How Control Loops Operate

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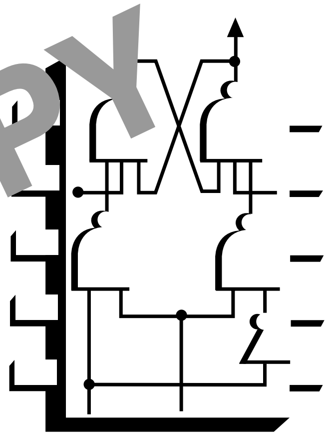
HOW CONTROL LOOPS OPERATE

Lesson One

Fundamentals of Control Loops



TPC Training Systems

28201

Lesson

1 Fundamentals of Control Loops

TOPICS

Control Loops
Control Loop Definitions
Process Sensors
Sensor Characteristics
Controllers
Recorders
Signal Conditioners
Final Control Elements
Control Loop Applications

OBJECTIVES

After studying this Lesson, you should be able to…

- Explain the difference between an open loop and a closed loop.
- Define error, feedback, disturbance, and feedforward control.
- List several kinds of process sensors and describe the operation of each.
- Explain how accuracy, resolution, sensitivity, linearity, and step response affect sensor operation.
- Describe the functions of process controllers, recorders, signal conditioners, and final control elements.
- Explain the basic operation of a typical control loop.

KEY TECHNICAL TERMS

Control loop 1.01 a group of components working together to control a process
Open loop 1.02 a control loop without feedback
Closed loop 1.04 a control loop with feedback
Sensor 1.14 a device used to convert a physical variable to an equivalent signal, usually electrical
Signal conditioner 1.37 a device that prepares signals for use by the controller

Previous Units concentrated on individual components in the control loop, and the last Unit focused on controller operation in particular. In this Unit, you will read about how all components together make a unified control system. In describing the control loop, this Lesson discusses a variety of instruments that measure flow rate, displacement, and temperature, as well as other instruments used to convert the controller output into actions that affect the process.

Control Loops

1.01 In general terms, a *control loop* is a group of components working together as a system to achieve and maintain the desired value of a system variable by manipulating the value of another variable in the control loop. Each control loop has at least one input and an output. There are two kinds of control loops—open and closed.

1.02 Figure 1-1 shows a block diagram of an *open-loop* system. It includes a controller and a controlled device, but no means for reporting the value of the process output back to the controller. The controlled device acts directly on the process input.

1.03 Figure 1-2 on the following page shows a simple open loop using a valve that regulates the flow of water. You (the controller) open the valve (the controlled device) to a certain fixed setting so that the water flows at the desired rate (the process). However, if the water pressure on the inlet side of the valve decreases, the flow rate decreases. Because no means is provided to monitor and correct the flow rate, it is no longer at the setpoint value, and an error now exists in the system.

1.04 Unlike an open-loop system, a *closed-loop* control system provides *feedback*—that is, a means for measuring and correcting the value of the process output (the process variable). The main advantage of closed-loop control is its ability to maintain more accurate control of a process, which justifies its use despite its greater cost.

1.05 In a *manually* controlled closed loop, a human operator provides the means for periodically monitoring the process variable and making any change needed at the controlled device to eliminate system error. For example, suppose that after opening the valve in Fig. 1-2, you notice a decrease in flow rate and open the valve farther. By adjusting the valve setting to compensate for changes in inlet pressure, you close the loop, thus maintaining the flow rate at the setpoint value.

1.06 Manual control is practical for adjusting the water temperature when you take your morning shower. However, for industrial situations where accurate and quick response is necessary to keep the system within tolerance, *automatic* closed-loop control is required.

1.07 Figure 1-3 on the following page is a block diagram of an automatic closed-loop system. A device

Fig. 1-1. Open-loop control

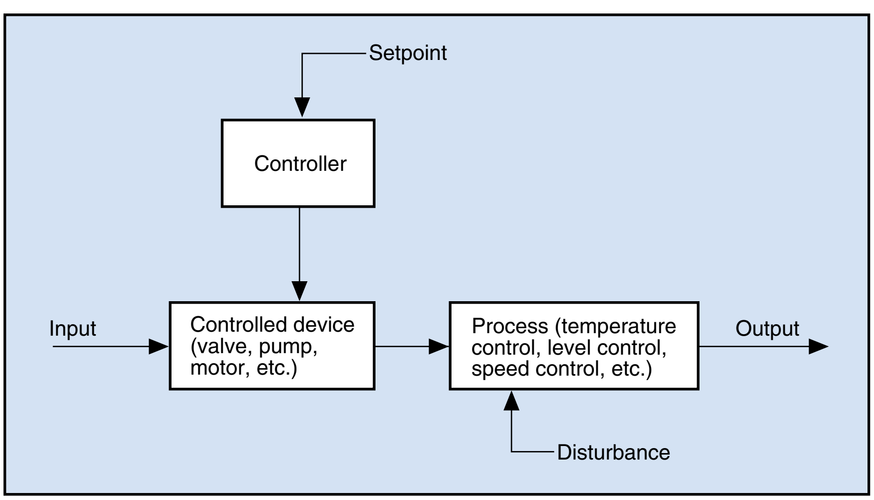
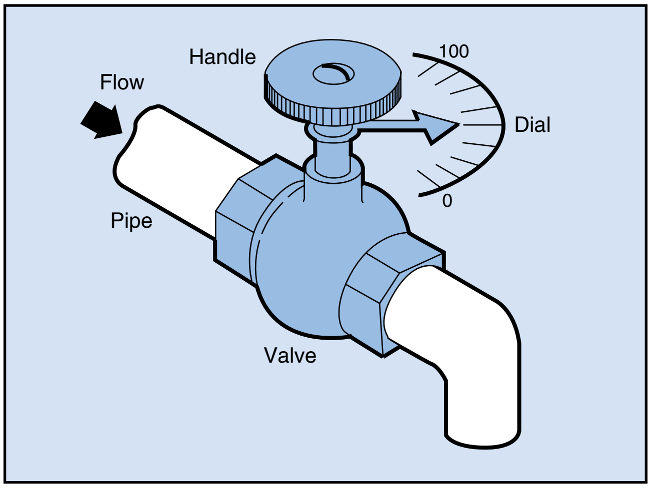


Fig. 1-2. Open loop—water valve



measures the actual value of the process variable and sends that information to the automatic controller. The controller continuously compares the value of the process variable against the setpoint value. If a difference exists, the controller manipulates the input (the manipulated variable) by means of the controlled device. This action restores the output to the setpoint value.

