize as operating temperature increases. The vapor produced by increasing temperatures within the enclosed system will increase the pressure on the bellows or diaphragm, causing a mechanical movement of the sensing element.

3. Solid Liquid Fill: If the entire space in the reservoir, the connecting tubing and the diaphragm housing is filled with a liquid, the pressure on the diaphragm will increase as rising temperatures in the system expand the CONTROLLER liquid fill. The solid liquid system will create a powerful force with relatively small movements of the diaphragm.

Bourdon Tube

The bourdon tube is another sensing element that reacts to changes in pressure. The bourdon tube is an elliptical tube that is curved along its length to form an incomplete circle (Figure 97.). One end of the tube is sealed and linked to the transducer, while the other end is exposed to the pressure to be controlled. As pressure in the tube increases, the tube will tend to straighten. The movement of the sealed end of the tube will be directly proportional to the amount of increased pressure. The bourdon tube can also be used to control temperature in closed systems. To control temperature, the tube is filled with a liquid or a liquid/vapor fill and both ends are sealed. In some cases for example, immersion thermostats - one end of the bourdon tube is connected to a temperature sensing bulb by flexible tubing.

When the bulb is heated, the liquid, vapor or liquid/vapor fill will expand. The additional pressure created within the closed system by this increase in volume will cause the bourdon tube to straighten. The bourdon tube is a versatile sensing element since it combines good movement and high available force.

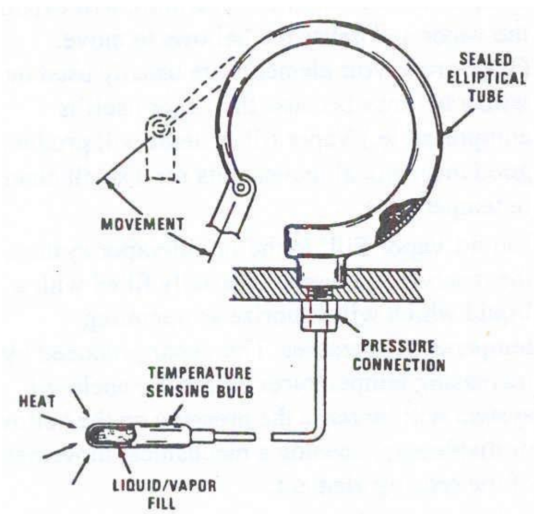


Figure 9-7: Bourdon tube used in many gauges is shown here used as a temperature sensor, say, for an immersion thermostat.

Resistance Elements

Resistance elements are sensing elements designed to vary their electrical resistance when exposed to changes in temperature or light intensity. Thermistors, photo-resistance cells and photocells are typical resistance elements.

Thermistors, which were discussed in a previous lesson, will offer less resistance to the flow of electrical current as temperature increases. Note how the curve representing a thermistors resistance moves upward as temperature increases in Figure 9-8.

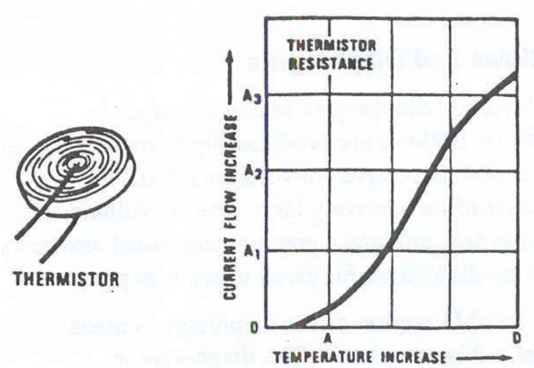


Figure 9-8: Thermistor resistance changes with temperature (decreases as temperature increases). Thus current flow in a circuit would increase with a temperature rise.

Cadmium-sulfide cells (CdS cells), or photo resistance cells, are resistance elements that react to changes in light intensity (Figure 9-9). A CdS cell is highly resistive to the passage of electrical current when its sensing base is in complete darkness. However, when exposed to light, the electrical resistance of a CdS cell drops in proportion to the intensity of the light. The current passing through a CdS cell which is exposed to light is enough to operate a relay without amplification. A photocell, however, will generate a small amount of electrical energy when its sensitive section (which is enclosed within a vacuum tube) is exposed to light. The electrical energy generated by a photocell must be amplified to develop the power necessary to operate a relay or transducer.

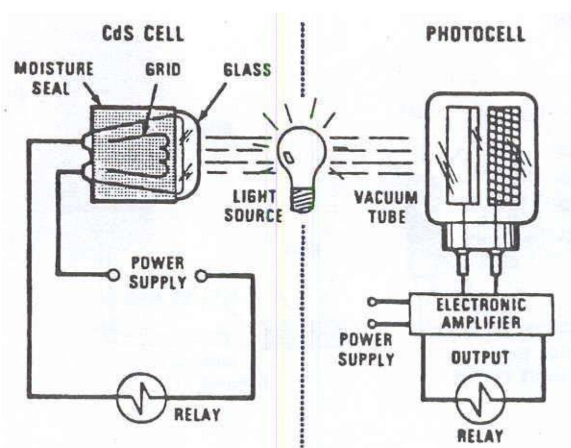


Figure 9-9: Light sensitive sensors include the CdS cell (left) and the photo cell (right). These devices can be used as sensors where luminous combustion is involved.

Self-Check, Lesson 9 Quiz

You should have read all the material in Lesson 9 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the answer key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F A controller reacts to changes in pressure, temperature, or liquid level.

2. T F Bellows and diaphragms react to pressure but can be made to react to temperature.

3. T F A controller can operate more than one set of electrical contacts.

4. T F A bimetal is composed of two different types of metal fused together.

5. T F Warping of the bimetal helps convert temperature change into mechanical motion.

6. T F The rod and tube sensing element is ordinarily more sensitive than a bimetal.

7. T F Vapor filled sensing systems are usually connected to a diaphragm.

8. T F A bourdon tube and resistance element can both serve as a temperature sensor in a control system.

9. T F A bourdon tube can be a liquid or a volatile liquid/vapor filled unit that responds to pressure.

10. T F A diaphragm can produce greater movement than a bellows.

In the following multiple choice questions, choose the phrase that <u>most</u> correctly completes the statement and circle the corresponding letter in front of the phrase.

11. A sensing element designed to vary, electrical resistance to either temperature or light intensity change is a:

a. bimetal. b. resistance element.
c. bourdon tube. d. rod and tube.

12. As the temperature decreases, the resistance of the thermistor:

a. lowers. b. increases.
c. remains constant. d. disappears.

13. The resistance of a CdS cell drops when exposed to:

a. electricity. b. gas.
c. light. d. water vapor.

14. The bimetal principle is used in:

a. room thermostats. b. warm air insertion controllers.
c. liquid immersion temperature controllers. d. all of the above.

15. The bellows and diaphragm sensing element can be used to control pressures and:

a. temperature. b. gas flow.
c. gas input. d. gas output.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

16. The two basic parts of a controller are the ______________ and the _______________.

17. Rod and ____________ or tube and _______________ bimetals produce large amounts of mechanical _______________ but at the sacrifice of _______________________.

18. The liquid in a solid liquid fill system exerts increased pressure on the ________________ through the increase in liquid volume caused by an increase in ________________________.

19. The ___________________ tube can also be used to react to changes in _______________ and ________________________.

20. List three types of system "fills" that provide bellows and diaphragms with temperature response characteristics.

1. __________________________________
2. __________________________________
3. __________________________________

21. Five basic types of sensing elements commonly used are:

1. ___________________________________
2. ___________________________________
3. ___________________________________
4. ___________________________________
5. ___________________________________

22. One metal in a bimetal sensor is ________________ ; the other is _________________.

Check Your Answers!

Lesson 10 Overview

Lesson 10 is a continuation of Lesson 9 and deals with the second functional component of a controller, namely the transducer. The transducer might be more accurately referred to as a (power) converter. The dictionary defines a transducer as a device activated by power from one system and supplying power to another.

In our case, a transducer takes the mechanical movement of a sensor (bimetal, bellows, etc.) and controls the flow of electricity (or at times pressure) to another device.

There are three basic types of transducers. The electronic transducer - an amplifying circuit - will be discussed in Lesson 12 when we take up the special subject of electronics. A second type involves pneumatic or compressed air powered controls, which is beyond the scope of this course. The third is the electric transducer, and this is what Lesson 10 is specifically concerned with. (A fourth transducer might be included. It's a combination of the electronic and pneumatic transducers - a kind of super black box to tie in electronic controls with pneumatic controls.)

Physically, the electric transducer takes on many forms depending on the type of control action desired (simple on-off, or the more sophisticated floating action, etc.). It can be a simple single pole switch, a double pole switch, or a wiper arm that moves along a potentiometer.

After discussing the three control actions that an electric transducer can provide, the lesson focuses on specific warm air and hydronic controllers that provide on-off control action. In these devices then, the transducer is usually a specialized electric switch.

After studying the second lesson on controllers, you should:

1. Be able to describe the three types of control action possible using electric transducers.

2. Be able to define control action terminology - set point, control point, offset, throttling range, etc.

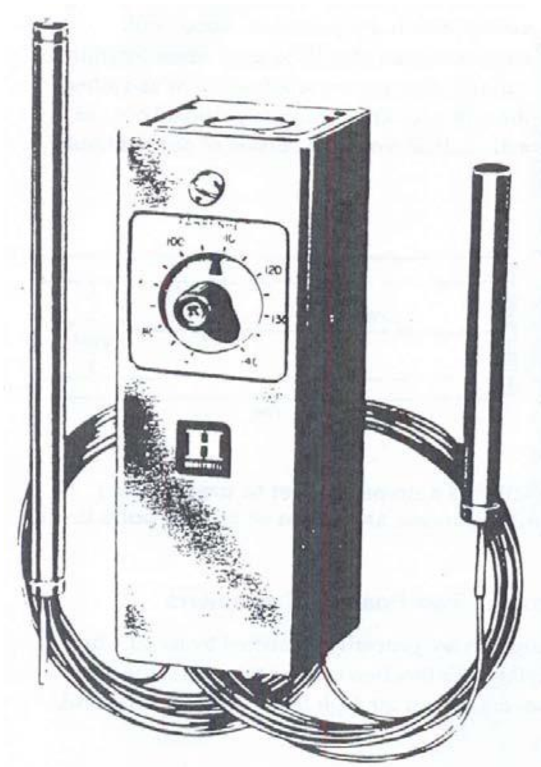
3. Recognize high limit/low limit controllers and their function in warm air and hydronic systems.

4. Understand how fan and pump controllers operate.

5. Understand that there are numerous variations of controllers to meet specific or specialized needs.

Now read Lesson 10 which begins on the next page.

Lesson 10: The Controller Part II – Transducers



The sensing elements discussed in Lesson 9 are often combined with electric transducers (switches) to produce a complete controller such as the one at left which increases supply air or water temperature automatically as outdoor temperature decreases (Honeywell Inc.).

Controllers contain two basic parts - the sensing element which was covered in the previous lesson and the *transducer*. A transducer is a device that is actuated by power from one system and supplies power to another system. The transducer section of a controller uses the energy developed in the sensing element to control electrical current or fluid pressure. There are three basic types of transducers in general use. A transducer, which controls the flow of compressed air, is known as a *pneumatic controller.* An *electronic transducer* uses an amplifier to sense minute changes in voltage produced by the sensing element to operate electrical or electro-hydraulic relays. And finally, the *electrical transducer* or switching transducer that operates electrical contacts to control the flow of electrical energy. *The remaining sections of this lesson on controllers will deal only with electrical transducers.*

Control Modus Using Electrical Transducers

Various control modes are possible using the simple switching transducer:

1. **Two-position** or "on-off" control action (Figure 10-1) is extremely simple and widely applied. Single pole, single throw (SPST) and single pole double throw (SPDT) controllers are commonly used to start and stop burners, pumps, relays, valves, compressors and other electrical loads.

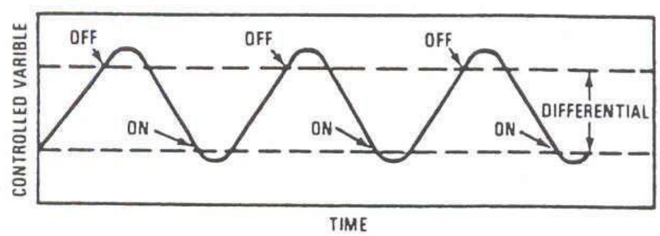


Figure 10-1: Two-position (on or off) control action is typical of the controllers discussed in this lesson.

2. **Floating control action** (Figure 10-2) is achieved by using a single pole, double-throw transducer that has a preset or adjustable zone of temperature or pressure where neither contact is closed. Floating control action, which usually closes position at a constant rate by switching from the “up” circuit to the “down” circuit, is used to control reversible motors such as those used to position dampers to maintain static pressure in ductwork. Floating control action is also used to monitor multiple speed blowers or high-low-off flow control devices.

