Instrumentation & Control

Process Control Fundamentals

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Introduction

Control in process industries refers to the regulation of all aspects of the process. Precise control of level, temperature, pressure and flow is important in many process applications. This module introduces you to control in process industries, explains why control is important, and identifies different ways in which precise control is ensured.

The following five sections are included in this module:

- ❑ The importance of process control
- ❑ Control theory basics
- ❑ Components of control loops and ISA symbology
- ❑ Controller algorithms and tuning
- ❑ Process control systems

As you proceed through the module, answer the questions in the activities column on the right side of each page. Also, note the application boxes (double-bordered boxes) located throughout the module. Application boxes provide key information about how you may use your baseline knowledge in the field. When you see the workbook exercise graphic at the bottom of a page, go to the workbook to complete the designated exercise before moving on in the module. Workbook exercises help you measure your progress toward meeting each section's learning objectives.

PERFORMANCE OBJECTIVE

After completing this module, you will be able to determine needed control loop components in specific process control applications.

The Importance of Process Control

Refining, combining, handling, and otherwise manipulating fluids to profitably produce end products can be a precise, demanding, and potentially hazardous process. Small changes in a process can have a large impact on the end result. Variations in proportions, temperature, flow, turbulence, and many other factors must be carefully and consistently controlled to produce the desired end product with a minimum of raw materials and energy. Process control technology is the tool that enables manufacturers to keep their operations running within specified limits and to set more precise limits to maximize profitability, ensure quality and safety.

LEARNING OBJECTIVES

After completing this section, you will be able to:

- ❑ Define process
- ❑ Define process control
- ❑ Describe the importance of process control in terms of variability, efficiency, and safety

Note: To answer the activity questions the Hand Tool (H) should be activated.

The Importance of Process Control

PROCESS

Process as used in the terms *process control* and *process industry,* refers to the methods of changing or refining raw materials to create end products. The raw materials, which either pass through or remain in a liquid, gaseous, or slurry (a mix of solids and liquids) state during the process, are transferred, measured, mixed, heated or cooled, filtered, stored, or handled in some other way to produce the end product.

Process industries include the chemical industry, the oil and gas industry, the food and beverage industry, the pharmaceutical industry, the water treatment industry, and the power industry.

PROCESS CONTROL

Process control refers to the methods that are used to control process variables when manufacturing a product. For example, factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product. Manufacturers control the production process for three reasons:

- ❑ Reduce variability
- ❑ Increase efficiency
- ❑ Ensure safety

Reduce Variability

Process control can reduce variability in the end product, which ensures a consistently high-quality product. Manufacturers can also save money by reducing variability. For example, in a gasoline blending process, as many as 12 or more different components may be blended to make a specific grade of gasoline. If the refinery does not have precise control over the flow of the separate components, the gasoline may get too much of the high-octane components. As a result, customers would receive a higher grade and more expensive gasoline than they paid for, and the refinery would lose money. The opposite situation would be customers receiving a lower grade at a higher price.

Activities

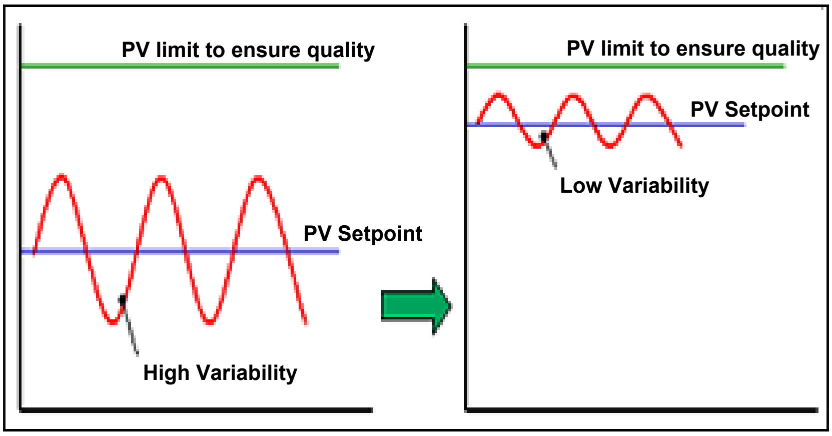
1. Process is defined as the changing or refining of raw materials that pass through or remain in a liquid, gaseous, or slurry state to to create end products.

2. Which of these industries are examples of the process industry?
   Select all options that apply.

   1 Pharmaceutical
   2 Satellite
   3 Oil and Gas
   4 Cement
   5 Power

The Importance of Process Control

Reducing variability can also save money by reducing the need for product padding to meet required product specifications. *Padding* refers to the process of making a product of higher-quality than it needs to be to meet specifications. When there is variability in the end product (i.e., when process control is poor), manufacturers are forced to pad the product to ensure that specifications are met, which adds to the cost. With accurate, dependable process control, the *setpoint* (desired or optimal point) can be moved closer to the actual product specification and thus save the manufacturer money.



Increase Efficiency

Some processes need to be maintained at a specific point to maximize efficiency. For example, a control point might be the temperature at which a chemical reaction takes place. Accurate control of temperature ensures process efficiency. Manufacturers save money by minimizing the resources required to produce the end product.

Ensure Safety

A run-away process, such as an out-of-control nuclear or chemical reaction, may result if manufacturers do not maintain precise control of all of the processg variables. The consequences of a run-away process can be catastrophic.

Precise process control may also be required to ensure safety. For example, maintaining proper boiler pressure by controlling the inflow of air used in combustion and the outflow of exhaust gases is crucial in preventing boiler implosions that can clearly threaten the safety of workers.

Activities

3. What are the main reasons for manufacturers to control a process? Select all options that apply.

1 Reduce variability
2 Ensure safety
3 Reduce costs
4 Increase efficiency
5 Increase productivity

COMPLETE WORKBOOK EXERCISE - THE IMPORTANCE OF PROCESS CONTROL

Control Theory Basics

This section presents some of the basic concepts of control and provides a foundation from which to understand more complex control processes and algorithms later described in this module. Common terms and concepts relating to process control are defined in this section.

LEARNING OBJECTIVES

After completing this section, you will be able to:

- ❑ Define control loop
- ❑ Describe the three tasks necessary for process control to occur:
  - Measure
  - Compare
  - Adjust
- ❑ Define the following terms:
  - Process variable
  - Setpoint
  - Manipulated variable
  - Measured variable
  - Error
  - Offset
  - Load disturbance
  - Control algorithm
- ❑ List at least five process variables that are commonly controlled in process measurement industries
- ❑ At a high level, differentiate the following types of control:
  - Manual versus automatic feedback control
  - Closed-loop versus open-loop control

Note: To answer the activity questions the Hand Tool (H) should be activated.