Control Loop Definitions

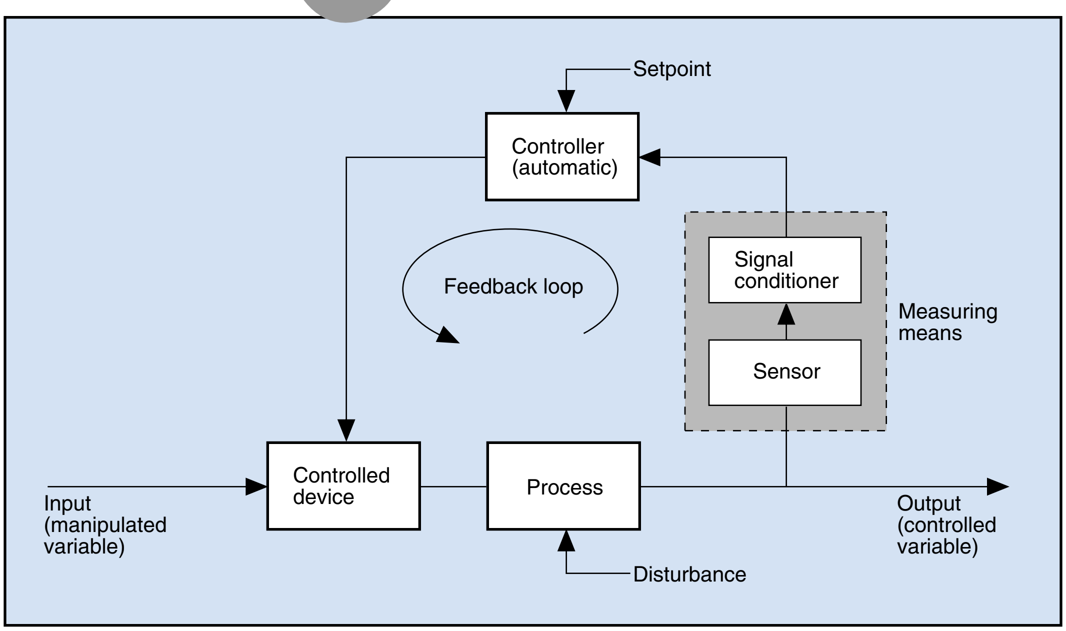
1.08 The following paragraphs define terms used often in process control. If you have studied previous Lessons in this Course, they will be familiar to you. The definitions serve as a review and background for later new terms and concepts.

1.09 **Error.** In process control, error is defined as the difference between the setpoint value (SP) and the measured value of the process variable (PV). The system usually allows for some small variation between SP and PV before correction is initiated.

1.10 **Feedback.** A difference between the SP value and the measured PV value results in a system correction that reduces system error to an acceptable value. The correction is made possible by feeding the PV signal back to the controller. A feedback arrangement that results in a reduction of system error is referred to as *negative feedback*.

1.11 **Disturbance.** A disturbance, as indicated in Figs. 1-1 and 1-3, is a change in a variable that affects the PV, but is not manipulated by the control loop. For example, a decrease in outside temperature is a disturbance that causes your home heating system to burn more fuel in order to maintain the SP temperature. Drawing hot water turns on your hot water heater in order to maintain the SP temperature of the hot water. Closed-loop control is necessary to correct for these process disturbances.

Fig. 1-3. Automatic closed-loop control



1.12 **Feedforward control.** Obviously, before the controller in the feedback loop can correct for system error, an error first must be present. Some processes are so slow in acting that when disturbances act on them and produce an error, a significant time may elapse before the error becomes great enough for the controller to begin corrective action. Furthermore, because of the slow response, there is additional delay before the error is corrected. This problem can be remedied by using feedforward control.

1.13 In feedforward control, the system attempts to identify possible process disturbances so that they can be monitored. These signals are fed to a separate feedforward controller, as diagrammed in Fig. 1-4, so that the input variable can be manipulated, cancelling out the disturbance before it affects the output.

1.14 A *sensor* is a device used to provide a signal that is a measure of the value of the controlled process variable. The sensor responds to the variable in such a way that one of its physical properties is affected in a predictable manner. Note that the term *transducer* often is used interchangeably with the term *sensor*, and sometimes the sensor is considered simply the measuring part of the transducer.

1.15 Either directly or indirectly, a sensor converts the controlled variable—for example, temperature, pressure, or flow rate—into an equivalent signal (usually electrical) proportional to the value of the variable. This signal then is used by the controller for comparison against the SP value. For example, a resistance temperature detector (RTD) can provide an output voltage signal that is a measure of temperature, if it is one arm of a Wheatstone bridge. The RTD is called a resistive temperature sensor—that is, its resistance changes proportionately with changes in temperature.

1.16 Sensors are divided into two categories:

- passive
- active.

The RTD is a *passive* sensor, because it does not directly generate the electrical temperature signal. Its resistance changes with temperature, and when the RTD is placed in a bridge circuit, the resistance change is translated into an electrical signal. On the other hand, the thermocouple (another temperature-sensing device) is an *active* sensor. This means that a thermocouple directly generates a very small DC voltage proportional to temperature.