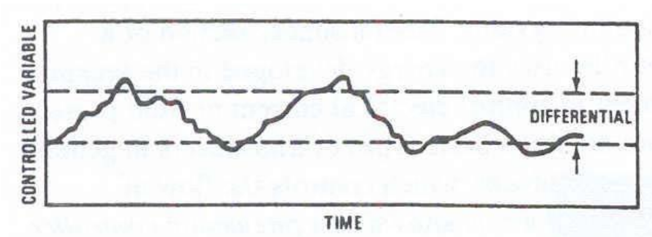


Figure 10-2: Floating action still only involves relatively simple SPDT switches.

3. **Proportional or modulating control action** (Figure 10-3) is achieved by using a potentiometer to vary the position of the controlled device in proportion to the temperature, pressure or flow variations felt by the sensing element. A potentiometer is nothing more than an adjustable three-wire variable resistor. The *throttling range* (usually adjustable) is the maximum change in the controlled variable which will cause the controller to move the wiper and (third wire contact on resistor) through its complete stroke from one end of the potentiometer's resistance element to the other. *Control point is* the actual value of the media being controlled and will vary within the throttling range according to the demand on the system. The set-point (usually adjustable) represents the desired value of the controlled media. The *offset* (droop, deviation, drift, slippage) is the difference between the control point and the set-point when system conditions are stabilized.

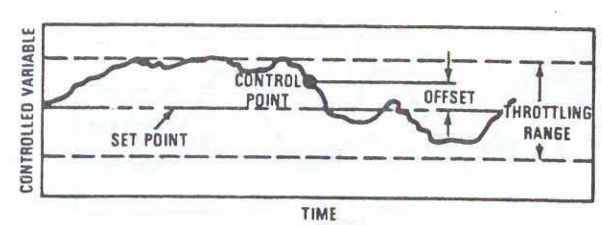


Figure 10-3: Proportional control action involves more complex switching circuits.

4. Proportional control action with automatic reset (Figure 10-4) operates as a standard proportional control system until an offset condition occurs. If an offset exists, the automatic reset will initiate action to shift the control point toward the set-point. Proportional control action with automatic reset combines the stability and relatively wide throttling range of proportional control action with the non-variable control point of floating control action. Proportional control with automatic reset should be used when controlled variable changes are relatively slow and when the offset resulting from proportional control action alone would be outside of desired limits.

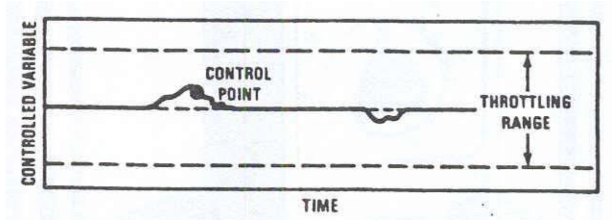


Figure 10-4: Adding automatic reset to proportional control minimizes any offset or control point droop.

Common Two-Position Controllers

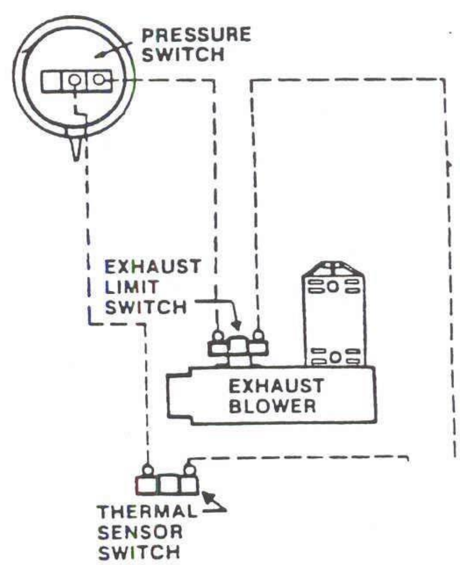
Controllers are generally identified by terms which describe their function and the type of media they sense: e.g., *warm air high limit* control, *fan* control, etc.

Here are the most common *air* and *hydronic controllers:*

High limit controls are used in almost all control systems. Their function is to limit temperatures, pressures, or flow rates to a safe maximum. High limit switches are usually SPST, normally closed switches that open an electric circuit when the value of the controlled variable exceeds safe levels. For example: a furnace high limit control would shut down the burner irrespective of room thermostat demands if furnace supply air exceeded pre-set limits. Some high limit controls use SPDT switches which open an electrical circuit when a high limit condition occurs and close auxiliary circuits to energize alarms, or initiate other desirable action. High limit controls can use either automatic reset or manual reset switches.

The sensing elements used in high limit controls for warm air systems are normally bimetals, snap discs, or filled elements (Figure 10-5). In hydronic systems, high limit sensing elements are normally filled elements, or diaphragms (Figure 10-6).

High efficiency gas furnaces using power venting/ induced draft blowers feature several specialized limit devices. To protect against faulty draft, a diaphragm actuated pressure switch is placed in series with an exhaust temperature limit switch and a second limit near the gas burner to react to flue spillage. (See sketch at right)



All limit controls should be positioned in the system so that they will quickly and accurately sense the actual value of the controlled media. Locations where extraneous influences may be erroneously sensed should be avoided.

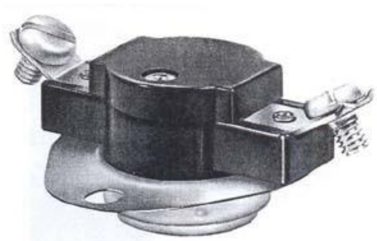


Figure 10-5: High limit control (left) utilizes snap disc bimetal (see Figure 9-2 previous lesson), while remote duct air controller (right) utilizes filled element. Both produce simple on-off action.

The common device for controlling the operation of fans or blowers is the **basic fan control.** (See below for details). There is also a time delay bimetal fan switch for use with counterflow and horizontal furnaces since the basic fan control does not work well. A relay is used with heat pumps and electric furnaces to operate the blower.

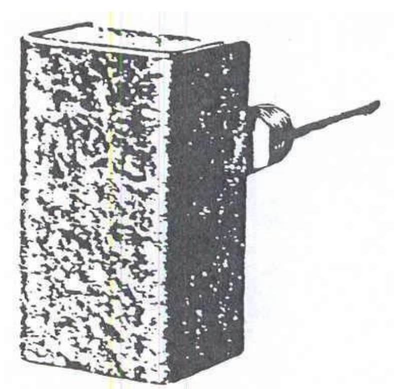


Figure 10-6: Typical hydronic high limit immersion controller uses filled elements as sensor and enclosed snap acting switch as the transducer (ITT General Controls).

The basic fan control closes a set of contacts on a rise in supply air temperature to energize the blower. Common sensing elements may be snap discs, bimetal strips or helices (Figs 10-7, 10-8 and 10-9). The temperature differential on most fan controls is adjustable. The "on" setting must be low enough to prevent a high temperature buildup before fan operation is started. Normally, the "on" setting is about 30° F above the "off" setting to prevent circulation of uncomfortable cold air. A narrow differential between the "on" and "off" setting can cause short cycling of the blower.

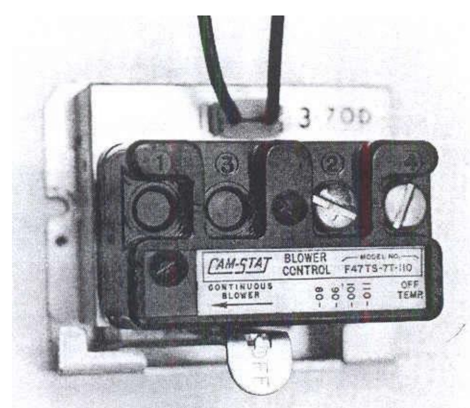


Figure 10-7: Adjustable fan control utilizes a bimetal strip sensor and electric contacts.

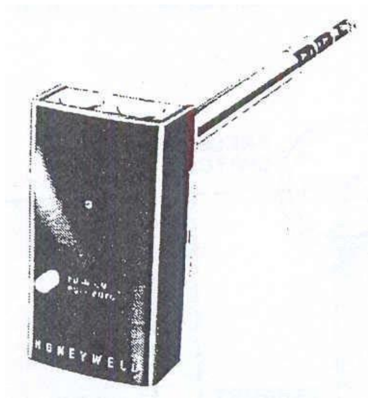


Figure 10-8: Combination fan-limit control (left) utilizes helix bimetal to activate switches, but other models may use spiral or flat bimetals, or even liquid filled elements (Honeywell Inc.).

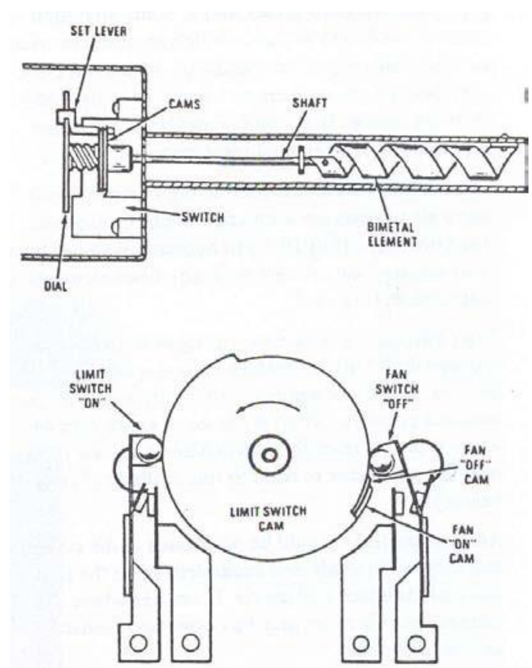


Figure 10-9: Details of one combination fan-limit control show how twisting motion of heated helix turns cams to activate fan and limit switches. Arrow on cam indicates counter clockwise rotation on temperature rise.

(Fan and limit controls must operate independently. Figure 10-10 shows fan and limit controls wired in parallel, which insures desired independent operation of these vital circuits.)

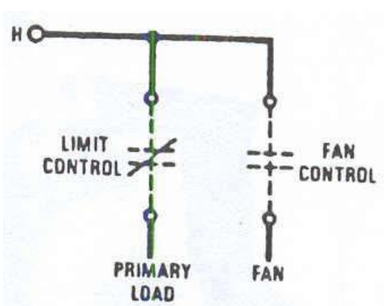


Figure 10-10: Parallel wiring assures independent fan and limits functions in a control circuit.

Control Sequence

In ordinary warm air and hydronic heating systems, the thermostat closes contacts and calls for heat. Burner starts, then...

... in a warm air system:

Fan control - an independent *fan controller* turns on when supply air temperature reaches a preset value and turns the fan off at a lower preset value. An alternate procedure is to bypass the controller and operate the fan continuously.

Limit control - a *high limit* controller shuts off the burner if plenum air temperature exceeds preset value and turns the burner back on when plenum air temperature returns to normal. The fan operates continuously during this time. No low limit controller is used.

A combination fan/limit controller can be used to perform all the above functions.

... in a hydronic system:

Pump control - room thermostat controller starts and stops the system pump directly. An alternate procedure is to operate the pump continuously and use an independent controller (sometimes called a reverse acting water temperature control) to shut pump off when boiler water temperature drops below a preset value. If a low limit is used, pump "off" sequence can be combined with low limit using SPDT switch.

Limit control - a *high* limit controller shuts the burner off if water temperature exceeds preset value and turns it back on when boiler "cools." The pump operates continuously during this period.

Low limit controller is used if boiler also supplies domestic hot water as well as heating. Low limit turns burner on when temperature falls below preset value. Pump is not affected if thermostat is not calling for heat so building will not be overheated.

A combination control can be used to provide all the above functions.

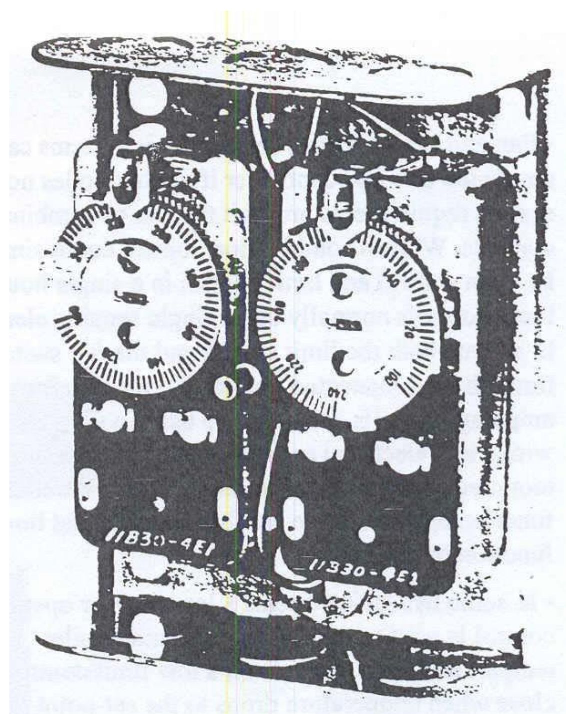
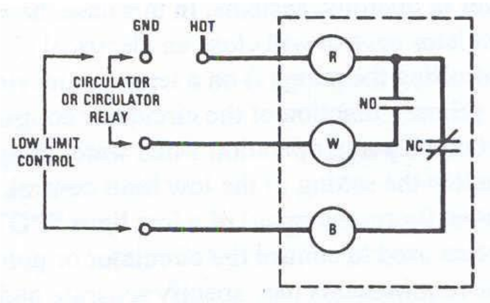


Figure 10-11: Controller features low limit (right) as well as separate high limit (left) functions for the hydronic boiler. Low limit starts burner when boiler temperature falls below preset minimum. This feature is useful when boiler provides domestic hot water as well as building heat.