The Control Loop

Imagine you are sitting in a cabin in front of a small fire on a cold winter evening. You feel uncomfortably cold, so you throw another log on the fire. This is an example of a *control loop*. In the control loop, a variable (temperature) fell below the setpoint (your comfort level), and you took action to bring the process back into the desired condition by adding fuel to the fire. The control loop will now remain static until the temperature again rises above or falls below your comfort level.

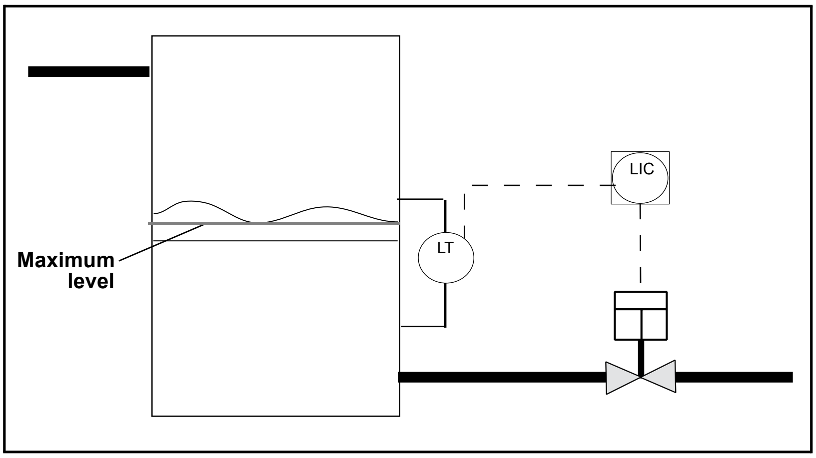
THREE TASKS

Control loops in the process control industry work in the same way, requiring three tasks to occur:

- ❑ Measurement
- ❑ Comparison
- ❑ Adjustment

In Figure 7.1, a level transmitter (LT) measures the level in the tank and transmits a signal associated with the level reading to a controller (LIC). The controller compares the reading to a predetermined value, in this case, the maximum tank level established by the plant operator, and finds that the values are equal. The controller then sends a signal to the device that can bring the tank level back to a lower level—a valve at the bottom of the tank. The valve opens to let some liquid out of the tank.

Many different instruments and devices may or may not be used in control loops (e.g., transmitters, sensors, controllers, valves, pumps), but the three tasks of measurement, comparison, and adjustment are always present.



A Simple Control Loop

Activities

1. The three tasks associated with any control loop are measurement, comparison, and adjustment. Is this statement true or false?

Process Control Terms

As in any field, process control has its own set of common terms that you should be familiar with and that you will use when talking about control technology.

PROCESS VARIABLE

A *process variable* is a condition of the process fluid (a liquid or gas) that can change the manufacturing process in some way. In the example of you sitting by the fire, the process variable was temperature. In the example of the tank in Figure 7.1, the process variable is level. Common process variables include:

- ❑ Pressure
- ❑ Flow
- ❑ Level
- ❑ Temperature
- ❑ Density
- ❑ Ph (acidity or alkalinity)
- ❑ Liquid interface (the relative amounts of different liquids that are combined in a vessel)
- ❑ Mass
- ❑ Conductivity

SETPOINT

The *setpoint* is a value for a process variable that is desired to be maintained. For example, if a process temperature needs to kept within 5 °C of 100 °C, then the setpoint is 100 °C. A temperature sensor can be used to help maintain the temperature at setpoint.
The sensor is inserted into the process, and a contoller compares the temperature reading from the sensor to the setpoint. If the temperature reading is 110 °C, then the controller determines that the process is above setpoint and signals the fuel valve of the burner to close slightly until the process cools to 100 °C. Set points can also be maximum or minimum values. For example, level in tank cannot exceed 20 feet.

Activities

2. A process variable is a condition that can change the process in some way.

3. Imagine you are in a cabin in front of a small fire on a cold winter evening. You feel uncomfortably cold, so you throw another log into the fire. In this scenario, the process variable is temperature. Is this true or false?

4. If the level of a liquid in a tank must be maintained within 5 ft of 50 ft, what is the liquid's setpoint?

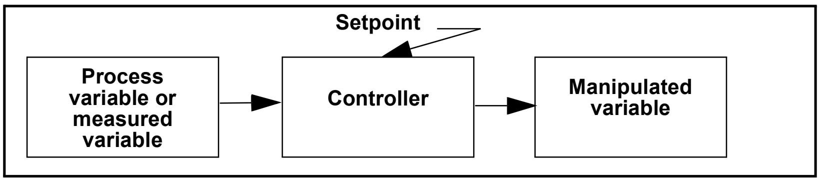
1 45 ft
2 55 ft
3 5 ft
4 50 ft

Process Control Terms

Measured Variables, Process Variables, and Manipulated Variables

In the temperature control loop example, the measured variable is temperature, which must be held close to 100 °C. In this example and in most instances, the measured variable is also the process variable. The *measured variable* is the condition of the process fluid that must be kept at the designated setpoint.

Sometimes the measured variable is not the same as the process variable. For example, a manufacturer may measure flow into and out of a storage tank to determine tank level. In this scenario, flow is the measured variable, and the process fluid level is the *process variable.* The factor that is changed to keep the measured variable at setpoint is called the *manipulated variable*. In the example described, the manipulated variable would also be flow (Figure 7.2).



Variables

Error

Error is the difference between the measured variable and the setpoint and can be either positive or negative. In the temperature control loop example, the error is the difference between the 110 °C measured variable and the 100 °C setpoint—that is, the error is +10 °C.

The objective of any control scheme is to minimize or eliminate error. Therefore, it is imperative that error be well understood. Any error can be seen as having three major components. These three components are shown in the figure on the folowing page

Magnitude

The magnitude of the error is simply the deviation between the values of the setpoint and the process variable. The magnitude of error at any point in time compared to the previous error provides the basis for determining the change in error. The change in error is also an important value.

Activities

5. ____________________ is a sustained deviation of the process variable from the setpoint.

6. A load disturbance is an undesired change in one of the factors that can affect the setpoint. Is this statement true or false?

Process Control Terms

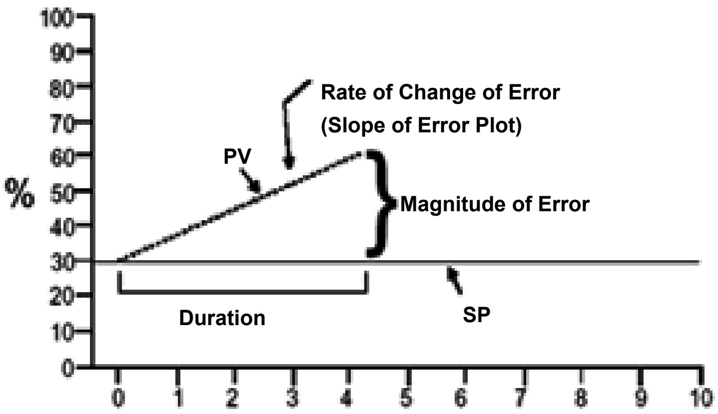
Activities

Duration

Duration refers to the length of time that an error condition has existed.