1.17 Many kinds of sensors are part of process control systems. The paragraphs that follow discuss three kinds:

Fig. 1-4. Feedforward control

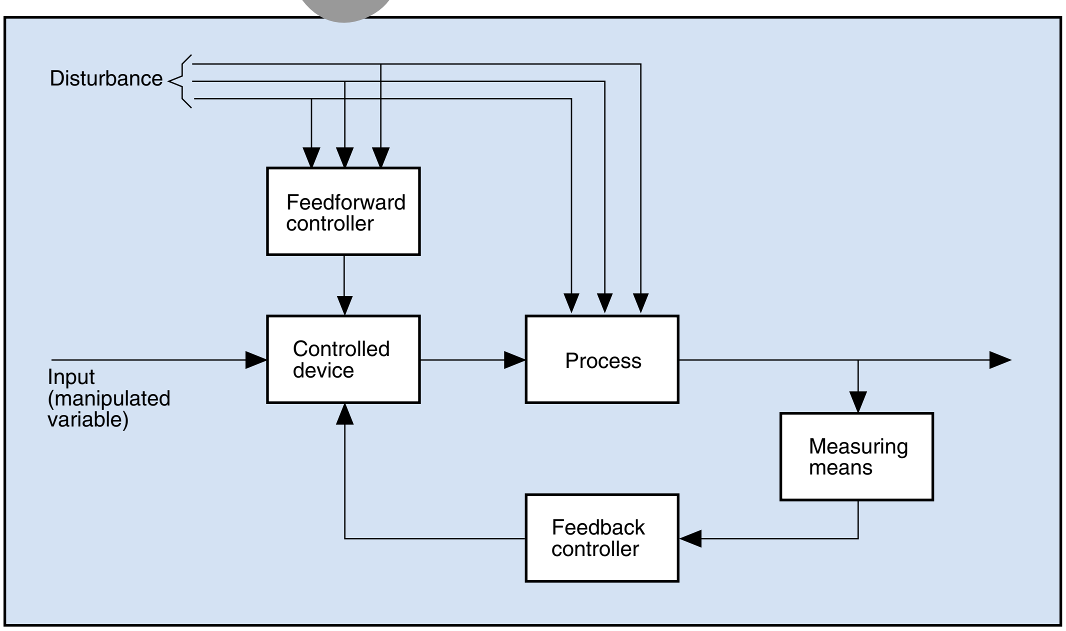


Fig. 1-5. Paddlewheel flowmeter

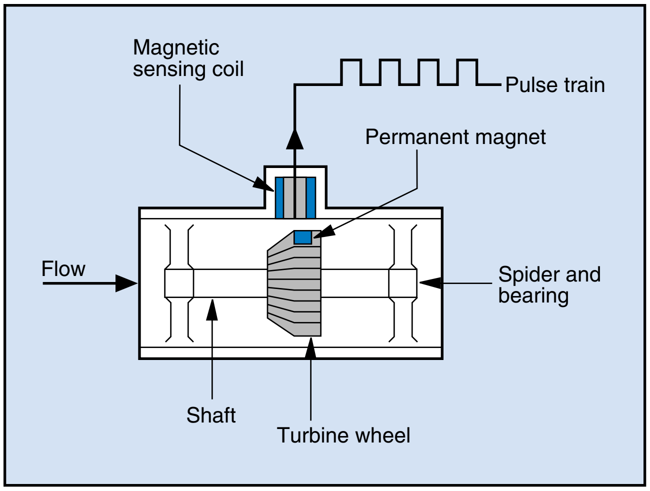
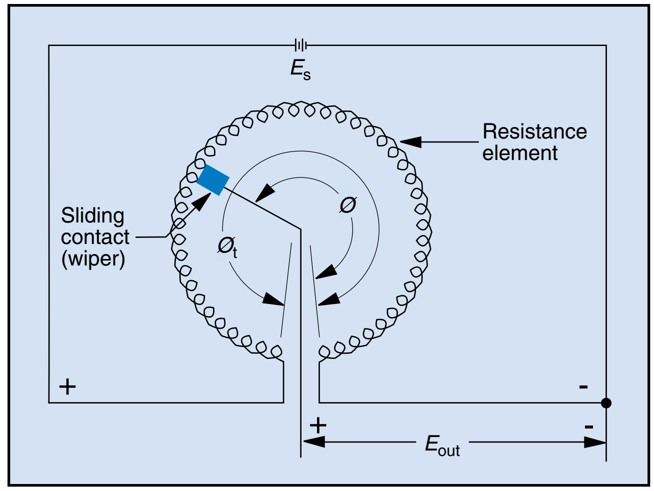


Fig. 1-6. Displacement potentiometer



- flow rate sensor
- displacement sensor
- temperature sensor.

1.18 **Paddlewheel flowmeter.** The paddlewheel or turbine wheel, shown in Fig. 1-5, is one of a very wide variety of flow rate sensors. The paddlewheel velocity is proportional to flow rate. As the permanent magnet passes the pickup coil, it generates a train of voltage pulses at the coil output. Therefore, the pulse frequency (pulses per second) is a measure of flow rate. The pulse frequency signal can be further processed by a frequency-to-voltage converter circuit. Then the converter output is a DC voltage proportional to flow rate, and this signal can represent flow rate for use by an analog controller.

1.19 Because the pulse train is basically a digital signal, it could be sent directly to a digital controller. By means of a frequency counter, a digital controller is able to convert the pulse frequency to a binary coded flow rate signal.

1.20 **Displacement sensor.** Figure 1-6 shows a displacement potentiometer. A *potentiometer* consists of a circular resistance element with a sliding contact, called a *wiper*, that can be rotated from one end of the element to the other. A potentiometer can be used to measure two kinds of displacement:

- linear displacement—for example, the change in the liquid level in a tank
- angular displacement—for example, the angle of rotation of an instrument shaft coupled to the potentiometer shaft by gearing.