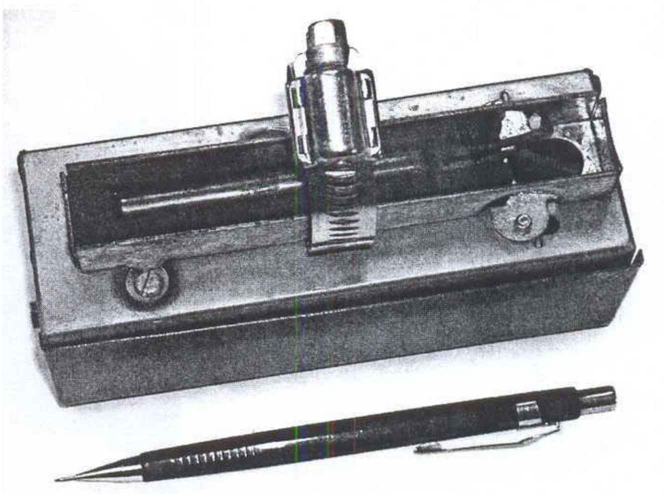


Figure 10-11: Surface mounted controller (at left), which senses water temperature through pipe, can be provided with normally closed contacts, or normally open contacts, or single pole, double throw contacts. With SPDT contacts diagram (above), controller can maintain minimum boiler water temperature and stop and start pump accordingly.

Fan and limit controls for warm air systems can be combined into one controller if neither codes nor system requirements prohibit the use of combination controls. While a combination control could simply be a fan control and limit control in a single housing, these controls normally use a single sensing element to actuate both the limit switch and the fan switch through interconnected linkage or cams. In low amperage circuits, a fan switch using a strip bimetal with a low electrical capacity snap disc switch mounted on the bimetal frame to handle the limit function can be used to combine the fan and limit function in one unit.

In some hydronic systems, a low limit or operating control is used to maintain a minimum boiler temperature. The contacts on a low limit control will close when temperature drops to the set-point to complete the circuits to operate the burner (Figure 10-11). Sensing elements for hydronic temperature controls are usually bellows or diaphragms with either a remote temperature sensing bulb or an immersion bulb. The temperature sensing elements are usually inserted in wells so that the system will not have to be drained to service the controls.

Pumps controlled by a reverse acting control similar to the low limit control are used to circulate water in hydronic systems. In this case, however, the circulator control will close an electrical circuit controlling the pump(s) on a temperature rise. Since the primary function of the circulator control is to shut down pump operation when water temperature is below the setting of the low limit control, the back contact (normally open) of a low limit SPDT switch is often used to control the circulator or pump. Local code requirements may specify separate and independent controls, and codes should be checked.

A combination control which combines most of the control components used in a hydronic system in a single housing with one sensing element can be used in some hydronic systems. These controls (Figure 10-12) generally include a thermostat and load terminal board, circulator relays, low limit and/or circulator controls, high limit controls, and a control circuit transformer. Installation costs may be reduced substantially by using combination controls; however, there are some control disadvantages, since all temperatures are sensed at one location.

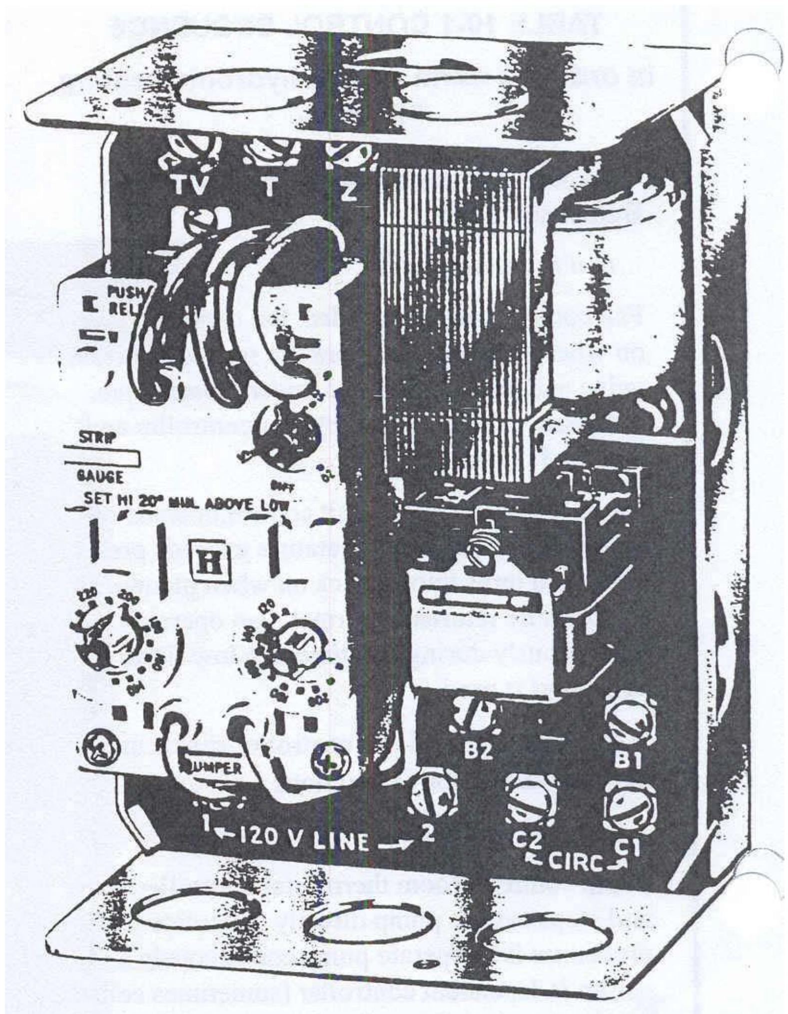


Figure 10-12: Combination hydronic controller can feature a variety of components in one economical housing - including the low voltage transformer (Honeywell Inc.).

Self-Check, Lesson 10 Quiz

You should have read all the material in Lesson 10 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the answer key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F Two position control action is sometimes known as on-off action.

2. T F It is not permissible to combine fan and limit functions into one controller on warm air systems.

3. T F A single sensing element which actuates both limit switch and fan switching is not acceptable.

4. T F A time delay type of fan control may be used on electric heat systems.

5. T F A controller is usually named for its function and the type of media it senses.

6. T F High limit devices are commonly used in all control systems.

7. T F In most hydronic systems, it is necessary to drain the entire system when servicing the controls.

8. T F In floating control action, a transducer can monitor the action of reversible motors or multi-speed blowers.

9. T F The control point is the value of the media being controlled.

10. T F The set point of the controller is not adjustable.

11. T F Offset is also known as droop.

In the following multiple-choice questions, choose the phrase which <u>most</u> correctly completes the statement and circle the corresponding letter in front of the phrase.

12. On-off control action requires the use of:

a. a SPST controller. b. a SPDT controller.
c. either a or b. d. neither a nor b.

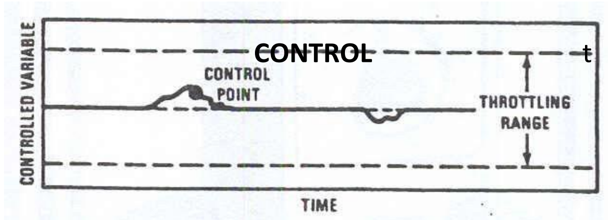
13. The offset is the difference between the control point and the set point when system conditions are:

a. the same. b. different.
c. stabilized. d. not working.

14. Sensing elements in hydronic limit controls are usually bellows or diaphragms with a:

a. capillary and remote bulb. b. integral immersion bulb.
c. either of the above. d. neither of the above.

15. The figure at right illustrates:



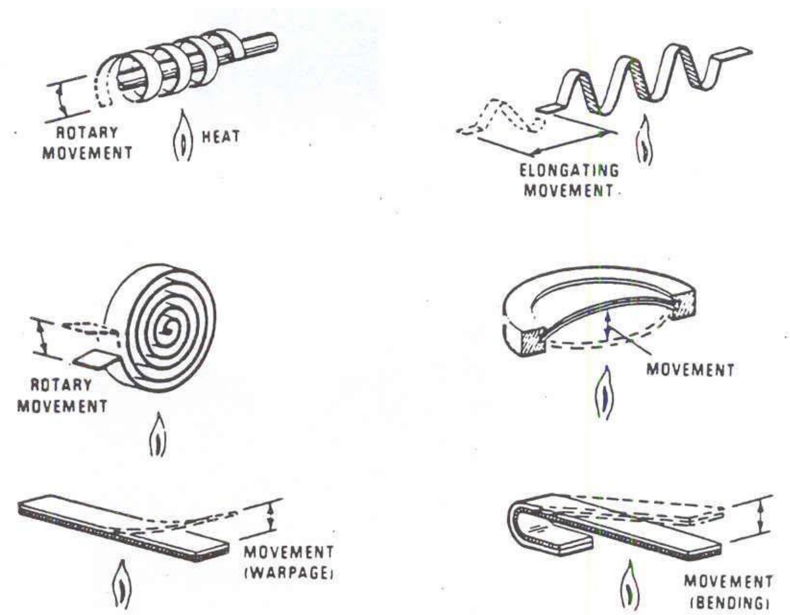
a. two position control.
b. floating control.
c. no control.
d. proportioning control with control point reset.

16. It is wise to use a proportioning control with control point reset where controlled variable changes are:

a. relatively slow. b. relatively quick.
c. static. d. fluctuating.

17. The figures below show various types of:

a. transducers. b. controllers.
c. sensing elements. d. damper openings.



For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

18. The primary function of a circulator control in a hydronic system is to prevent circulation of _______________________________.

19. A combination hydronic immersion control usually includes these five components:

1. ____

2. ____

3. ____

4. ____

5. ____

20. A high limit control keeps the value of the controlled variable within a/an ________________________ value.

21. The most common device to start and stop fans and blowers is the ____.

22. Proportion control action modulates the position of the controlled device in direct relation to the _______________ _________________ _________________ ________________ felt by the sensing element.

23. The room ____________________ starts and stops both the ___________________ and the burner in many hydronic systems.

24. A furnace blower may be ____________________ and _________________ by an independent controller sensing temperature.

Check Your Answers!

Now compare your answers with those given in the answer key at the back of this book. The answer key also directs you to a page in the lesson to review the text for any questions you may have missed.

Lesson 11 Overview

In Lesson 10, we discovered that the high sounding transducer in many controllers is merely a specialized electric switch. Another switch that is used many times in a control circuit is an electromagnetic switch or relay. Lesson 11 is concerned with the design and construction of the *relay* and its heftier partner, the *contactor.*

Most relays and all contactors are electromagnetic devices. That is, an *electric* current produces *magnetic* forces to move electric contacts. However, there is a second type of relay - the thermal or bimetal relay, and this type is also discussed in the lesson.

The relay is an extremely important switching device. It's an economical 'black box" that permits low voltage devices to operate high voltage equipment. In this context, the independent relay might be considered a type of transducer. However classified, the relay is a versatile control auxiliary that should be thoroughly understood.

Lesson 11 should help you:

1. Understand the difference between a relay and contactor.
2. Know operating and construction details of a relay.
3. Appreciate good contact design to avoid arcing, pitting, etc.
4. Select relays that minimize 60 cycle hum and chatter.
5. Understand how a thermal relay operates.

Now turn to Lesson 11 which begins on the next page.

Lesson 11: The Electrical Relay

Most relays and all contactors are electromagnetic switches. With these devices, it's possible to use sensitive low voltage controllers to switch on and off equipment operating on higher voltage. Relays are used to control electrical loads that draw less than 20 amperes, such as motors, valves, ignition transformers, and small compressors. Contactors, which are actually high capacity relays, are designed to handle over 20 amperes, and are used on large heating and air conditioning systems. Both devices are identified by their specific job function - *changeover* relay, *condenser fan* relay, compressor contactor, etc.