Rate Of Change

The rate of change is shown by the slope of the error plot.



Components of Error

OFFSET

Offset is a sustained deviation of the process variable from the setpoint. In the temperature control loop example, if the control system held the process fluid at 100.5 °C consistently, even though the setpoint is 100 °C, then an offset of 0.5 °C exists.

LOAD DISTURBANCE

A *load disturbance* is an undesired change in one of the factors that can affect the process variable. In the temperature control loop example, adding cold process fluid to the vessel would be a load disturbance because it would lower the temperature of the process fluid.

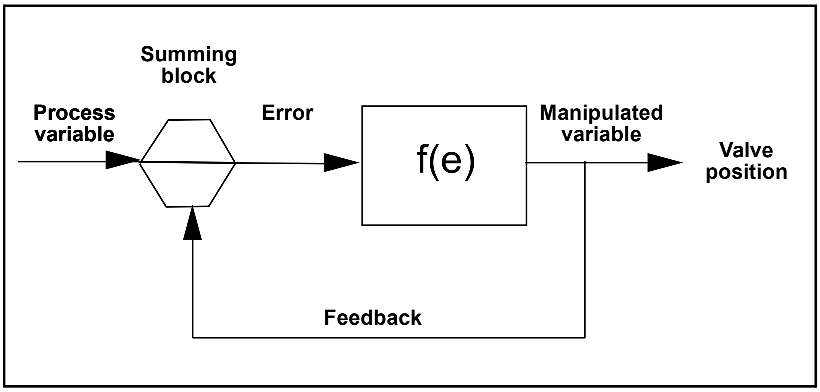
CONTROL ALGORITHM

A *control algorithm* is a mathematical expression of a control function. Using the temperature control loop example, V in the equation below is the fuel valve position, and e is the error. The relationship in a control algorithm can be expressed as:

Process Control Terms

$$V = f(\pm e)$$

The fuel valve position (V) is a function (f) of the sign (positive or negative) of the error (Figure 7.3).



Algorithm Example

Control algorithms can be used to calculate the requirements of much more complex control loops than the one described here. In more complex control loops, questions such as "How far should the valve be opened or closed in response to a given change in setpoint?" and "How long should the valve be held in the new position after the process variable moves back toward setpoint?" need to be answered.

MANUAL AND AUTOMATIC CONTROL

Before process automation, people, rather than machines, performed many of the process control tasks. For example, a human operator might have watched a level gauge and closed a valve when the level reached the setpoint. Control operations that involve human action to make an adjustment are called *manual control* systems. Conversely, control operations in which no human intervention is required, such as an automatic valve actuator that responds to a level controller, are called *automatic control* systems.

Activities

7. Automatic control systems are control operations that involve human action to make adjustment. Is this statement true or false?

Process Control Terms

Closed and Open Control Loops

A *closed control loop* exists where a process variable is measured, compared to a setpoint, and action is taken to correct any deviation from setpoint. An *open control loop* exists where the process variable is not compared, and action is taken not in response to feedback on the condition of the process variable, but is instead taken without regard to process variable conditions. For example, a water valve may be opened to add cooling water to a process to prevent the process fluid from getting too hot, based on a pre-set time interval, regardless of the actual temperature of the process fluid.

Activities

8. Under what circumstances does an open control loop exist?
Select all options that apply.

1 Process variable is not measured
2 Process variable is not compared
3 Process variable is measured and compared to a setpoint
4 Action is taken without regard to process variable conditions
5 Action is taken with regard to process variable conditions

COMPLETE WORKBOOK EXERCISE - CONTROL THEORY BASICS

Components of Control Loops and ISA Symbology

This section describes the instruments, technologies, and equipment used to develop and maintain process control loops. In addition, this section describes how process control equipment is represented in technical drawings of control loops.

LEARNING OBJECTIVES

After completing this section, you will be able to:

- ❑ Describe the basic function of and, where appropriate, the basic method of operation for the following control loop components:
  - Primary element/sensor
  - Transducer
  - Converter
  - Transmitter
  - Signal
  - Indicator
  - Recorder
  - Controller
  - Correcting element/final control element
  - Actuator
- ❑ List examples of each type of control loop component listed above
- ❑ State the advantages of 4–20 mA current signals when compared with other types of signals
- ❑ List at least three types of final control elements, and for each one:
  - Provide a brief explanation of its method of operation
  - Describe its impact on the control loop
  - List common applications in which it is used
- ❑ Given a piping and instrumentation drawing (P&ID), correctly label the:
  - Instrument symbols (e.g., control valves, pumps, transmitters)
  - Location symbols (e.g., local, panel-front)
  - Signal type symbols (e.g., pneumatic, electrical)
- ❑ Accurately interpret instrument letter designations used on P&IDs

Control Loop Equipment and Technology

The previous section described the basic elements of control as measurement, comparison, and adjustment. In practice, there are instruments and strategies to accomplish each of these essential tasks. In some cases, a single process control instrument, such as a modern pressure transmitter, may perform more than one of the basic control functions. Other technologies have been developed so that communication can occur among the components that measure, compare, and adjust.

Primary Elements/Sensors

In all cases, some kind of instrument is measuring changes in the process and reporting a process variable measurement. Some of the greatest ingenuity in the process control field is apparent in sensing devices. Because sensing devices are the first element in the control loop to measure the process variable, they are also called *primary elements*. Examples of primary elements include:

- ❑ Pressure sensing diaphragms, strain gauges, capacitance cells
- ❑ Resistance temperature detectors (RTDs)
- ❑ Thermocouples
- ❑ Orifice plates
- ❑ Pitot tubes
- ❑ Venturi tubes
- ❑ Magnetic flow tubes
- ❑ Coriolis flow tubes
- ❑ Radar emitters and receivers
- ❑ Ultrasonic emitters and receivers
- ❑ Annubar flow elements
- ❑ Vortex sheddar

Primary elements are devices that cause some change in their property with changes in process fluid conditions that can then be measured. For example, when a conductive fluid passes through the magnetic field in a magnetic flow tube, the fluid generates a voltage that is directly proportional to the velocity of the process fluid. The primary element (magnetic flow tube) outputs a voltage that can be measured and used to calculate the fluid's flow rate. With an RTD, as the temperature of a process fluid surrounding the RTD rises or falls, the electrical resistance of the RTD increases or decreases a proportional amount. The resistance is measured, and from this measurement, temperature is determined.