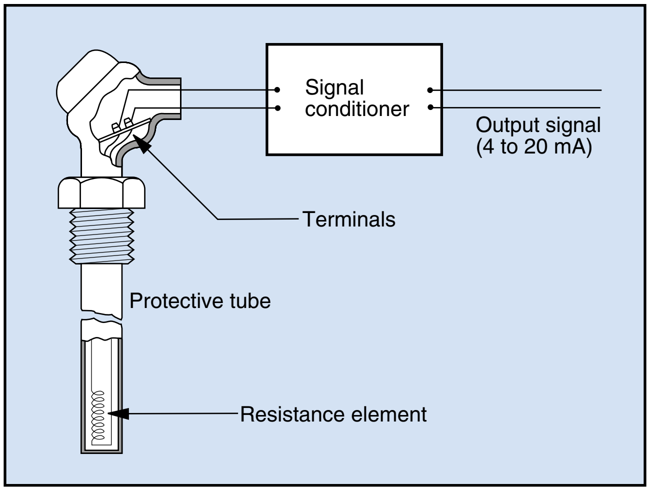
1.21 If a voltage (E_s in Fig. 1-6) is applied across the entire resistance element, there is a uniform decrease in the voltage across each turn of wire in the resistance element. As the potentiometer shaft is rotated, the sliding contact (wiper) moves along the resistance element. The voltage (E_{out}) measured across the sliding contact and one end of the resistance element varies as the sliding contact moves along the resistance element. As a result, E_{out} is an analog voltage signal that is proportional to the angle of rotation of the sliding contact (Ø in Fig. 1-6) through the maximum angle of rotation ($Ø_t$) of the potentiometer.

1.22 **Temperature sensors.** Platinum wire most often is used as the resistance element in RTDs for three reasons.

- Its resistance is highly stable over time.
- It is very sensitive to temperature changes.
- It has a linear resistance-versus-temperature response curve.

The operating range of the platinum RTD is -240°C to +650°C. To translate resistance change to a temperature measurement, the RTD is made the arm of a bridge circuit or is incorporated into a resistance-to-temperature converter.

Fig. 1-7. RTD sensor with signal conditioner



1.23 Figure 1-7 shows an RTD sensor mounted in a protective tube that enables the sensor to measure the temperature of a liquid in a tank. The signal con-ditioner contains a resistance-to-current converter circuit. The output in this circuit is a current signal proportional to the measured temperature.

1.24 The thermocouple (TC) operates on the principle that when wires of dissimilar metals are joined together to form a junction, that junction generates a very small voltage proportional to temperature. In order to respond to different ranges and applications, thermocouples with different combinations of metals are available.

1.25 Thermocouple measurements are made by comparing the temperatures of two junctions. One junction—called the reference or "cold" junction—must be maintained at a certain temperature. The second junction—the measurement or "hot" junction—is in contact with the measured medium. The potential difference between these two junctions, which are placed in series, is the voltage corresponding to the temperature. Most modern thermocouple transmitters or controllers have this reference junction built in and therefore do not require an external reference thermocouple. The TC is small in size, rugged, and operates over a wide range of temperatures. For example, the Type J thermocouple is useful from 0 to 760°C.

The Programmed Exercises on the next page will tell you how well you understand the material you have just read. Before starting the exercises, remove the Reveal Key from the back of the book. Read the instructions printed on the Reveal Key. Follow these instructions as you work through the Programmed Exercises.

1-1. Unlike the open loop, the closed loop includes ________.	1-1. FEEDBACK Ref: 1.04
1-2. The difference between the values of SP and PV is known as the system ________.	1-2. ERROR Ref: 1.09
1-3. Closed-loop control is necessary to correct for system ________.	1-3. DISTURBANCES Ref: 1.11
1-4. In ________ control, the system attempts to cancel out disturbances before they affect the output.	1-4. FEEDFORWARD Ref: 1.13
1-5. Instruments designed to measure the value of the controlled variable are called process ________.	1-5. SENSORS Ref: 1.14
1-6. The RTD is a(n) ________ sensor, but the thermocouple is a(n) ________ sensor.	1-6. PASSIVE; ACTIVE Ref: 1.16
1-7. A frequency counter enables a digital controller to convert a pulse frequency to a(n) ________ signal.	1-7. BINARY Ref: 1.19
1-8. A potentiometer can measure linear or angular ________.	1-8. DISPLACEMENT Ref: 1.20

Sensor Characteristics

1.26 Several sensor characteristics are important in determining how effective a device is for a particular application. These characteristics include:

- accuracy
- resolution
- sensitivity
- linearity
- step response.

1.27 **Accuracy.** Accuracy, which is expressed as a percentage, answers the question, "How close is the measured value to the true value?" In equation form:

$$\text{accuracy} = \left(1 - \left|\frac{\text{measured value} - \text{true value}}{\text{true value}}\right|\right) \times 100\%$$

Note that only the magnitude of the error, not the direction (+ or -), is used in the equation. Note also that this equation becomes meaningless for measured values beyond ±50% of the true value, because any component that inaccurate would be worthless.

1.28 **Resolution.** Resolution is the smallest change in the measured variable that results in a detectable change at the sensor output. Because some sensor output signals do not respond to very small changes in the input variable, they are unsuitable for certain applications. To increase the resolution of the potentiometer displacement transducer, for example, you can use an instrument with more turns of wire in the resistance element.

1.29 **Sensitivity.** Sensitivity is the ratio of change in output for a unit change in the sensor input. For example, thermocouple sensitivity is measured in volts output per degree Celsius.

1.30 **Linearity.** The ideal curve of sensor output versus sensor input is a straight line, which represents total linearity. The input-versus-output curve of any sensor is a measure of the sensor's degree of linearity.

1.31 **Step response.** The characteristics described above are *static* characteristics. That is, they are not dependent on time. The *dynamic* response of a transducer describes its performance when the transducer input undergoes a sudden (step) change. No transducer can respond immediately to a step input change. Instead, the transducer takes some measurable time, depending on its mass, its shape, and the material of which it is made.

1.32 A measure of a transducer's step response is its *time constant*. For example, assume that a certain transducer is used to make a temperature measurement, and that the temperature suddenly increases by 10°C. If it takes 10 seconds for the transducer to show a 6.3°C increase (63% of 10°), the transducer is said to have a 10-second time constant. Smaller time constants indicate better dynamic response.