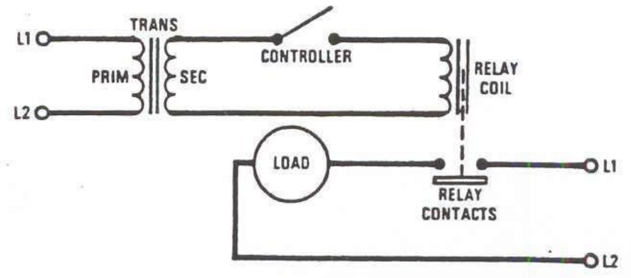


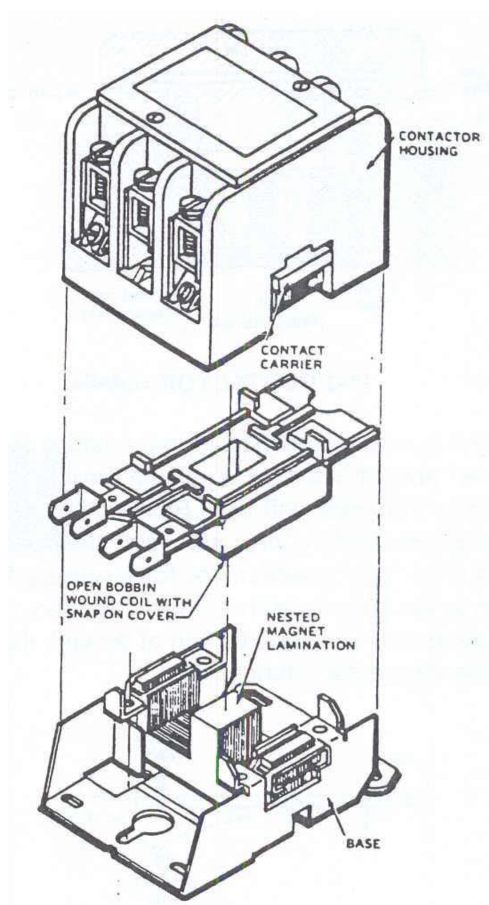
Figure 11-1: Schematic of a basic - control, relay and load circuit.

Electrical circuits supplying power to both relay and contactor coils are opened and closed by thermostats, pressure switches, float switches, timers, and other controllers.

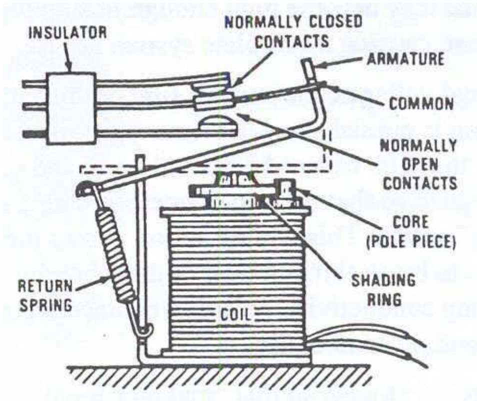
The volt-ampere draw of commonly used relay and contactor coils is low; therefore, low voltage transformers can supply enough power to operate these devices (Figure 11-1). The transformer used to operate the relay or contactor coils, however, must match the voltage and frequency of the coil and also supply enough power to handle the loads imposed on it from all the components in the circuit.

How Magnetic Relays Work

Figure 11-2 and 11-3 are cross sectional illustrations of magnetic relays and contactors. There are two basic sections - a switching section and an electromagnetic section. The coil, which sets up the magnetic field, is installed around a pole piece. The shading ring is used to establish an off-phase component of the magnetic field surrounding the coil to avoid alternating current hum commonly referred to as 60 cycle hum. The armature moves in response to coil energization to open or close the electrical contacts, and return springs are used to pull the armature to the de-energized position.



40 AMP, 3-pole contactor suitable for low voltage control of an air conditioner's compressor (Honeywell Inc.).



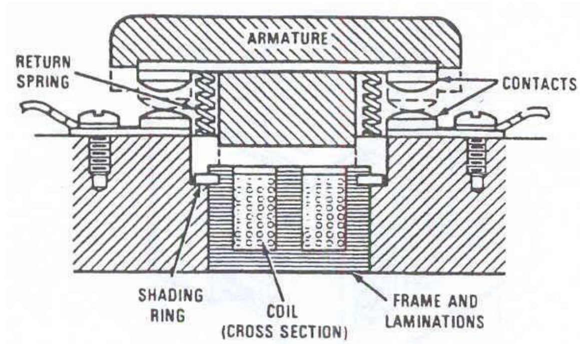


Figure 11-2: Relay details. **Figure 11-3: Contractor details.**

Figure 11-4 is a simplified diagram representing the "forces" present in a relay. Applying force to the end of a long, thin blade will bend (deflect) the blade. Releasing the applied force will allow the blade to return to its "free" position. The force causing the return action is the "reactive force." In a relay, the applied force is the magnetic pull of the coil; the reactive force is the return spring.

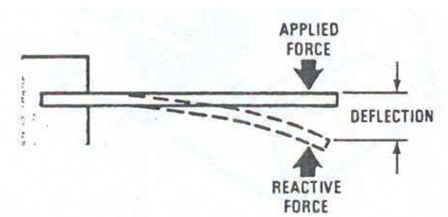


Figure 11-4: Simplified diagram of forces at work in a relay.

Contacts

Contacts used in relays and contactors are usually made of silver or silver alloys since these materials are excellent conductors and have a minimum tendency to weld.

Oxidation of contact material will produce a surface film on the contacts that will increase contact resistance. The heat generated by increasing contact resistance may become high enough to stop the flow of current, causing a complete system failure.

At normal voltages, the surface film oxidation is burned away. However, in low voltage circuits this film cannot be burned away and contacts are designed so that they open or close with a slight "wiping" action. This wiping action allows the contacts to break through film or dirt, thereby increasing conductivity, reducing contact heating, and extending contact life.

Contacts are aligned so that "make-or-break" actions occur in the middle half of the contacts. If "make-or-break" action does not take place near the center of the contacts, an electric arc will result which will vaporize the copper alloys used in the contact arms. Vaporized copper deposited on the contact surfaces will ultimately weld the contacts together. Rounded contact surfaces usually assure center contact operation.

The Electromagnetic Section

The electromagnetic section of the relay (coil, frame, armature, and core) converts electrical energy in the coil to mechanical energy required to operate switching contacts. Since electric current flowing in a conductor will create a magnetic field around the conductor, a magnetic circuit is established whenever the coil is energized. The strength of the magnetic field will depend on the amount of current flowing through the coil and on the number of turns in the coil. The magnetic attraction between the core and the armature (Figure 11-5) is applied force that operates the electrical switch.

In any relay, the input voltage at which the magnetic force established in the coil will overcome the reactive force supplied by the return springs, allowing the armature to move, is called the pull-in voltage. The voltage at which the magnetic force falls just below the reactive force, allowing the armature to fall away, is called the drop-out voltage.

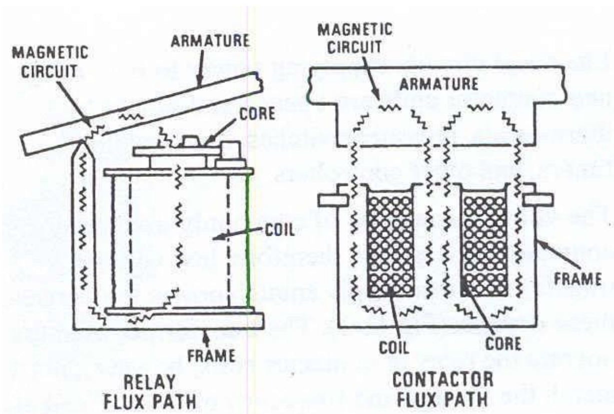


Figure 11-5: Comparison of magnetic fields in a relay (left) and a contactor (right).

Since contactors handle heavier electrical loads, they are larger and stronger than relays. Contactors usually use a double break or a two air gap system (Figure 11-6) and cadmium silver alloys as contact material to handle these heavier electrical loads. Contactors also have stronger magnetic circuits (Figure 11-5) - larger air gaps, double magnetic circuits, and coil fully surrounded by steel - to provide enough force to operate the switching section. These necessary differences between contactors and relays do cause some unwanted conditions such as magnetic eddy currents. These eddy currents, which flow at right angles to the desired magnetic path, cause a loss of applied force and overheating if they are not eliminated by laminations (thin sheets of iron insulated on one face and stacked around the coil.) The insulation on the laminations breaks up the unwanted eddy currents to produce more efficient contactor operation.

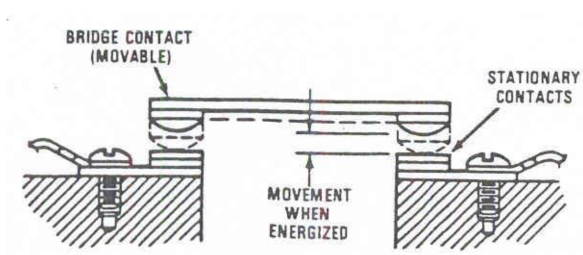


Figure 11-6: Double break feature is common in contactors because of heavier switching loads.

Beating AC Hum

Alternating current flows in first one direction, and then it reverses and flows in the opposite direction. However, when it changes direction of flow, it does not jump from full value in one direction to full value in the other direction. It builds up gradually in one direction to maximum, then drops off gradually to zero. Then it builds up gradually in the opposite direction of flow to maximum and, again, gradually drops back to zero.

If contactors and relays are used on AC circuits, the magnetic field produced by the current flowing in the coil will, when plotted against time, take shape of the familiar sine wave (Figure 11-7). Ordinary alternating current in the United States is 60 cycle (two alternations per cycle) current. Therefore, the magnetic field produced by AC current will drop to zero each 1/120 of a second. When the field around the coil drops to zero, the armature will attempt to return to its free position; however, the magnetic field quickly increases as the cycle progresses and again pulls the armature toward the coil. The rapid oscillations produced by magnetic field alternations result in an objectionable noise called *hum* or *chatter.*

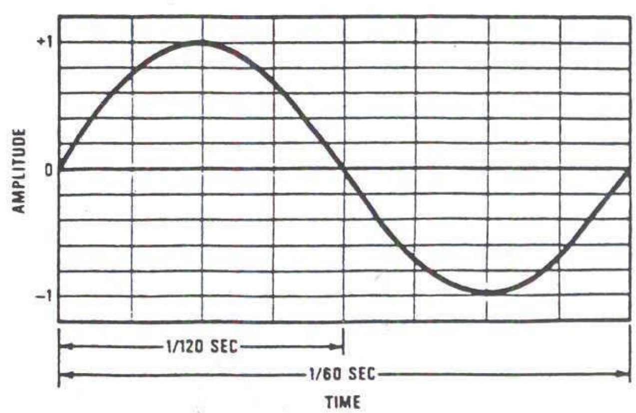


Figure 11-7: Current vs. time in an AC circuit.
Note value of current is 0 each 1/120 of a second.

AC hum is eliminated by shading rings on the coil. The shading rings produce a secondary electromagnetic field which is out of phase with the primary field. (Figure 11-8) Therefore, the magnetic field pulling at the armature never drops to zero when the coil is energized.

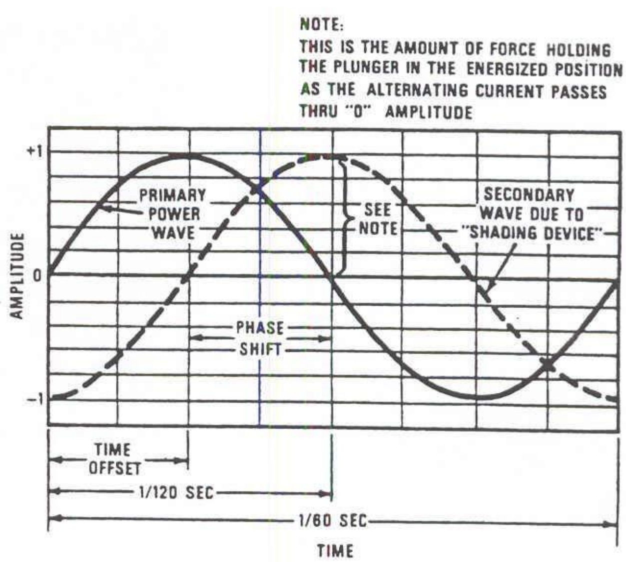


Figure 11-8: AC hum is eliminated by adding shading rings that produce a secondary "holding" field.

Residual Magnetism

Whenever a magnetic material such as the soft iron core of a relay coil is placed in a magnetic field, the material will become *magnetized.* The soft iron core will retain some of its magnetism

after power to the coil is shut off. This remaining magnetic flux is called residual magnetism. Residual
magnetism may cause the core piece and armature of the relay to hold the contacts in the energized position even though there is no current flowing through the coil. And, even if the residual magnetism is not strong enough to overcome the return spring force, it will attract particles of extraneous material which will cause noise and heating problems if not corrected.

Problems caused by residual magnetism can be eliminated by proper design of contactor and relay coils. The usual practice is to design a permanent air gap in the magnetic circuit by placing a brass washer at the bottom of the coil. Since the air gap has a high resistance to magnetic flux, the residual magnetism remains ineffective. Proper selection of the material used in the core and armature also aid in reducing residual magnetism.

Thermal Relay

To complete the relay story, it is important to mention briefly a second type of electric relay that has come into use comparatively recently - the so-called thermal relay.

The thermal relay uses a resistance heater and a bimetal element instead of a magnetic coil and switch arm. When the low voltage circuit is energized, say by thermostat action, the low voltage heater warms the bimetal which warps and closes a switch on the high voltage side.

The thermal relay's chief advantage is its quiet action, and therefore it is well suited to low capacity residential type switching needs.