Activities

1. Identify three examples of a primary element/sensors in process control?
   Select all options that apply.

   1 Resistance Temperature Detectors
   2 Thermocouples
   3 Control Valve
   4 Converter
   5 Pitot tubes

2. Primary elements will not make direct contact with the process fluid. Is this statement true or false?

Control Loop Equipment and Technology

TRANSDUCERS AND CONVERTERS

A *transducer* is a device that translates a mechanical signal into an electrical signal. For example, inside a capacitance pressure device, a transducer converts changes in pressure into a proportional change in capacitance.

A *converter* is a device that converts one type of signal into another type of signal. For example, a converter may convert current into voltage or an analog signal into a digital signal. In process control, a converter used to convert a 4–20 mA current signal into a 3–15 psig pneumatic signal (commonly used by valve actuators) is called a *current-to-pressure converter*.

TRANSMITTERS

A *transmitter* is a device that converts a reading from a sensor or transducer into a standard signal and transmits that signal to a monitor or controller. Transmitter types include:

- ❑ Pressure transmitters
- ❑ Flow transmitters
- ❑ Temperature transmitters
- ❑ Level transmitters
- ❑ Analytic (O_2 [oxygen], CO [carbon monoxide], and pH) transmitters

Activities

3. A ____________ is a device that translates a mechanical signal into an electrical signal.

4. A transmitter is a device that converts a reading from a transducer into a standard signal and transmits that signal to a monitor or controller. Is this statement true or false?

Control Loop Equipment and Technology

SIGNALS

There are three kinds of signals that exist for the process industry to transmit the process variable measurement from the instrument to a centralized control system.

1. Pneumatic signal
2. Analog signal
3. Digital signal

Pneumatic Signals

Pneumatic signals are signals produced by changing the air pressure in a signal pipe in proportion to the measured change in a process variable. The common industry standard pneumatic signal range is 3–15 psig. The 3 corresponds to the lower range value (LRV) and the 15 corresponds to the upper range value (URV). Pneumatic signalling is still common. However, since the advent of electronic instruments in the 1960s, the lower costs involved in running electrical signal wire through a plant as opposed to running pressurized air tubes has made pneumatic signal technology less attractive.

Analog Signals

The most common standard electrical signal is the 4–20 mA current signal. With this signal, a transmitter sends a small current through a set of wires. The current signal is a kind of gauge in which 4 mA represents the lowest possible measurement, or zero, and 20 mA represents the highest possible measurement.

For example, imagine a process that must be maintained at 100 °C. An RTD temperature sensor and transmitter are installed in the process vessel, and the transmitter is set to produce a 4 mA signal when the process temperature is at 95 °C and a 20 mA signal when the process temperature is at 105 °C. The transmitter will transmit a 12 mA signal when the temperature is at the 100 °C setpoint. As the sensor's resistance property changes in response to changes in temperature, the transmitter outputs a 4–20 mA signal that is proportionate to the temperature changes. This signal can be converted to a temperature reading or an input to a control device, such as a burner fuel valve.

Other common standard electrical signals include the 1–5 V (volts) signal and the pulse output.

Activities

5. Identify the signal types that are used in the process control industry?
   Select all options that apply.

1 Hydraulic signals
2 Digital signals
3 Analog signals
4 Pneumatic signals
5 Electro-magnetic signals

Control Loop Equipment and Technology

Digital Signals

Digital signals are the most recent addition to process control signal technology. Digital signals are discrete levels or values that are combined in specific ways to represent process variables and also carry other information, such as diagnostic information. The methodology used to combine the digital signals is referred to as protocol.

Manufacturers may use either an open or a proprietary digital protocol. Open protocols are those that anyone who is developing a control device can use. Proprietary protocols are owned by specific companies and may be used only with their permission. Open digital protocols include the HART® (highway addressable remote transducer) protocol, FOUNDATION™ Fieldbus, Profibus, DeviceNet, and the Modbus® protocol.

(See *Module 8: Communication Technologies* for more information on digital communication protocols.)

INDICATORS

While most instruments are connected to a control system, operators sometimes need to check a measurement on the factory floor at the measurement point. An indictor makes this reading possible. An *indicator* is a human-readable device that displays information about the process. Indicators may be as simple as a pressure or temperature gauge or more complex, such as a digital read-out device. Some indicators simply display the measured variable, while others have control buttons that enable operators to change settings in the field.

Activities

6. The ___________ is a human-readable device that displays information about the process or the instrument it is connected to.

7. Which of the following are examples of a digital signal?
   Select all options that apply.

1 Profibus
2 4 - 20 mA
3 1 - 5 v
4 Fieldbus
5 3 - 15 psig

Control Loop Equipment and Technology

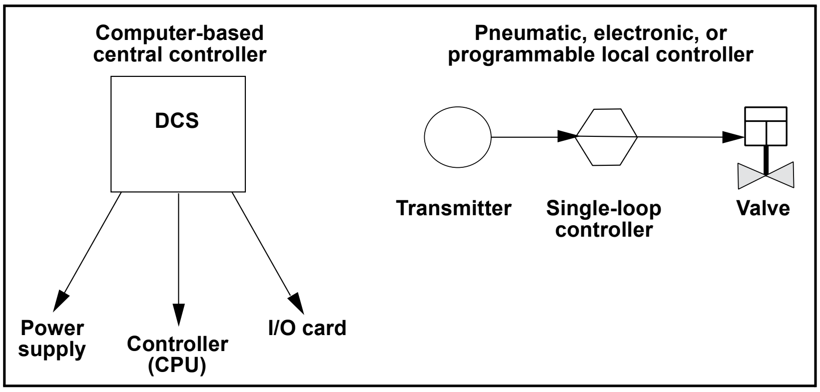
RECORDERS

A *recorder* is a device that records the output of a measurement devices. Many process manufacturers are required by law to provide a process history to regulatory agencies, and manufacturers use recorders to help meet these regulatory requirements. In addition, manufacturers often use recorders to gather data for trend analyses. By recording the readings of critical measurement points and comparing those readings over time with the results of the process, the process can be improved.

Different recorders display the data they collect differently. Some recorders list a set of readings and the times the readings were taken; others create a chart or graph of the readings. Recorders that create charts or graphs are called *chart recorders.*

CONTROLLERS

A *controller* is a device that receives data from a measurement instrument, compares that data to a programmed setpoint, and, if necessary, signals a control element to take corrective action. *Local controllers* are usually one of the three types: pneumatic, electronic or programmable. Contollers also commonly reside in a digital control system.