Controllers

1.33 The controller acts to eliminate error, which is the difference between the value of SP and the value of PV. Any disturbance to the process or change in the selected SP value results in a change in the controller output. The controller output then acts on the controlled device—for example, a valve, pump, or motor. The final control element then manipulates the input to keep the PV tracking the SP.

1.34 An important characteristic of the controller is the way in which it uses the error to provide control action. A number of methods, called control *modes*, may be selected to control a particular process. These modes are discussed in detail in Lesson Two.

1.35 Electronic controllers use electronic circuits to generate the desired control action. Electronic controllers are available in either analog or digital design. Analog controllers use analog circuits (operational amplifiers, or op amps), but a digital controller uses a microprocessor and a control program (software) to implement control.

Recorders

1.36 A recorder is an important component in the overall control system. Figure 1-8 on the following page shows one of many kinds of recorders. A chart trace provides a history (log) of process variables over an extended period of time. The recorder is useful—indeed, often essential—for the purposes of system testing, calibration, and maintenance.

Application 1-1

A manufacturing plant uses a gas-fired furnace to heat-treat its metal products in order to obtain the hardness and strengths required by its customers. The products are placed in containers and moved by conveyor through each of four different temperature zones within the furnace. This movement through the furnace, in accordance with a specific time sequence, results in the desired product properties.

A controller supervising the furnace operation is programmed with the desired zone temperatures and cycle times. The temperature of each furnace zone is monitored by thermocouples connected to the furnace controller. The controller modulates the valves supplying gas to the burners in each zone to maintain the zones at the proper temperatures. The controller also oversees the movement of the furnace conveyor. The controller monitors the time each container has been in the appropriate zone, as well as the temperature of the zone, and moves the containers in accordance with the predetermined schedule.

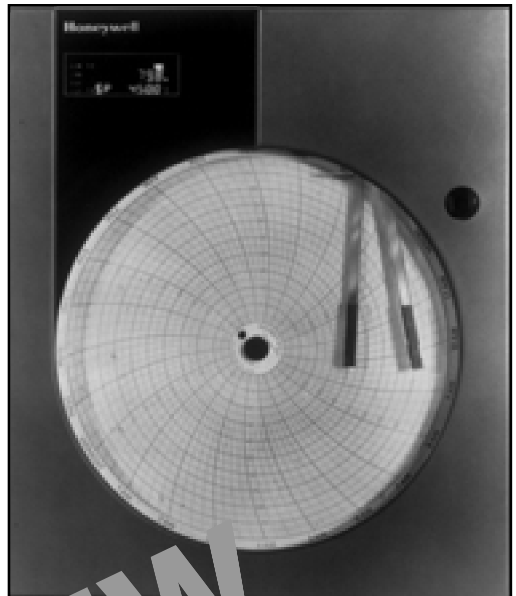
In the event of a system malfunction or the failure of a zone to maintain proper temperature, the controller adjusts the process to prevent damage to the material and activates an alarm to notify operators of the fault. Zone temperatures and cycle times are recorded on strip-chart recorders. The results are available to both operating personnel and customers for the purpose of verifying that the heat-treating process is being adhered to properly.

Signal Conditioners

1.37 The output signal of the sensor measuring the controlled variable does not go directly into the controller. The signal first is *conditioned* to prepare it for the controller. One example of signal conditioning is the earlier example of the RTD sensor incorporated into a Wheatstone bridge to produce a temperature signal. Other forms of signal conditioning are:

- filtering to eliminate excessive electrical noise
- amplifying a sensor output signal that is too small to operate the controller properly.

Fig. 1-8. Recorder



In some cases, the controller itself may incorporate one or more signal-conditioning functions.

1.38 Some signal conditioners require the input signal to be in the form of a current rather than a voltage. In these cases, a sensor voltage signal is converted to a current in a circuit specifically designed for this purpose. For example, suppose a signal of 1 to 5 V represents a certain temperature range. This voltage signal can be converted to a 4- to 20-mA current signal to represent the same temperature range. Signal conditioners that translate sensor output signals to

Fig. 1-9. Transmitter

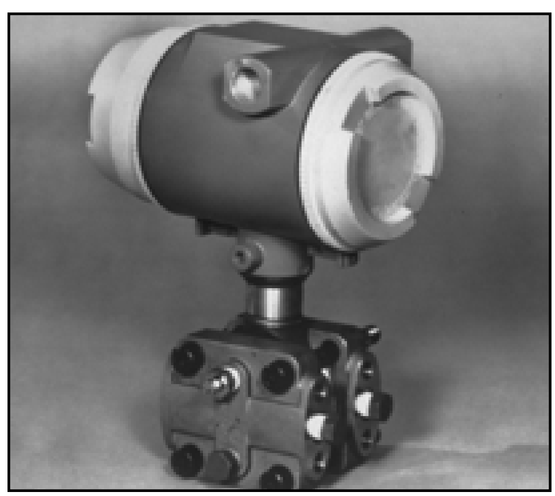
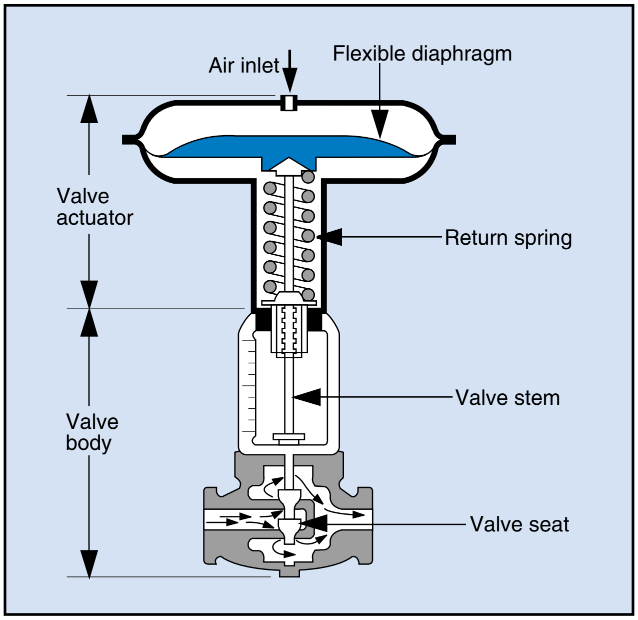