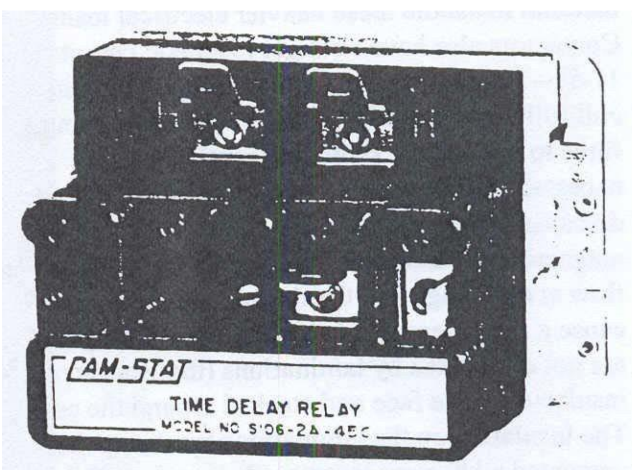


Figure 11-9: Inside a thermal relay, there's a heated bimetal to make and break contact rather than magnetic coil (Cam-Stat, Inc.).

Self-Check, Lesson 11 Quiz

You should have read all the material in Lesson 11 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the answer key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F A relay and a contactor are basically switches.

2. T F No more force is required to operate the switch system of a contactor than of a relay.

3. T F Eddy currents can be minimized by placing iron around the coil in a contactor.

4. T F AC hum or chatter can be caused by rapid oscillation of the contactor armature.

5. T F Shading rings help prevent the force pulling at the armature from dropping to zero.

6. T F Whenever an electric field passes through a magnetic material, strong forces can be developed.

7. T F Residual magnetism in a contactor or relay will not affect operation.

8. T F Strength of the magnetic filed in a coil is not affected by the amount of current flowing through the coil.

9. T F Contactors can be the same physical size as relays even though they handle heavier electrical loads.

10. T F Contacts should be aligned so that physical contact is made in the middle half of the contacts.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

11. Residual magnetism in a relay or contactor can be remedied by:

a. changing contact materials.
b. lowering the voltage.
c. reversing current flow.
d. adding an air gap in the magnetic circuit.

12. Besides utilizing the electromagnetic principle, some relays utilize the action of:

a. heated bimetal.
b. a permanent magnet.
c. an induction coil.
d. a solenoid plunger.

13. As contact resistance increases due to oxidation, the amount of heat generated:

a. increases.
b. decreases.
c. remains constant.
d. dissipates.

14. A contactor is designed to carry loads drawing:

a. under 100 amps.
b. under 50 amps.
c. over 20 amps.
d. over 10 amps.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

15. Silver and its alloys are used to make contacts because of high ________________ and a minimum tendency to ___________________________.

16. _______________________________ voltage is input voltage at which the applied force overcomes the spring force holding the armature.

17. When power to a coil is shut off, some of the magnetism remains. This is known as __________________ magnetism.

18. Relay noise or AC hum can be minimized by adding a/an _______________ _____________ which produces an out of _______________ secondary field.

19. ____________________ currents in a contactor can cause a loss in force if not eliminated.

20. The __________________ section and the _______________ section are the two basic functional components of a relay or contactor.

21. A relay is used to control loads of less than _________________ amperes.

22. ___________________ produces a surface _______________ on a relay's contacts that increases electrical ________________ and causes __________________________________.

Check Your Answers!

Lesson 12 Overview

The final lesson in Unit 3 deals with electronics. Electronics is that division of electricity which is concerned with the emission behavior and amplification of electrons in vacuum tubes and other devices, rather than just electron flow in ordinary wires, resistors, and coils.

Starting with very elementary concepts, such as those derived from Thomas Edison's early and primitive experiments with electron emission, you'll proceed through an explanation of the basic operating principles of today's solid state devices.

A great many manufacturers now offer solid state controls as options on their furnace, boiler and air conditioning lines. Convenient and reliable speed control of AC motors is one of the major breakthroughs provided by solid state electronics.

Many of the latest controls are also hybrid or combination solid state, electro-mechanical devices. In Lesson 18, for example, the use and benefit of solid state elements in oil burner flame safeguards are discussed. Thus, much of what you learned in Lesson 12 can be applied in other lessons where specific controls are discussed. And while this lesson is primarily "theory," examples of how a solid state thermostat and an AC motor control might operate are also presented.

Lesson 12 should be viewed as another key lesson, one that offers a very comprehensive look at a very sophisticated field, the field of electronics.

Upon completion, the student will be expected to:

1. Understand how a vacuum tube works and what diode and triode tubes provide in a circuit.

2. Understand how a solid state diode and transistor work and what each brings to the electronic circuit.

3. Understand how an SCR works and how it can provide AC motor speed regulation.

4. Understand how a thermistor can be used as a sensing element in a solid state thermostat.

5. List the advantages and disadvantages of solid state components as compared to their vacuum tube counterparts.

6. Know what an integrated circuit is, and its effect, if any, on the air conditioning industry.

Now read Lesson 12 which begins on the next page.

Lesson 12: Solid State Devices

Electronic components termed *solid state* devices are slowly finding their way into air conditioning and heating systems and products. Temperature sensors, speed controllers and flame safeguards are just a few of the current applications in which solid state components form a part of the control circuit. The thermistor and CdS all have been mentioned briefly in previous lessons.

What are solid state devices and how do they work?

In 1948, the Bell Telephone Laboratory made public the development of the transistor. This much-heralded event is generally acknowledged to be the start of the *modern* day technology called solid state electronics.

The phrase *solid state* is a physical description --- *solid* meaning not hollow, interior filled with matter, and *state* indicating mode or condition of being. The term is used to separate a new group of electronic components from the more traditional electronic devices - specifically electron *tubes* formed when electrodes are enclosed in an evacuated (or gas filled) glass or metal container. In the past, we have usually referred to these devices simply as vacuum tubes.

Before considering solid versions of the vacuum tube, we should first review how the basic device works and what its function is in an electrical circuit. By doing so, we will have an easier time understanding the role of sold state devices.

Practical Electronic Principles

Not too surprising, it was Thomas Edison who discovered what is now termed *thermionic* emission; for years the phenomenon was simply referred to as the *Edison effect.*

In 1883, still working on a model of the incandescent light, Edison rigged a metal plate inside a light bulb and connected it to a small battery and ammeter as shown in Figure 12-1. With the lamp turned on, the ammeter indicated a current flow, which meant that current or electrons were getting across the gap between the hot filament and the nearby plate. However, when the battery connections were reversed (positive and negative connections switched) no current flow was noted. Only when the plate had a positive potential relative to the hot filament did current flow.

What Edison observed was a boiling off of electrons on the surface of the filament wire. When the wire is heated, loosely-held electrons are activated to the point where they break out and fly into space. With a small battery to make the plate positive, the electrons, which are negative, are attracted to the plate, as opposite poles of magnets attract each other. When the poles of the battery are reversed, the plate becomes negative, and electrons (also negative) are repelled - hence no current flows.

This arrangement, in effect, is a simple *diode* (two-pole) tube. A heater circuit boils off electrons from a cathode filament (sometimes heater wire and cathode wire are one and the same, sometimes not). A plate, maintained positive by a voltage source, then collects these electrons to allow current to flow in the plate-to-cathode circuit.

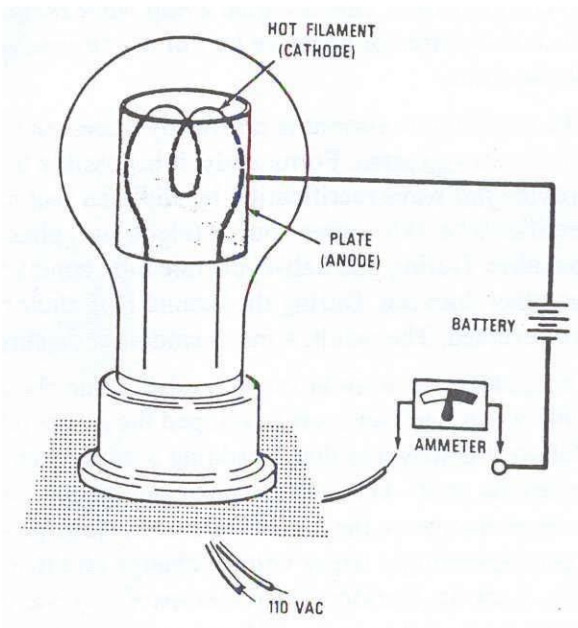


Figure 12-1: Edison's first experiment showing that electrons could be "boiled off" from a heated wire.

One example of the use of a diode is to convert alternating current (AC) to direct current (DC), say in order to charge storage batteries. Figure 12-2 shows the essentials of the circuit.

AC voltage fluctuates from positive to negative in the manner of the familiar sine wave. In the first half of the AC cycle, when the voltage is positive, the plate in the diode tube is positive also, and current is allowed to pass and flow to the storage batteries. During the second half or negative portion of the voltage pulse, the plate is made negative, electrons are repelled and no current flows. This is called a *half wave rectifier* since the bottom or negative half of the current wave is blocked out.

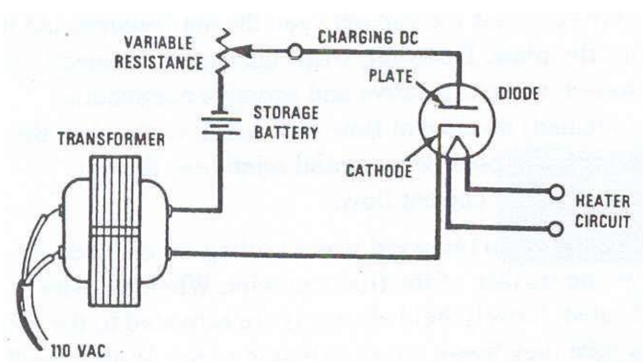
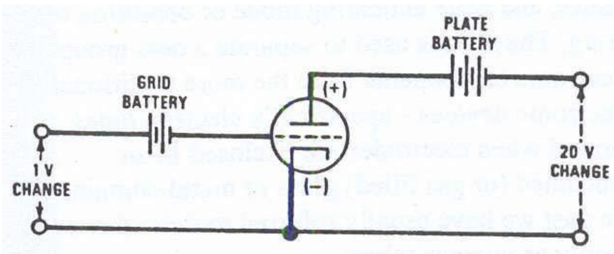


Figure 12-2: Diode tube can be used to convert AC to DC current because the tube conducts current flowing in only one direction.

The resulting DC current is not steady under such a simple arrangement. Fortunately, it is possible to provide full wave rectification by adding a second rectifier tube 180 degrees out of (electrical) phase with the other. During one half-cycle, one tube conducts and the other does not. During the second half, their roles are reversed. The result is a much smoother DC current.

The greatest advance in vacuum tubes came about in 1907 when Lee DeForest developed the *triode* tube. DeForest discovered that by adding a third electrode called the grid - between the plate and cathode, a small voltage change on the "inlet" side of the tube produced a correspondingly larger voltage change on the load side. A triode, therefore, provides *amplifying*



action which is so vital to radio, TV and control circuits.

Figure 12-3: Circuit symbol used to identify a triode (three electrodes) tube in a control diagram.

Figure 12-3 shows the symbolic representation of a triode tube. Figure 12-4 illustrates a simple circuit diagram. A small voltage change impressed across the grid and cathode leads could be magnified perhaps 20 times across the plate and cathode connections. In this diagram, the plate is kept positive by a battery as is the grid potential relative to the cathode.

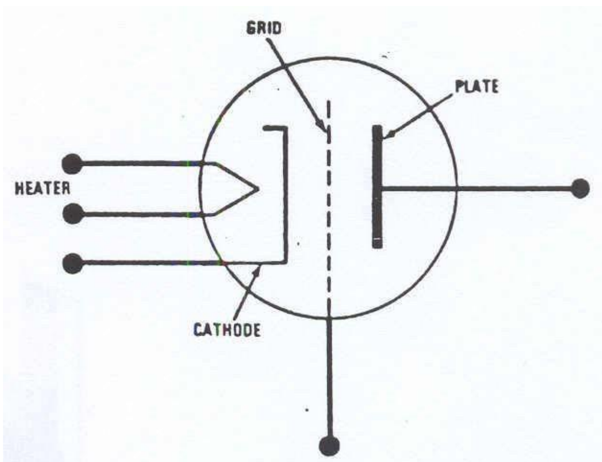


Figure 12-4: Triode tube circuit shows amplifying action - a one volt change on one side produces a 20 volt change on the other.

A positive grid increases electron flow between plate and cathode, a negative grid decreases flow. In many instances additional circuits are provided to produce the correct grid and plate bias (dissimilarity) without the aid of batteries (as in an ordinary AC radio).

Since the development of the triode, additional electrodes have been added between the plate and cathode to improve (and also vary) tube characteristics – there's the tetrode (4 electrodes) and the pentrode (5 electrodes) for example. Also, there are twin tubes which are two or more basic tubes placed in a common envelope. Finally, there are electron tubes that operate on a different principle than thermionic emission. Consider the photo tube that emits electrons when light strikes the surface of the cathode or the cold cathode tubes often used in AC spot welder circuits.