Controllers

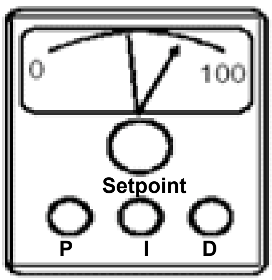
Activities

8. A recorder is a device that records the ________________ of a measurement or control device.

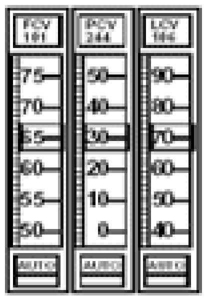
Control Loop Equipment and Technology

Controllers may perform complex mathematical functions to compare a set of data to setpoint or they may perform simple addition or subtraction functions to make comparisons. Controllers always have an ability to receive input, to perform a mathematical function with the input, and to produce an output signal. Common examples of controllers include:

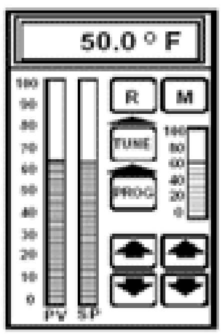
- *Programmable logic controllers* (PLCs)—PLCs are usually computers connected to a set of input/output (I/O) devices. The computers are programmed to respond to inputs by sending outputs to maintain all processes at setpoint.
- *Distributed control systems* (DCSs)—DCSs are controllers that, in addition to performing control functions, provide readings of the status of the process, maintain databases and advanced man-machine-interface.



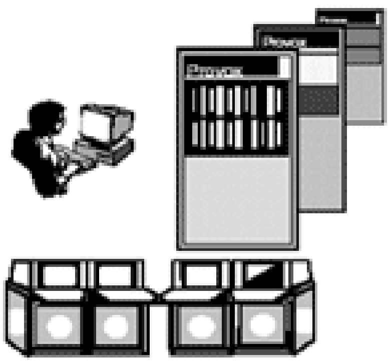
Pipestand Controller (Pneumatic or Electronic)



Analog Rack Mount Controller (Electronic)



Single Loop Digital Converter (Electronic)



Distributed Control System (Electronic)

Types of Process Controllers

Activities

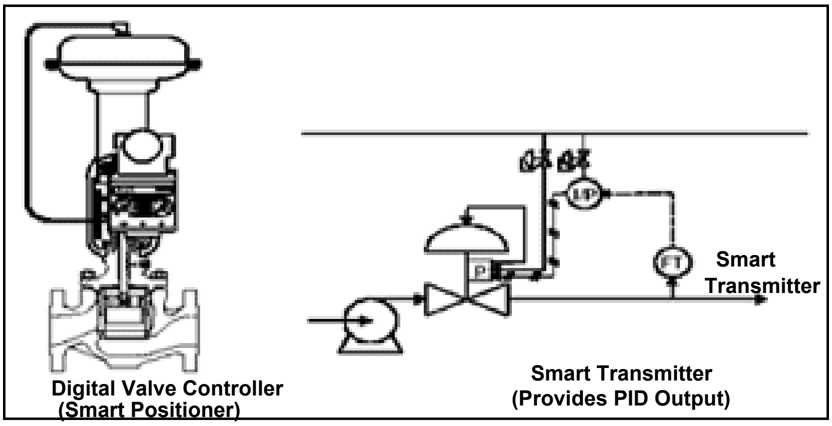
9. Which of the following have the ability to receive input, to perform a mathematical function with the input, and produce an output signal?

1 Actuators
2 Transmitters
3 Transducers
4 Controllers

10. Which of the following is the most common final control element in process control industries?

1 Agitator
2 Pump motor
3 Valve
4 Louver

Control Loop Equipment and Technology



Types of Process Controllers

CORRECTING ELEMENTS/FINAL CONTROL ELEMENTS

The *correcting* or *final control element* is the part of the control system that acts to physically change the manipulated variable. In most cases, the final control element is a valve used to restrict or cut off fluid flow, but pump motors, louvers (typically used to regulate air flow), solenoids, and other devices can also be final control elements.

Final control elements are typically used to increase or decrease fluid flow. For example, a final control element may regulate the flow of fuel to a burner to control temperature, the flow of a catalyst into a reactor to control a chemical reaction, or the flow of air into a boiler to control boiler combustion.

In any control loop, the speed with which a final control element reacts to correct a variable that is out of setpoint is very important. Many of the technological improvements in final control elements are related to improving their response time.

ACTUATORS

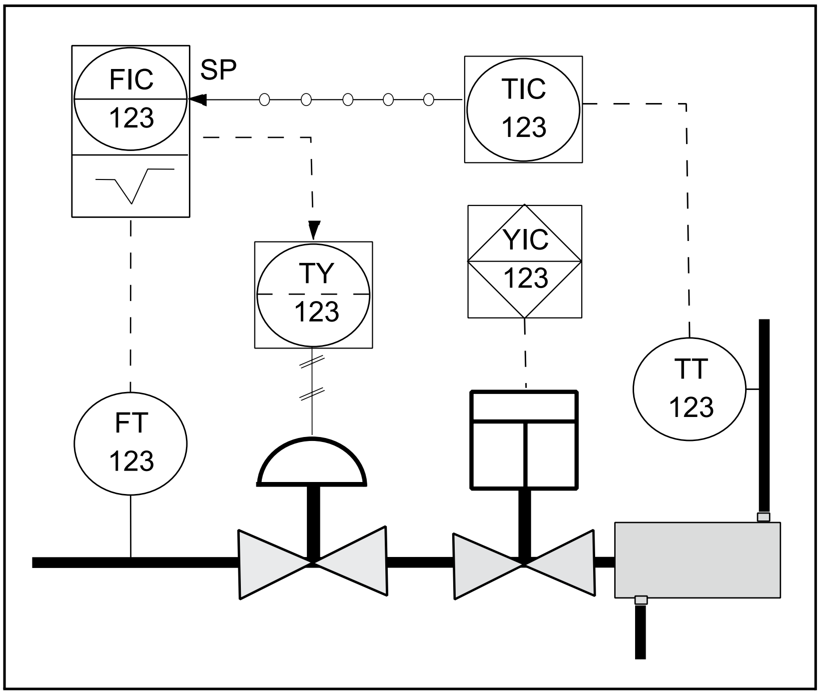
An *actuator* is the part of a final control device that causes a physical change in the final control device when signalled to do so. The most common example of an actuator is a valve actuator, which opens or closes a valve in response to control signals from a controller. Actuators are often powered pneumatically, hydraulically, or electrically. Diaphragms, bellows, springs, gears, hydraulic pilot valves, pistons, or electric motors are often parts of an actuator system.

Activities

11. _______________ is a part final control device that causes a physical change in the final control device when signaled to do so.

ISA Symbology

The Instrumentation, Systems, and Automation Society (ISA) is one of the leading process control trade and standards organizations. The ISA has developed a set of symbols for use in engineering drawings and designs of control loops (ISA S5.1 instrumentation symbol specification). You should be familiar with ISA symbology so that you can demonstrate possible process control loop solutions on paper to your customer. Figure 7.5 shows a control loop using ISA symbology. Drawings of this kind are known as *piping and instrumentation drawings* (P&ID).