Fig. 1-10. Pneumatic control valve

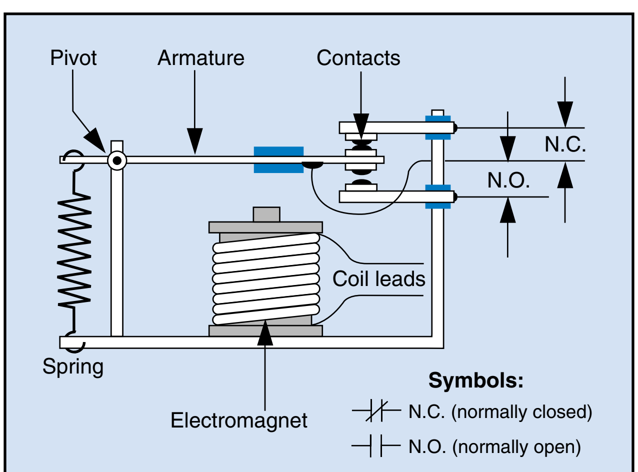


equivalent current signals are called *transmitters* (or *transducers*), although "transmitter" also is used to refer to any device that sends the signal to the controller. Figure 1-9 shows a transmitter.

Final Control Elements

1.39 The controlled devices are referred to as *final control elements*, sometimes called *FCEs*. These are the components that actually manipulate the input variable. Examples of final control elements include motors, pumps, valves, and relays.

Fig. 1-11. Electromechanical relay



1.40 **Valves.** A control valve regulates the supply of material delivered to the process by adjusting an opening through which the material flows. The opening is a variable orifice in the input line. Flow rate through a valve is proportional to the area of the valve opening and to the square root of the pressure drop across the valve. An important valve characteristic is the curve of actual flow rate (referenced to the maximum flow) versus percentage valve travel (position). This characteristic depends on the design of the valve. Many designs are available, providing a choice of valve characteristics.

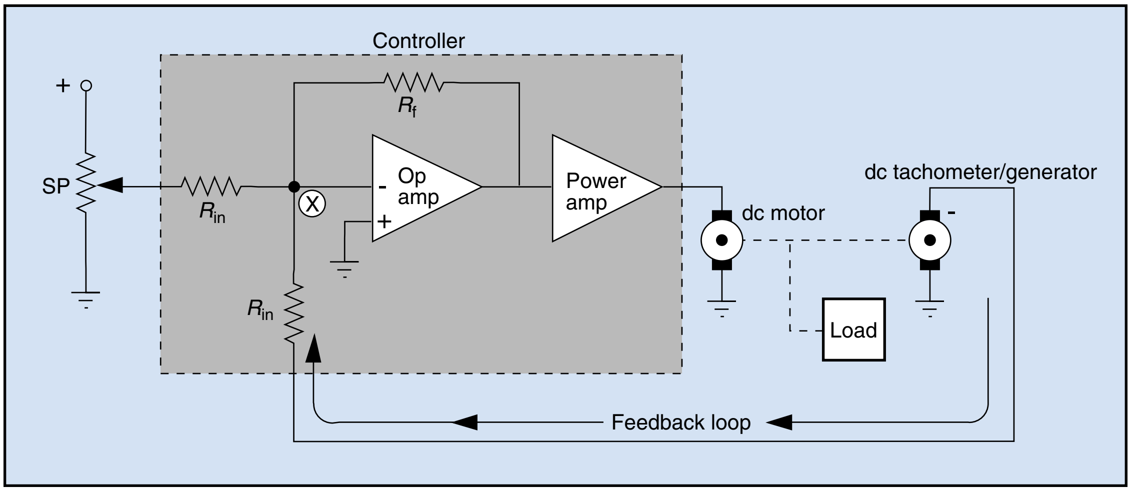
1.41 The following are three of the many considerations that must be taken into account in the selection of control valves:

- the environmental effects of process flow material—for example, corrosion, abrasion, and abnormal temperature or pressure
- the valve characteristic of percentage travel versus flow rate—it must be appropriate for the particular process
- the size of the valve—in general, the smallest valve that can pass the desired maximum flow will provide the greatest control and economy.

1.42 The diaphragm-style pneumatic control valve shown in Fig. 1-10 includes a valve actuator. An *actuator* is a device that translates the controller output signal into action at the final control element. In the diaphragm valve, the actuator consists of a flexible diaphragm acting against a spring. Increasing air pressure drives the diaphragm down and reduces the valve opening. This kind of actuator requires a high-pressure air supply.

1.43 **Relays.** An electromechanical relay, shown in Fig. 1-11, is a device that includes one or more sets of electrical contacts whose state (open or closed) is controlled by an electromagnet (relay coil). The relay contacts are identified as being either normally open (N.O.) or normally closed (N.C.). The contacts will change state from the normal condition when the relay is energized by having a rated current applied through the relay coil. The closed contacts can pass a load current of far greater amplitude than the rated coil current.

Fig. 1-12. Motor speed control loop



Control Loop Applications

1.44 The remainder of this Lesson discusses three representative control loops. These loops control the following variables:

- motor speed
- level
- temperature.

1.45 **Motor speed control system.** Figure 1-12 shows a simple closed-loop motor speed control system. This circuit is practical only for small DC motors. The tachometer/generator is a small DC generator, which acts as a transducer converting shaft speed (input) to a proportional DC output voltage. The output signal is typically one or two volts per thousand rpm. The motor shaft is coupled to the tachometer/generator shaft through gearing.