Solid State Concepts

In electricity, materials are commonly classified as insulators or conductors of electricity. A closer inspection shows, however, that this two-division classification is incomplete - there are materials that do not fit neatly into either grouping. The resistance of these materials is too high to be called a good conductor of electricity and at the same time it is too low to be called a good insulator. So a third category, termed *semi-conductors,* is needed. Materials under this heading include silicon - one of the most abundant elements on earth - termanium, selenium and cuprous oxide.

Now rectifiers made of cuprous oxide coated discs have been around for 30 years or more, and in the early days of radio, crystal detectors made of silicon were used to rectify an incoming radio signal. So solid state electronics are not really a brand new field. It's just that new developments in both products and the cost of products have now created new and much broader applications for solid state devices.

If carefully prepared crystals of germanium or silicon are mixed with certain kinds of other materials - called impurities or dopants (e.g. arsenic, boron, phosphorous, aluminum and antimony), the resulting materials may be made to have either an excess of electrons in their atomic structure or a deficiency. If the material has an excess, it is termed an *n* type (n for negative) material; if it has a deficiency, the material is called a *p* type (p for positive).
If pieces of *n* and *p* type materials are brought together as shown in Figure 12-5, *a junction type* diode is formed. With no voltage applied across the connections, the negative electrons and positive deficiencies (sometimes referred to as holes) are rather uniformly arranged in each material. Application of a voltage potential in one direction causes the electrons and holes to be drawn toward the junction, with the result that conduction of current across the junction is made fairly easy. If the polarity is reversed, the positive holes and negative electrons move away from the junction causing an extremely high resistance to current flow in that direction.

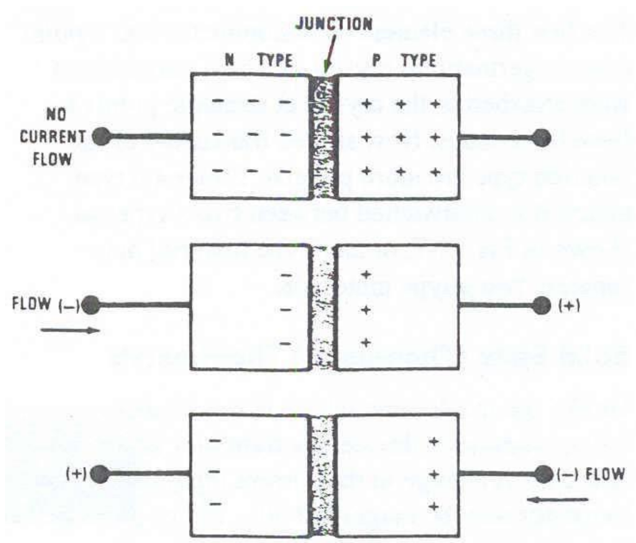


Figure 12-5: Solid state version of simple diode. Also see Figure 12-2. Current only flows easily in one direction - from left to right in the middle figure.

With these directional characteristics, a junction diode can replace the vacuum tube diode used in the AC-to-DC rectifier circuit of Figure 12-2. The junction type diode will only conduct current half the time, since during the reverse or negative half of the AC cycle its resistance will be too high to conduct. Figure 12-6 shows the circuit symbol used to represent a junction diode.

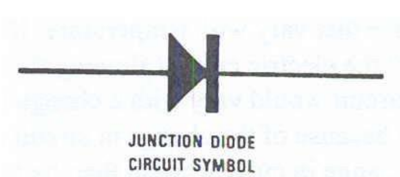


Figure 12-6: Circuit symbol used to represent a junction type diode.

As DeForest did, with the addition of a third electrode to the vacuum tube to form a triode, J. Bardeen and W. Brittain of the Bell Laboratory made a major breakthrough in solid state devices by adding a third element to semi-conductors to form what is called a transistor. At this point, semi-conductors now became capable of amplifying action too.

The first three element semi-conductor was a point *contact* germanium crystal in which cat whiskers were attached to the crystal at strategic points to form three leads. Now silicon transistors of the junction type are more popular. Either a *p* type material is sandwiched between two *n* types as shown in Figure 12-7, or an n type material may separate two p type materials.

Solid State (Thermistor) Thermostats

Unlike the triode tube which is technically a *voltage-operated* device, the transistor is *current* operated. A change in the current input to a typical transistor may be magnified 50 - 100 or more times. Connected to, say, a *thermistor,* such transistor characteristics can be very useful.

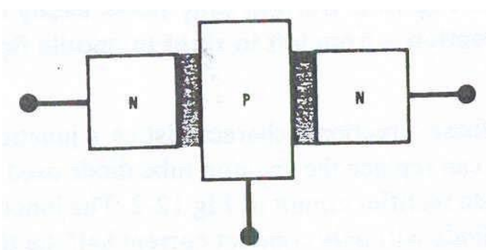


Figure 12-7: A "P" type transistor - a solid state device that's capable of amplifying action.

As we learned in Lesson 9, a thermistor is a semiconductor material with electrical resistance characteristics that vary with temperature. Used as a "thermostat," the electric current flowing through a thermistor circuit would vary with a change in room temperature because of the change in circuit resistance. This small change in current could then be amplified 100 times or more via a transistor circuit to do work --- such as close a relay, open a solenoid, etc. This control operation could be a proportioning or modulating action rather than simply on-off.

Figure 12-8 is a circuit diagram of a simple temperature control. The diagram serves the purpose of showing how transistors are utilized to amplify small changes in current from temperature change and regulate the heat from an electric heater.

(Note: Figure 12-9 shows the circuit symbol used to indicate an N type (N between two Ps) transistor. The names of the leads are identified and their approximate counterparts in a triode vacuum tube are shown as well. We see that the transistor's base connection is loosely comparable to the triode's grid, the collector compares to the plate and the emitter resembles the cathode. The symbol of a p type transistor is the same except that the arrow on the emitter lead is reversed.)

In Figure 12-8, thermistor T is the temperature sensor. Rl is a rheostat for manual adjustment of the desired temperature. Ql and Q2 are the transistors. R2, R3, and R4 are bias resistors. The bias resistors drop and divide voltage from the 28 volt DC power supply to provide the voltage required on the transistor terminals for proper operation. R5 is a current limiting resistor.

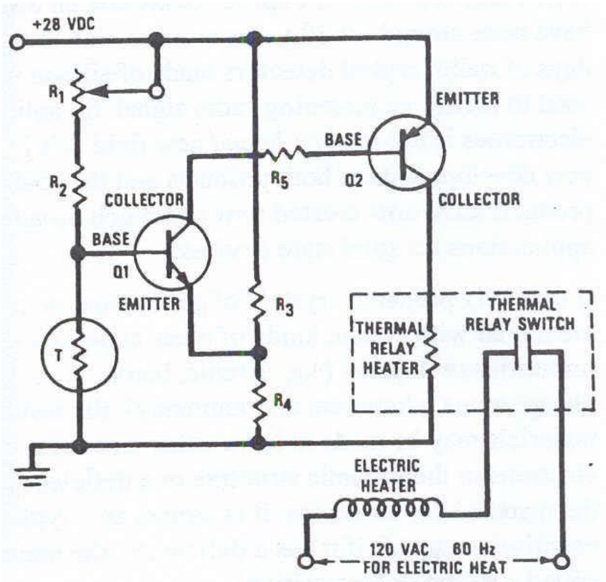


Figure 12-8: Thermistor sensor is teamed up with two amplifying transistors to become a solid state thermostat controlling electric heat.

Assume R1 has been adjusted to maintain a desired room temperature, and the air temperature decreases below that desired, and the thermistor senses this decrease. The thermistor is a negative type, so its resistance increases as the temperature decreases. This causes the 28 volts across Rl, R2 and the thermistor to be divided differently. The voltage at a point between the thermistor and R2 connected to the base terminal of transistor Ql increases. The voltage difference between the emitter and base terminals of transistor Q1 is now greater. The current through the emitter and the base of Q1 increases. The increase in base current causes a much larger increase in collector-emitter current of Ql.

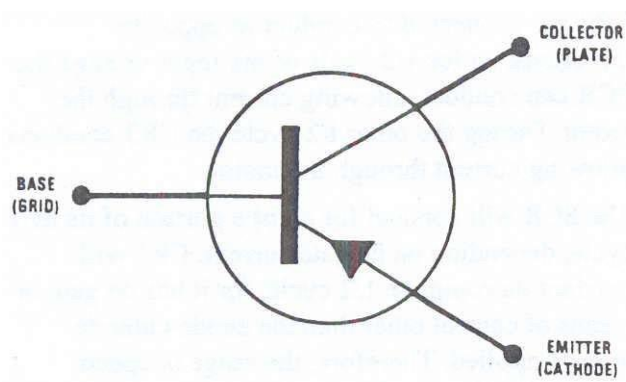


Figure 12-9: Circuit symbol used to identify a transistor.

The amplified current from the collector of Q1 passes through the base of transistor Q2. The increase in the base current of Q2 causes a much greater increase in the collector current of Q2. The collector current of Q2 goes through a thermal relay heater. The increase in temperature of the thermal relay heater causes the thermal relay switch to operate. The thermal relay switch energizes an electric heater and the air temperature rises. Now the thermistor heats up so the thermistor resistance decreases causing a decrease of current from the transistors, which reduces heat to the thermal relay, shutting off the electric heater. If the current change to the base of transistor Q1 had been 0.0001 amp as a result of the thermistor resistance change and the transistor Q1 had a gain of 100, then the collector current of Q1 would have increased 0.01 amp (100 x 0.0001). Then with an increase in base current of Q2 of 0.01 amp and another gain of 100, the current to the thermal relay would increase 1 amp (0.01 x 100).

SCR Motor Speed Control

Again, as in the case of the vacuum tube where adding more electrodes altered tube characteristics, making a stacked sandwich of n and p materials produces new characteristics for semi-conductors.

One of the most talked about devices is the SCR --- the Silicon Controlled Rectifier.

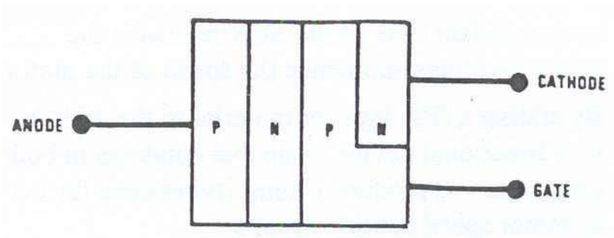


Figure 12-10: SCR (Silicon Controlled Rectifier) is essentially an electronic "switch" with no moving parts.

An SCR consists of four silicon elements, two Ns and two Ps alternately stacked (See Figure 12-10). The p side is of course logically designated the anode and the n side the cathode. A third lead called the gate is connected to the p material right next to the cathode (Figure 1211) shows its circuit symbol).

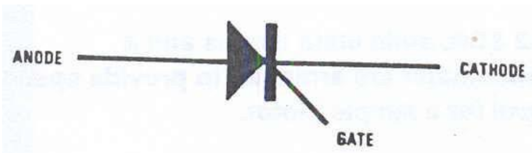


Figure 12-11: Circuit symbol used to identify a SCR in a control schematic.

First of all, an SCR acts like a simple N-P junction type diode. That is, it will conduct current essentially only in one direction (hence, the use of the word rectifier in its name).
More importantly, even with the polarity in the right direction (anode positive, cathode negative), an SCR will not conduct current until the device is triggered by a load impressed on the gate. Once triggered, however, the SCR will continue to conduct, irrespective of the gate current, until such time as the potential on the anode and cathode connections is removed or reversed. (The SCR has its approximate counterpart in the tube family --- a gas-filled tube called a thryatron is "fired" by controlling grid voltage.)

To summarize, the SCR can be considered an electronic switch - no moving parts but capable of turning current on and off.

With one or two SCRs and appropriate attending circuits, it is possible to control AC motor speeds. Such a technique is called modulation. The percent on or conduct time of the SCR regulates the motor windings and hence the speed of the motor.

By adding a fifth layer of material to the SCR, a two directional device - one that conducts in both directions - is produced, simplifying even further AC motor speed control circuits.

a

120

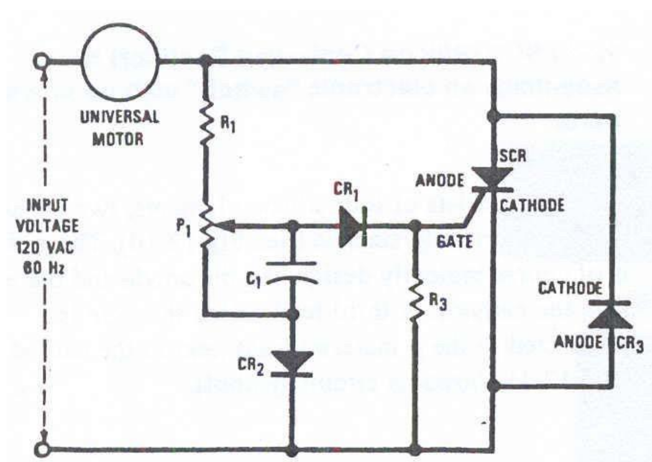


Figure 12-12: SCR, solid state diodes and potentiometer are arranged to provide speed control for a simple motor.