Piping and Instrumentation Drawing
(P&ID)

Activities

12. What does the acronym P&ID stand for?

1 Piping and Instrument Designing
2 Piping and Instrumentation Drawing
3 Process Control and Installation Drawing
4 Proportional, Intergral and Derivative control

ISA Symbology

SYMBOLS

In a P&ID, a circle represents individual measurement instruments, such as transmitters, sensors, and detectors (Figure 7.6).

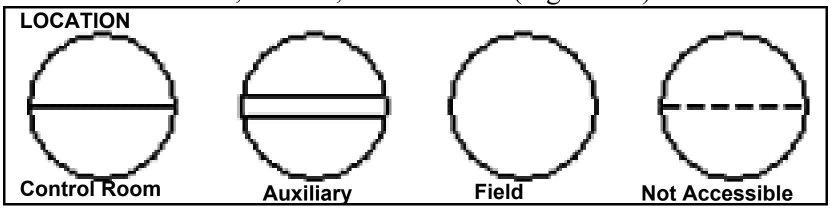
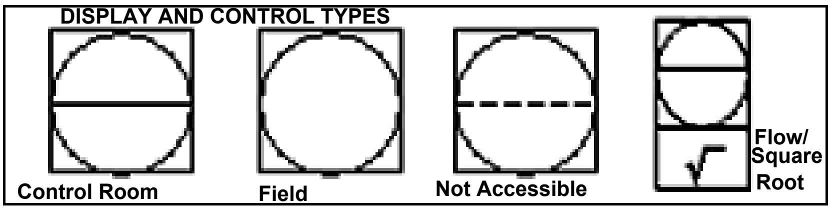


Figure 7.6: Discrete Instruments

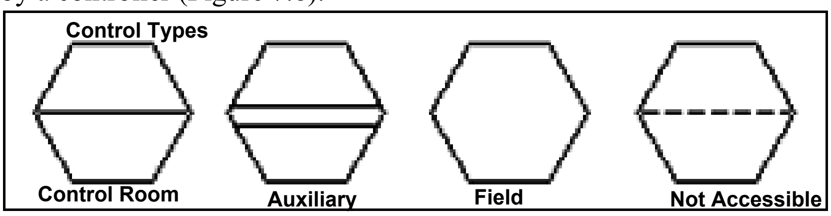
A single horizontal line running across the center of the shape indicates that the instrument or function is located in a primary location (e.g., a control room). A double line indicates that the function is in an auxiliary location (e.g., an instrument rack). The absence of a line indicates that the function is field mounted, and a dotted line indicates that the function or instrument is inaccessible (e.g., located behind a panel board).

A square with a circle inside represents instruments that both display measurement readings and perform some control function (Figure 7.7). Many modern transmitters are equipped with microprocessors that perform control calculations and send control output signals to final control elements.



Shared Control/Display Elements

A hexagon represents computer functions, such as those carried out by a controller (Figure 7.8).

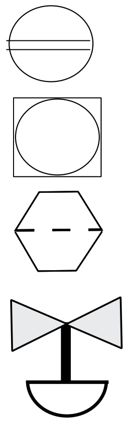


Computer Functions (Controllers)

Activities

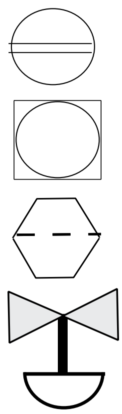
13. Which of the following is a symbol of a transmitter in an auxiliary location?

1
2
3
4



14. Which of the following is a symbol of a field-mounted control/display element?

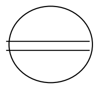
1
2
3
4

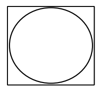


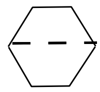
ISA Symbology

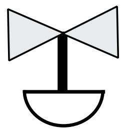
Activities

15. Which of the following is a symbol of a controller located behind a panel?

1 

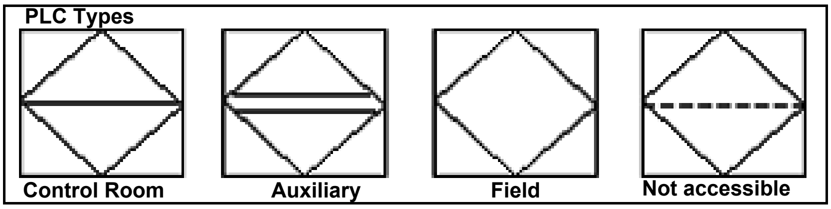
2 

3 

4 

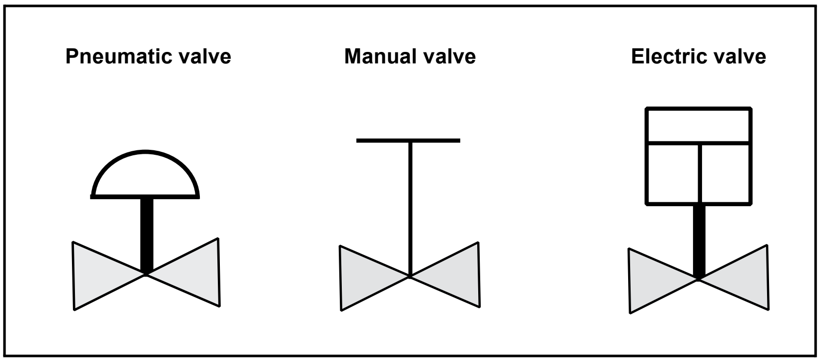
ISA Symbology

A square with a diamond inside represents PLCs (Figure 7.9).



PLCs

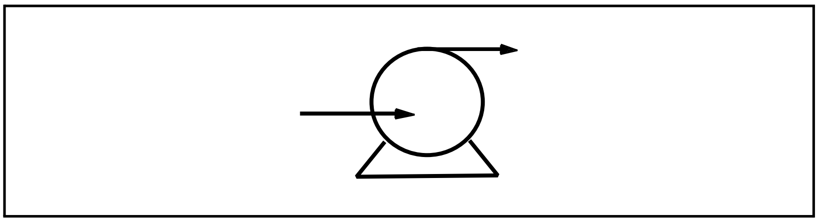
Two triangles with their apexes contacting each other (a "bow tie" shape) represent a valve in the piping. An actuator is always drawn above the valve (Figure 7.10).



Valves

Pumps

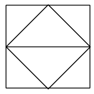
Directional arrows showing the flow direction represent a pump (Figure 7.11).



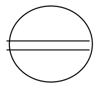
Pumps

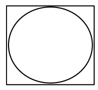
Activities

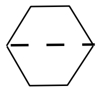
16. The symbol displayed below denotes a PLC in a primary location. Is this statement true or false?