1.46 If the tachometer has a sensitivity of 1 V per 1000 rpm, the operator selects an SP voltage of 1 V to achieve the desired 1000-rpm motor speed. After being turned on, the motor stabilizes at a speed very close to 1000 rpm, because in a high-gain op amp the voltage at point X always has a value very close to zero volts. Note that the tachometer phasing is shown negative, but the SP voltage is positive.

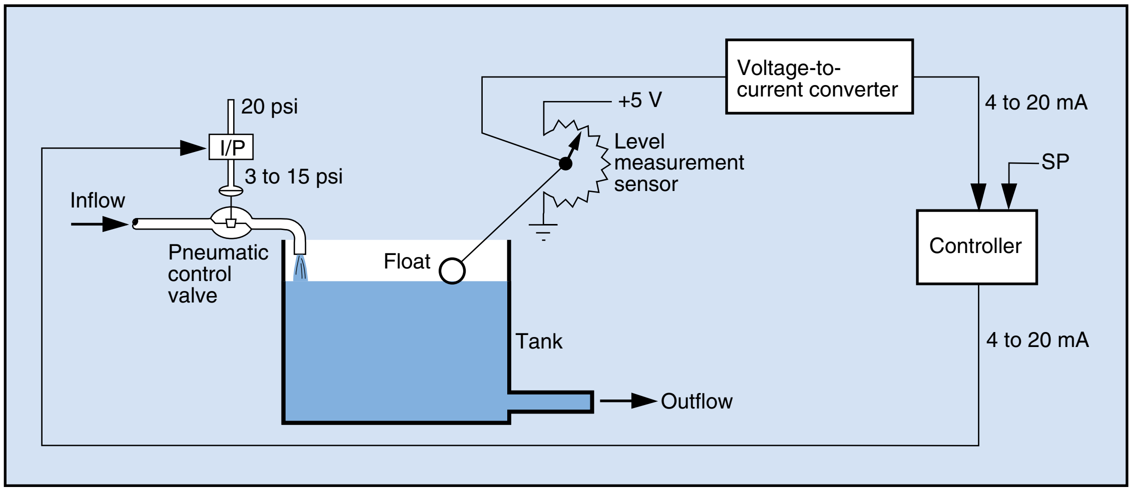
1.47 Suppose a process disturbance—for example, an increase in load on the motor shaft—momentarily reduces shaft speed. The reduction in shaft speed reduces the tachometer output voltage, in turn raising the voltage at point X. The increase in voltage at point X increases motor speed, in turn raising the tachometer output. The voltage at point X returns to zero. The negative feedback action thus restores motor speed to the SP value.

1.48 **Level control system.** In the system shown in Fig. 1-13, the operator uses the SP control to select the desired liquid level in a tank. At the selected level, the process reaches equilibrium when the inflow and outflow rates are equal. If the pressure on the inflow side increases (a disturbance), the inflow rate also increases and the level begins rising. Any increase in level increases the controller output current above the equilibrium value, reducing the valve opening and restoring the process to equilibrium.

1.49 The level sensor uses a potentiometer to sense displacement (level) so that a rising level in the tank increases the voltage at the wiper. The float can be coupled mechanically to the potentiometer shaft by means of a pulley arrangement. The controller output current signal is capable of controlling the valve opening, ranging from fully open (4 mA) to fully closed (20 mA).

1.50 A current-to-pressure converter (I/P) uses the controller output current signal to modulate the applied air pressure to the valve diaphragm. Thus, a 4-mA signal to the converter results in a minimum pressure value of 3 psi on the diaphragm, and a 20-mA

Fig. 1-13. Level control loop



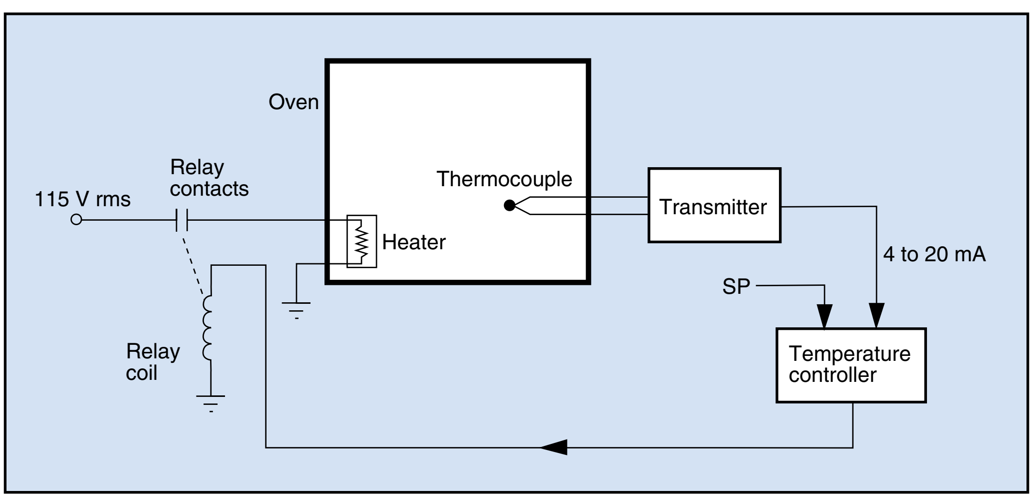
signal raises the applied pressure to the maximum value of 15 psi. All intermediate inputs and outputs are proportional.

1.51 **Temperature control.** The process shown in Fig. 1-14 is designed to control the temperature of an industrial oven. The operator dials the SP temperature into the controller. The final control element is the relay. The manipulated variable is the heat input from the electrical heater. The sensor is a thermocouple.

1.52 The temperature transmitter includes an electronically simulated and compensated reference junction, permitting the use of only a single thermocouple to make the temperature measurement. The transmitter output signal is a current proportional to the oven temperature. The current output range corresponds to the range of SP temperatures anticipated by the oven user. For example, the temperature transmitter could be one in which 4 mA corresponds to 50°C and 20 mA corresponds to 250°C.