Figure 12-12 is a circuit diagram for speed control of a universal type motor. The input to the motor and control circuit is volts, 60 cycles, AC. The voltage input is alternating at the rate of 60 cycles per second. By “chopping off” part of the time power is supplied to the motor each cycle, the speed can be reduced and regulated. This process of changing the wave shape of voltage and current to the motor is termed phase modulation.

In slowing down the motor, the time voltage and current is applied to the motor each cycle, 1/60 of a second is reduced. There are periods of time during each 1/60 of a second there is no power to the motor. This suggests that the motor would alternately speed up and slow down every cycle. But as a result of the inertia of the motor and the load, and the frequency at which power on and power off occurs, there is no noticeable hunting or change of speed. The effect is a steady slower speed.

The universal motor is connected to the 120 volt, 60 cycle supply through the parallel combination of the SCR (Silicon Controlled Rectifier) and rectifier CR3. Ignore the rest of the control circuit for the moment, for it is of such high impedance, motor current through this part of the circuit is nil. The SCR and CR3 are connected to conduct in opposite directions, so for 1/2 cycle of the input voltage the SCR can conduct, allowing current through the motor. During the other 1/2 cycle, the CR3 conducts, allowing current through the motor.

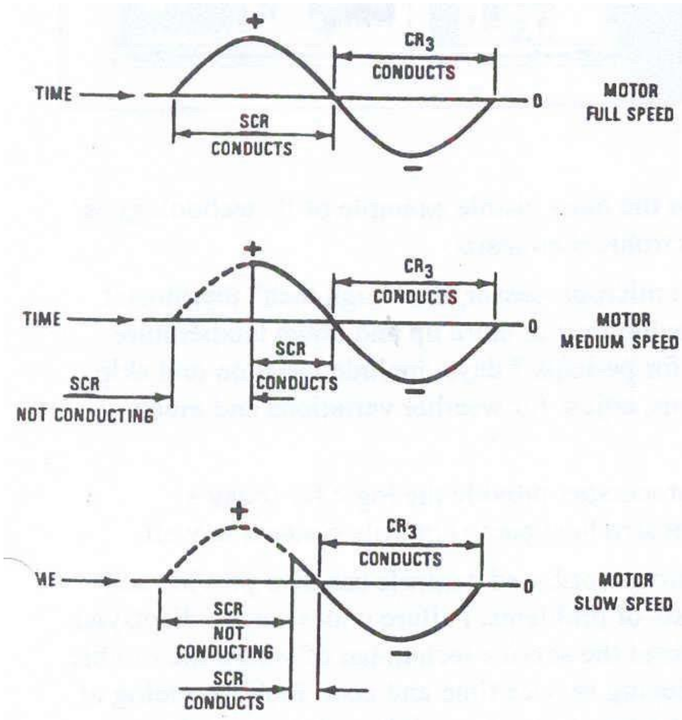
The SCR will conduct for all or a portion of its half cycle, depending on its gate current. CR3 will conduct its complete 1/2 cycle, for it has no gate or means of control other than the anodecathode voltage applied. Therefore, the range of speed control for this circuit is limited to about 50% which is the period of time the SCR can conduct each 1/2 cycle. The rectifier CR3 could be replaced by a second SCR and more complex circuit added so a wider range of speed could be attained by means of having control over the complete cycle.

Motor speed is regulated through the control circuit by manual or automatic adjustment of the arm of the potentiometer Pl. In studying this circuit, keep in mind that speed is changed by changing the gate current of the SCR.

The current through the gate of the SCR is dependent on the voltage on capacitor Cl. The rate the voltage increases in Cl to trigger the SCR, and allow the SCR to become low resistance and conduct, is controlled by the amount of resistance in series with the capacitor. The greater the resistance in series with the capacitor, the longer it requires to develop the voltage needed to cause the necessary gate current to lower the SCR anode-cathode resistance and let it conduct. By adjusting the arm on potentiometer P1, this change in resistance in series with capacitor Cl is accomplished.

Rectifier CR2 is connected to conduct when the SCR anode-cathode voltage is also forward. This is necessary so the capacitor Cl will charge during the 1/2 cycle forward voltage is applied to the SCR. During the other 1/2 cycle, while CR3 is low resistance and conducting, CR2 prevents changing Cl. Also, Cl can then quickly discharge through the portion of the resistance of P1 in parallel with C preparing for the next SCR 1/2 cycle.

Rectifier CR1 merely prevents current through the gate of the SCR in the direction which could cause damage. Resistor R3 is a bias resistor which maintains proper voltages on the gate.



If by adjusting the arm of potentiometer P1, the gate signal on SCR is just sufficient to trigger the SCR, allowing voltage and current to the motor for the complete 1/2 cycle, and the other 1/2 cycle CR3 is low resistance and conducting, the motor will run full speed. The wave shape of current through the SCR, CR3 and the motor are shown. See Figure 12-13.

Figure 12-13: Speed control is achieved by controlling the gate current to the SCR - hence its conducting time every 1/60 of a second. Current vs. time curves show how current is "switched" off for longer periods to obtain slower motor speeds.

The + and - signs designate current direction. The shape of the wave above and below zero shows how the magnitude of current varies with the time for one cycle. If the arm of P1 is moved in the opposite direction the speed decreases. See Figure 12-13.

Radio Interference Possible

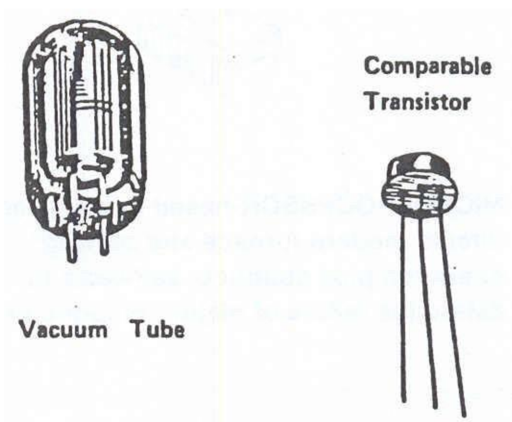
In the speed control circuit, the SCR is suddenly able to conduct by the gate signal. Depending on the anode-cathode voltage on the SCR when the SCR is made to conduct, the current instantly goes from zero to some "high" value. This sudden event causes an instantaneous peak of current far beyond the normal value. Due to the reactive components in the circuit, there is a sudden increase and decrease in current occurring very fast. This occurs at a high, or radio frequency. This radio frequency will be generated once every cycle (once every 1/60 of a second). This RF could be radiated into the atmosphere and it sometimes is necessary to provide RF suppression to prevent interference with communications. This is accomplished by including additional circuit components - capacitors, coils, etc. The universal type motor, instead of the shaded pole or permanent split capacitor (PSC) motor so popular in the air conditioning industry was used in the control example to avoid a more complex circuit and explanation. With conventional shaded pole and PSC motors, further circuit provisions are necessary to prevent motor overheating.

In Lesson 18, we'll see how the SCR and simple diode are teamed to provide a flame safeguard for oil fired equipment.

Advantages of Solid State Components

Besides matching vacuum tube components, semiconductors, or if you prefer, solid state components, actually offer greater versatility. Other advantages over vacuum tubes are: 1) solid state devices are smaller in size --- consider the pocket radio or IPOD; 2) solid state devices require no warm up time - an excellent feature for safety controls; 3) solid state devices consume less energy and “run” cooler; 4) solid state devices offer improved reliability and longer life; 5) solid state devices can take more physical abuse - vacuum tubes by comparison are made of relatively fragile materials, i.e. glass, fine wire, etc. On the other hand, solid state components cannot withstand significant surges in voltage and current - they “burn out” easily. Consequently, protective auxiliary circuits are often necessary. For some applications, solid state devices may be a more costly solution than a traditional electromechanical device.

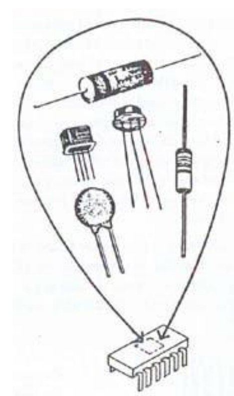
Solid state components are routinely found in residential controls today. Such devices are oil burner controls, blower controls, pilot ignition systems, electronic air cleaners and many more are fitted with solid state electronics.



But even the transistor has already been displaced as the glamour product of the electronics industry. What has taken its place? - microelectronics or integrated circuits (ICs).

It’s now possible to manufacture whole circuits - transistors, diodes, resistors, etc. – sometimes including thousands of components onto a tiny “chip” no more than one-quarter inch square. Part of this technique involves photographic and etching processes.

There are two basic groups of ICs - Analog (or linear) and Digital. Analog ICs include many kinds of amplifiers, timers, and voltage regulators.
Digital ICs include microprocessors, memory logic and microcomputers.



Perhaps the most visible example of IC technology is the electronic thermostat.

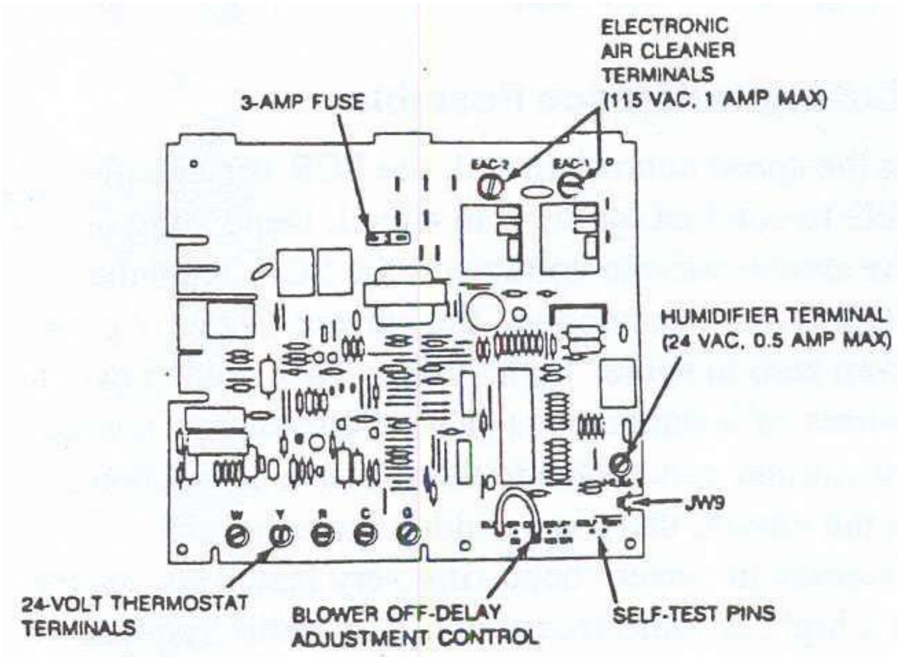
Using a microprocessor, this “high tech” thermostat can provide four or more up and down temperature cycles for perhaps 7 days, include vacation and skip functions, adjust for weather variations and much more.

Microprocessors provide the logic for today’s sophisticated heat pump controls systems as well as the newer versions of “communicating” thermostats.

Microprocessor based controls can also provide self diagnosis of problems. Failure codes (or LED display) can be displayed that inform the service technician of where the trouble is - reducing service time and cost. Field servicing of microprocessors is not possible and they are simply replaced when they malfunction.

In general, solid state devices help handle many control functions better than before and in many cases do jobs that simply could not be done before using electromechanical devices.

Microprocessor based control center directs modern furnace and blower operation plus conducts self-tests to determine failure of major components.



Self-Check, Lesson 12 Quiz

You should have read all the material in Lesson 12 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the answer key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F The "era" of solid state electronics began in 1948.
2. T F Heating a filament can "boil off" loosely- held electrons.
3. T F A simple diode tube has two poles - cathode and plate.
4. T F The plate is negative and the cathode is positive in a vacuum tube.
5. T F A rectifier is a diode that converts DC to AC current.
6. T F A grid is a third electrode that adds amplifying action to an electron tube.
7. T F An "N" type material has an excess of electrons and therefore is a negative material.
8. T F "P" type material is positive.
9. T F "P" and "N" type materials joined together form a triode.

In the following multiple choice questions, choose the phrase that <u>most</u> correctly completes the statement and circle the corresponding letter in front of the phrase.

10. A standard SCR consists of:

a. four germanium crystals.
b. one "N" and two "P" type materials.
c. two "N" and two "P" type silicon elements.
d. alternate layers of crystals.

11. The latest development in electronics is an IC or:

a. inspection current relay.
b. internal control device.
c. inside circuit.
d. integrated circuit.

12. The SCR varies AC motor speed by:

a. reducing voltages. b. switching current on and off rapidly.
c. converting to DC. d. changing phase between current and voltage.

13. One familiar pre-war example of a solid state device is:

a. a crystal (radio) set. b. a rheostat.
c. a transformer. d. a variac.

14. Current amplification for a typical transistor ranges from:

a. 2 to 3 times. b. 2 to 10 times.
c. 2 to 20 times. d. 50 to 100 times.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

15. The “Edison effect” is now termed ________________________________.

16. Materials that are neither good conductors of electricity nor act as good insulators are called _________________________.