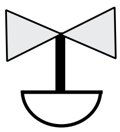


17. Which of the following is a symbol of a pneumatic valve?

1 

2 

3 

4 

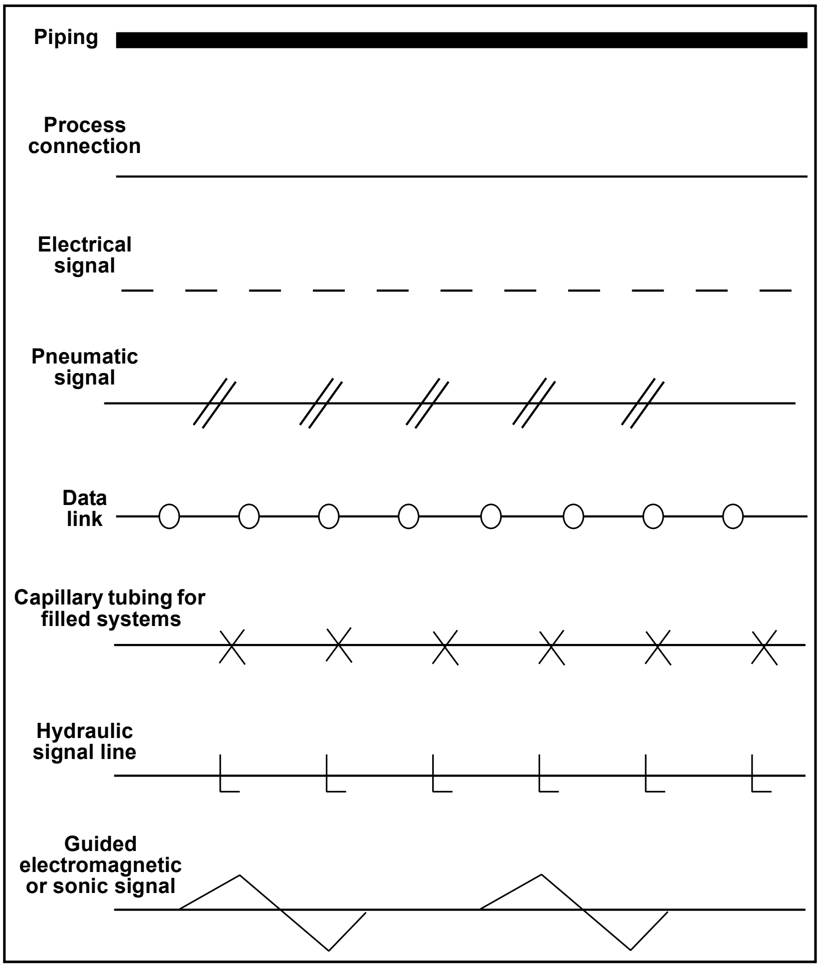
ISA Symbology

Piping and Connections

Piping and connections are represented with several different symbols (Figure 7.12):

- ❑ A heavy solid line represents piping
- ❑ A thin solid line represents process connections to instruments (e.g., impulse piping)
- ❑ A dashed line represents electrical signals (e.g., 4–20 mA connections)
- ❑ A slashed line represents pneumatic signal tubes
- ❑ A line with circles on it represents data links

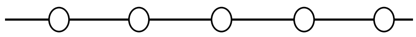
Other connection symbols include capillary tubing for filled systems (e.g., remote diaphragm seals), hydraulic signal lines, and guided electromagnetic or sonic signals.



Piping and Connection Symbols

Activities

18. The symbols displayed below represent a data link and a process connection. Is this statement true or false?



____

ISA Symbology

IDENTIFICATION LETTERS

Identification letters on the ISA symbols (e.g., TT for temperature transmitter) indicate:

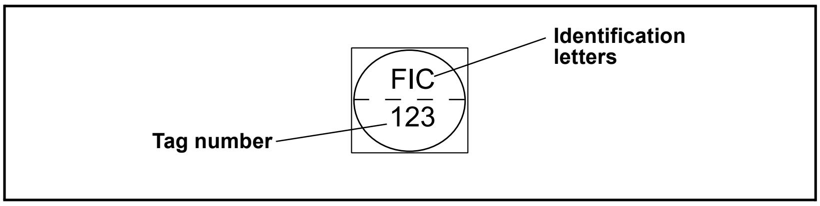
- ❑ The variable being measured (e.g., flow, pressure, temperature)
- ❑ The device's function (e.g., transmitter, switch, valve, sensor, indicator)
- ❑ Some modifiers (e.g., high, low, multifunction)

Table 7.1 on page 26 shows the ISA identification letter designations. The initial letter indicates the measured variable. The second letter indicates a modifier, readout, or device function. The third letter usually indicates either a device function or a modifier.

For example, "FIC" on an instrument tag represents a flow indicating controller. "PT" represents a pressure transmitter. You can find identification letter symbology information on the ISA Web site at http://www.isa.org.

TAG NUMBERS

Numbers on P&ID symbols represent instrument tag numbers. Often these numbers are associated with a particular control loop (e.g., flow transmitter 123). See Figure 7.13.