1.53 When the oven temperature decreases to a value below the SP value, the controller energizes the relay coil, causing the normally open (N.O.) contacts to close. This action turns on the heater to restore oven temperature to the SP value. When system error is reduced to zero, the relay coil is de-energized.

Fig. 1-14. Oven temperature control loop



1-9. A sensor's ________ tells you how close the measured value is to the true value.	1-9. ACCURACY Ref: 1.27
1-10. A Type J thermocouple shows an output change of 50 μV/°C change in temperature. This ratio is a measure of the thermocouple's ________.	1-10. SENSITIVITY Ref: 1.29
1-11. A thermocouple with a 0.1-second time constant has a(n) ________ measurement response to a step change than a thermocouple with a 1.0-second time constant.	1-11. FASTER Ref: 1.32
1-12. A device used to translate sensor output voltage signals to equivalent current signals is called a(n) ________.	1-12. TRANSMITTER (or TRANSDUCER) Ref: 1.38
1-13. Valves, relays, and motors are examples of ________.	1-13. FINAL CONTROL ELEMENTS (FCEs) Ref: 1.39
1-14. A pneumatic diaphragm-style control valve requires a high-pressure ________ for operation.	1-14. AIR SUPPLY Ref: 1.42
1-15. A normally closed set of relay contacts will ________ when the relay coil is energized.	1-15. OPEN Ref: 1.43
1-16. The minimum input to an I/P is ________, and the maximum output is ________.	1-16. 4 mA; 15 psi Ref: 1.50

Answer the following questions by marking an "X" in the box next to the best answer.

1-1. All control loops must have a(n)

- ☐ a. control valve
- ☐ b. feedback loop
- ☐ c. input and an output
- ☐ d. signal conditioner

1-2. The device that continuously compares the value of the process variable to the setpoint is the

- ☐ a. controller
- ☐ b. final control element
- ☐ c. sensor
- ☐ d. transmitter

1-3. The purpose of negative feedback is to

- ☐ a. cancel out disturbances
- ☐ b. change the setpoint
- ☐ c. decrease system error
- ☐ d. increase system sensitivity

1-4. Which of the following devices is a passive sensor?

- ☐ a. Paddlewheel flowmeter
- ☐ b. Relay
- ☐ c. RTD
- ☐ d. Thermocouple

1-5. Which of the following signals could be sent directly to a digital controller?

- ☐ a. 1 to 5 V
- ☐ b. 3 to 15 psi
- ☐ c. 4 to 20 mA
- ☐ d. Pulse train

1-6. Which of the following devices can be used to measure angular or linear displacement?

- ☐ a. Potentiometer
- ☐ b. RTD
- ☐ c. Tachometer
- ☐ d. Thermocouple

1-7. The sensor that works by comparing the temperatures of two junctions is a(n)

- ☐ a. paddlewheel flowmeter
- ☐ b. potentiometer
- ☐ c. RTD
- ☐ d. thermocouple

1-8. What is the accuracy of a temperature sensor that measures 110°C when the true temperature is 100°C?

- ☐ a. 10%
- ☐ b. 45%
- ☐ c. 70%
- ☐ d. 90%

1-9. The time constant is a measure of a sensor's

- ☐ a. accuracy
- ☐ b. linearity
- ☐ c. sensitivity
- ☐ d. step response

1-10. The system component that converts a voltage signal to a current signal is a(n) ________, which is part of the ________.

- ☐ a. amplifier, controller
- ☐ b. recorder, final control element
- ☐ c. sensor, feedback loop
- ☐ d. transmitter, signal conditioner

SUMMARY

The basic control loop is either an open or a closed system. An open loop can only set a device to control a process variable (PV). A closed loop includes a feedback loop to provide continuous process control. The setpoint (SP) establishes the value for the feedback loop to maintain. System error is the difference between setpoint and the measured value of the process variable.

A sensor measures the PV and sends a signal, usually electrical, to the controller. Sensors may be active (for example, the thermocouple) or passive (for example, the RTD), depending on whether they convert the PV into a signal directly or indirectly. Other examples of sensors are the paddlewheel flowmeter and the potentiometer displacement sensor.

Five important sensor characteristics are accuracy, resolution, sensitivity, linearity, and step response. Accuracy is given as a percentage of how close the measured value is to the true value. Resolution is the smallest change in the measured variable that results in a detectable change at the sensor output. Sensitivity is the ratio of change in output for a unit change in the sensor input. Linearity is a measure of the proportionality between input and output. Step response, a dynamic characteristic, describes a transducer's response to a sudden change and is expressed as a time constant.

The controller acts to eliminate error and may be an analog or a digital device. The recorder keeps the system log and is useful for testing, calibration, and maintenance. Signal conditioners prepare the sensor output signal for use by the controller and may include filters or amplifiers. Signal conditioners that translate sensor output signals to equivalent current signals are referred to as *transmitters*. A final control element, which often includes an actuator, manipulates the input variable. Examples of final control elements include motors, pumps, valves, and relays.

Control loops may consist of many varied components and may control different variables—for example, speed by means of a tachometer/generator and motor, level by means of a potentiometer displacement sensor and control valve, or temperature by means of a thermocouple and relay. However, all perform in much the same manner, regardless of their arrangement or their purpose.

Answers to Self-Check Quiz

1-1. c. Input and an output. Ref: 1.01

1-2. a. Controller. Ref: 1.07

1-3. c. Decrease system error. Ref: 1.10

1-4. c. RTD. Ref: 1.16

1-5. d. Pulse train. Ref: 1.19

1-6. a. Potentiometer. Ref: 1.20

1-7. d. Thermocouple. Ref: 1.25

1-8. d. 90%. Ref: 1.27

1-9. d. Step response. Ref: 1.32

1-10. d. Transmitter, signal conditioner. Ref: 1.38

Contributions from the following sources are appreciated:

Figure 1-8 Honeywell Inc.
Figure 1-9 Honeywell Inc.