17. Complete the list of the three external leads of a transistor and their triode tube counterparts:

Transistor	*Triode Tube*
a. _______________	compares to Grid.
b. Collector	compares to ________________
C. Emitter	compares to ________________

18. ___________________ is one of the most abundant materials on earth and is an excellent ______________________ material.

19. A triode is ______________ operated and a transistor is _____________ operated.

20. A thermistor has a/an ______________ electrical resistance and can be teamed with a/an _________________ to make sensitive room air.

21. SCR stands for ______________ ______________ _______________ and the device is used as an electronic ___________________ that can turn current on and off.

22. An SCR can be used to vary the speed of several types of ____________ motors, including shaded _____________ and permanent ___________ __________________ designs.

23. List five advantages of solid state devices and two chief disadvantages as compared to vacuum tubes:

Advantages	Disadvantages
a. ______________	a. ______________
b. ______________	b. ______________
c. ______________	
d. ______________	
e. ______________	

Check Your Answers!

Now compare your answers with those given in the answer key at the back of this book. The answer key also directs you to a page in the lesson to review the text for any questions you may have missed.

YOU ARE NOW READY TO TAKE YOUR ONLINE UNIT EXAMINATION, EXAM #2.

GOOD LUCK!

Self-Check Lesson 9

1. T
2. T
3. T
4. T
5. T
6. F
7. F
8. T
9. T
10. F
11. b
12. b
13. c
14. d
15.
16. sensing element/transducer
17. tube/channel/force/sensitivity
18. diaphragm/temperature
19. bourdon/pressure/temperature
20. vapor filled/liquid/vapor filled/liquid filled
21. bimetals/rod and tube/bellows and diaphragms/bourdon tubes/resistance element.
22. active/inactive

Self-Check Lesson 10

1. T
2. F
3. F
4. F
5. T
6. T
7. F
8. T
9. T
10. F
11. T
12. C
13. c
14. c
15. d
16. a
17. c
18. water
19. transformer/high limit/low limit/pump relay/terminal board
20. safe maximum
21. basic fan controller
22. temperature/pressure/flow variation
23. thermostat/pump
24. started/stopped/plenum air

Self-Check Lesson 11

1. T
2. F
3. T
4. T
5. T
6. T
7. F
8. F
9. F
10. T
11. d
12. a
13. a
14. c
15. conductivity/weld together
16. pull-in
17. residual
18. shading ring/phase
19. eddy/applied
20. electromagnetic/switching
21. 20
22. oxidation/film/resistance/overheating

Self-Check Lesson 12

1. T
2. T
3. T
4. F
5. F
6. T
7. T
8. T
9. F
10. c
11. d
12. b
13. a
14. d
15. thermionic emission
16. semi conductors
17. base/plate/cathode
18. silicon/semi conductor
19. voltage/current
20. variable/transistor/thermostat
21. silicon controlled rectifier/switch
22. AC/pole/split capacitor
23. Advantages:

a. small size
b. no warm up
c. less energy needed and runs cooler
d. longer life and reliability
e. takes more physical abuse

Disadvantages:

a. costs more
b. burns out easily

Appendix B: Glossary

AMBIENT TEMPERATURE: The Temperature surrounding or in the vicinity of a control.

ANTICIPATOR: Small resistance heater placed inside thermostat housing to help thermostat lead or "anticipate" room heating and cooling needs by artificially warming thermostat's sensing elements.

AUTOMATIC PILOT: Refers to the system that provides ignition and safety shutoff for gas burners using a tiny "pilot" flame.

BIMETAL: Sensing element made of two metals with different coefficients of expansion rigidly joined together to cause useful mechanical motion due to heating or cooling of the bimetal.

CdS CELL: Acronym for photo resistance cell made of Cadmium Sulfide. This solid state device changes its electrical resistance when exposed to light. Use: Oil burner safety shutdown.

CHANGEOVER RELAY: Control element is used in heat pump systems to activate refrigerant reversing valve for heating or cooling operation. Not to be confused with reversing relay.

COMBINATION FURNACE CONTROLS: A common controller that combines the functions of the fan switch and high limit safety control into one device.

COMPENSATED CONTROL: The set point of a controller is adjusted up or down as conditions elsewhere change (e.g., set point of room thermostat is raised as outdoor temperature decreases).

CONTACTOR: A magnetic relay of suitable high capacity that can switch large motorcompressor electrical loads.

CONTACTS: The switch side of a relay or contactor.

CONTROL AGENT: The medium regulated by a controlled device. It may be air or gas flow, steam or water, or even electric current.

CONTROLLED DEVICE: A device in a control system that responds to the signals sent by a controller to start and stop or otherwise vary the operation of conditioning equipment (e.g., a gas valve that starts or stops fuel input).

CONTROLLED VARIABLE: The variable condition, temperature, humidity, or pressure that must be held constant.

CONTROLLER: Principal device, say a thermostat, in a control system that measures some variable condition that must be held constant (e.g., room air), and then activates a second device to regulate a medium (e.g., fuel) that affects the variable condition.

CONTROL POINT: The pressure, temperature or humidity actually being maintained as distinguished from the controller's set point which may be higher or lower.

CSR: Acronym for capacitor start, capacitor run indication motor.

DIODE: An electronic device (vacuum tube or solid state) that conducts electricity in only one direction. One use is to convert ac to dc current.

DROOP: The difference between a controller's set point and the actual control point (e.g., room thermostat set at 75° F, but room air stays at 73° F). Also called drift, deviation or offset.

FACTORY WIRING: Control circuit diagrams presented in functional arrangement using symbols and other shorthand notation.

FAN SWITCH: A controller that features a switch and sensing element inserted in a furnace that turns blower on or off at present leaving air temperatures.

FIELD WIRING: Control circuit diagrams presented in a pictorial or "as installed" fashion.

FINAL CONTROL ELEMENT: Last component in control chain. That portion of the controlled device that regulates control agent—valve, damper, etc.

HIGH LIMIT CONTROL: A controller that features normally closed switch and sensing element inserted in a furnace (or boiler) that shuts down burner (or electric heater) regardless of room thermostat demand when circulating air (or water) exceeds present limits.

HUMIDISTAT: A controller designed to sense changes in moisture levels in air. Uses nylon or hair sensor to open and close low voltage switch.

IMPEDANCE RELAY: Prevents compressor startup after a high or low refrigerant pressure shutdown, until a manual reset is performed. Sometimes called a lockout relay.

INHERENT PROTECTOR: A temperature and current sensitive device placed in a hermetic compressor to provide motor overload protection.

LINE VOLTAGE: Full voltage available for use. Usually 110 or 220 volts.

LOW LIMIT CONTROL: A controller that features a switch and sensing element used in heating boilers that also provide domestic use by activating burner regardless of heating thermostat demand.

LOW VOLTATE: Voltage that is 30 volts or less. Usually provided by means of a step-down transformer.

MODULATING CONTROL: Differs from simple on-off or two position control action in that control agent can be regulated from fully on down to fully off in continuous or discreet steps.

MOTOR STARTER: A magnetic contactor that also contains a current overload relay to protect motor.

NEC: Acronym for National Electrical Code published by the National Fire Protection Association.

NEMA: Acronym for National Electrical Manufacturers Association.

OPERATING DIFFERENTIAL: The overall swing (high point minus low point) of a controlled variable that's necessary to activate a controller.

OPERATOR: One of two functional components in a controlled device. The operator converts signal from controller into a useful local action (e.g., motor that converts electric signal into rotating mechanical motion). See also final control element.

PHOTOCELL: A special vacuum tube that generates small electric current when exposed to light.

PILOT GENERATOR: Refers to pilot burner/thermocouple side of automatic gas pilot system, and is usually applied to systems using other than just a single couple.

PF: Acronym for power factor, the correction factor to be applied to the product of volts times amps in ac circuits to account for voltage and current phase differences.

POTENTIAL RELAY: Sometimes called starting or voltage relay. This device cuts out starting circuit in CSR motor driven compressors.

PRIMARY CONTROL: Used most often in reference to an oil burner controller whose functions include starting and stopping burner, ignition, and safety shutdown.

PSC: Acronym for permanent split capacitor motor.

RELAY: An electric switch that permits low voltage controllers to operate equipment powered by high voltages.

REVERSING RELAY: Permits SPDT thermostat to control heating and cooling equipment by forming an interlock that prevents mutual operation.

SAFETY DEVICE: A control that is added to detect a dangerous condition and stop an action or take a new action to remedy problem.

SCR: Acronym for Silicon Controlled Rectifier. It is, in effect, a solid state or electronic switch with no moving parts that can turn current on and off.

SENSING ELEMENT: One of two recognizable components in a controller. Sensing element measures any change in the controlled variable. See also transducer.

SET POINT: The value of the controlled variable (e.g., room air) at which the controller (e.g., thermostat) is set and represents the desired or idealized value to be maintained.

SOLENOID: An electric device for converting electric energy into a mechanical displacement. Usually consists of a magnetic coil and plunger that can move short back and forth distances as the coil is energized or de-energized.

SOLID STATE DEVICE: A group of electronic components that perform jobs similar to vacuum tubes, but unlike tubes they are not electrodes enclosed in glass but rather specifically prepared solid matter.

SWITCHING ACTION: The term pole and throw in combination with the terms single and double are used to describe the action or electric switches. A single-pole switch has functionally one movable “blade” contact. A double=pole switch has two. A single-throw switch can connect to only one circuit or one fixed contact. A double-throw switch can connect a common lead to either of two circuits or two different fixed contacts. These features are usually abbreviated SPST—single-pole, single-throw; SPDT—single-pole, double-throw, etc.

THERMAL DELAY RELAY: Prevents short cycling of compressor by delaying thermostat’s call for cooling for several seconds.

THERMISTOR: A solid state sensing device whose electrical resistance varies dramatically with changes in temperature.

THERMOCOUPLE: A means to directly convert heat into small amounts of useful electric current. One end of two dissimilar wires connected together is heated, producing a small voltage across the other ends.

THERMOSTAT: Once a trade name, it has become a standard term for a temperature controller, but particularly in reference to a room air temperature sensing device.

TIMER MOTOR: Electric motor drives a cam that actuates defrost switch at specific time intervals to begin defrosting of outdoor coil when heat pump is on heating cycle.

TRADE NAMES: Because of pioneering development, or merely common usage, some control devices are referred to by their manufacturer's marketing names. The new control technician should not let this become confusing.

TRANSDUCER: Current amplifying solid state device that's equivalent to a triode vacuum tube.

TRANSFORMER: An electrical device that efficiently converts high voltage power to low voltage power (or vice versa).

TWO POSITION CONTROL: A mode of control action that can only turn equipment fully on or fully off.

Wiring Symbols and Abbreviations

Schematic or factory type wiring diagrams are used most often to illustrate electrical component functions. It is essential that the student become thoroughly familiar with the standard symbols and circuit abbreviations used in the heating and air conditioning industry.

Line Voltage Terminals	**Function**
L1, L2, L3	Incoming power connections
T1, T2, T3	Switched power load connections
(4) (5) (6)	Auxiliary switched load connections

Load Designations	**Component**
CC	Contactor Coil
CC1, CC2, CC3	Contactor Contacts
FR	Fan Relay Coil
FR1, FR2, FR3	Fan Relay Contacts
SR	Solenoid Relay or Reversing Valve
SR1, SR2	Solenoid Relay Contacts
TD	Time Delay Device
TD1, TD2	Time Delay Contacts

Low Voltage Terminal Designations

Two distinct systems of low voltage terminal designations have been used in the heating and air conditioning industry. One was based on the function of the specific load to which the terminal was connected—“F” for fan circuit, “C” for cooling circuit, etc. The other system was based on a color code. In this system, “G” was used for the fan circuit, “Y” for the cooling circuit, “W” for the heating circuit, and “R” for the power supply. Using color-coded cable—green for the fan circuit, yellow for the cooling circuit, etc.—simplified system hookup and troubleshooting.

The existence of both systems caused some confusion; and for a period of time, a combination terminal marking system was used. In the combination system, terminal designations for a fan circuit were marked “F/G” and terminals for a cooling circuit were marked “C/Y.” At the present time, only the color code method is used for low voltage terminal designations.

Low Voltage Code

Color **Function**

R V Hot switched leg of 24 volt ac power used on heating only thermostats and heat/cool thermostats with a common power supply
W H Heating—single stage
Y C Cooling—single stage
G F Fan circuit
B Z Heating circuit—constant energization through a manual switch
O D Cooling circuit—constant energization through a manual switch
RH M Isolated power terminal for heating circuit used on heat/cool thermostats with isolated circuits—jumper supplied
RC V Isolated power terminal for a cooling circuit used on heat/cool thermostats with isolated circuits—jumper supplied
W1 H1 Heating—first stage of two-stage units
W2 H2 Heating—second stage of two-stage units
Y1 C1 Cooling—first stage of two-stage units
Y2 C2 Cooling—Second stage of two-stage units
X L Warning light (dirty filter, electric heat, etc.)