Identification Letters and Tag Number

Activities

19. The initial letter on an ISA symbol indicates the measured variable. Is this statement true or false?

20. What does the third letter on an ISA symbol indicate?

1. Device function or a modifier
2. Measured variable
3. Readout
4. Type of process fluid

ISA Symbology

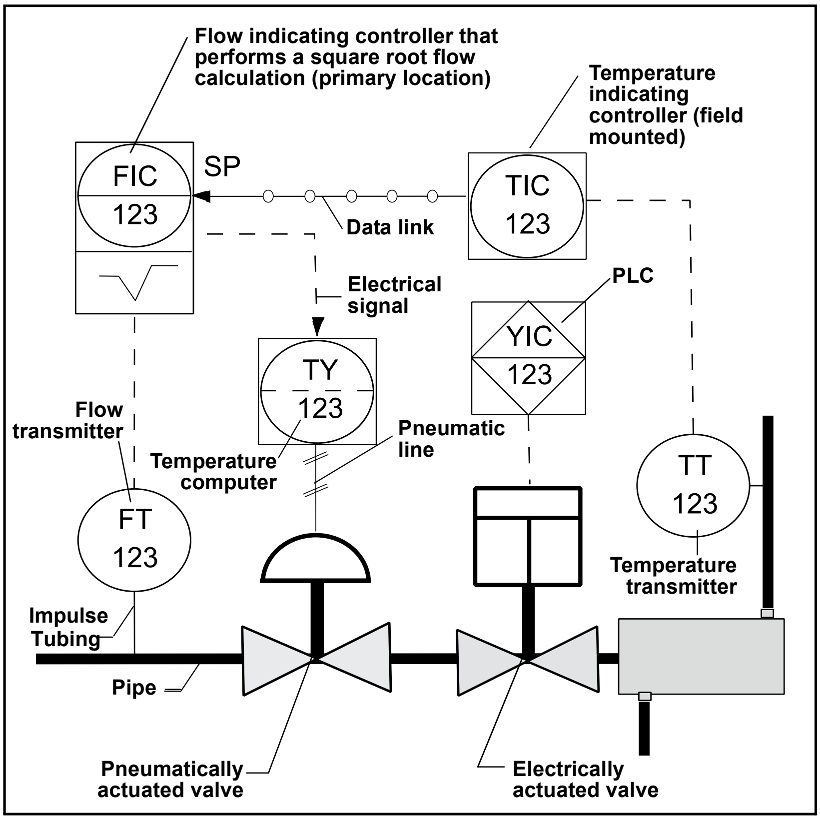
	Measured Variable	Modifier	Readout	Device Function	Modifier
A	Analysis		Alarm		
B	Burner, combustion		User's choice	User's choice	User's choice
C	User's choice			Control	
D	User's choice	Differential			
E	Voltage		Sensor (primary element)		
F	Flow rate	Ration (fraction)			
G	User's choice		Glass, viewing device		
H	Hand				High
I	Electrical Current		Indication		
J	Power	Scan			
K	Time, time schedule	Time rate of change		Control station	
L	Level		Light		Low
M	User's choice	Momentary			Middle, intermediate
N	User's choice		User's choice	User's choice	User's choice
O	User's choice		Orifice, restriction		
P	Pressure, vacuum		Point, test connection		
Q	Quantity	Integrate, totalizer			
R	Radiation		Record		
S	Speed, frequency	Safety		Switch	
T	Temperature			Transmit	
U	Multivariable		Multifunction	Multifunction	Multifunction
V	Vibration, mechanical analysis			Valve, damper, louver	
W	Weight, force		Well		
X	Unclassified	X axis	Unclassified	Unclassified	Unclassified
Y	Event, state, or presence	Y axis		Relay, compute, convert	
Z	Position, dimension	Z axis		Driver, actuator	

ISA Identification Letters

ISA Symbology

ISA Symbology Review

Figure 7.14 shows the elements of ISA symbology used in a P&ID.



P&ID with ISA Symbology

Activities

21. In Figure 7.14, what kind of signal is transmitted out from the temperature transmitter?

1. Data link
2. Mechanical signal
3. Electrical signal
4. Pneumatic signal

COMPLETE WORKBOOK EXERCISE - COMPONENTS OF CONTROL LOOPS AND ISA SYMBOLOGY

Controller Algorithms and Tuning

The previous sections of this module described the purpose of control, defined individual elements within control loops, and demonstrated the symbology used to represent those elements in an engineering drawing. The examples of control loops used thus far have been very basic. In practice, control loops can be fairly complex. The strategies used to hold a process at setpoint are not always simple, and the interaction of numerous setpoints in an overall process control plan can be subtle and complex. In this section, you will be introduced to some of the strategies and methods used in complex process control loops.

LEARNING OBJECTIVES

After completing this section, you will be able to:

- ❑ Differentiate between discrete, multistep, and continuous controllers
- ❑ Describe the general goal of controller tuning.
- ❑ Describe the basic mechanism, advantages and disadvantages of the following mode of controller action:
  - Proportional action
  - Intergral action
  - Derivative action
- ❑ Give examples of typical applications or situations in which each mode of controller action would be used.
- ❑ Identify the basic implementation of P, PI and PID control in the following types of loops:
  - Pressure loop
  - Flow loop
  - Level loop
  - Temperature loop

Note: To answer the activity questions the Hand Tool (H) should be activated.

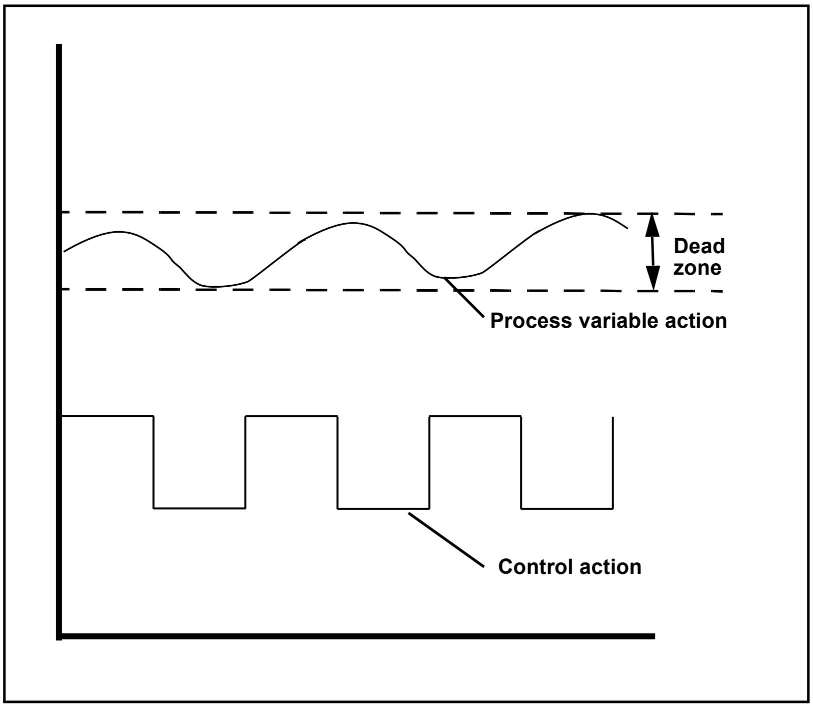
Controller Algorithms

The actions of controllers can be divided into groups based upon the functions of their control mechanism. Each type of contoller has advantages and disadvantages and will meet the needs of different applications. Grouped by control mechanism function, the three types of controllers are:

- ❑ Discrete controllers
- ❑ Multistep controllers
- ❑ Continuous controllers

DISCRETE CONTROLLERS

Discrete controllers are controllers that have only two modes or positions: on and off. A common example of a discrete controller is a home hot water heater. When the temperature of the water in the tank falls below setpoint, the burner turns on. When the water in the tank reaches setpoint, the burner turns off. Because the water starts cooling again when the burner turns off, it is only a matter of time before the cycle begins again. This type of control doesn't actually hold the variable at setpoint, but keeps the variable within proximity of setpoint in what is known as a *dead zone* (Figure 7.15).



Discrete Control

Activities

1. Which one of the following is an everyday example of a discrete controller?
   Select the options that apply.

1 Refrigerator
2 Electric iron
3 Air conditioner
4 Rice cooker

Controller Algorithms

MULTISTEP CONTROLLERS

Multistep controllers are controllers that have at least one other possible position in addition to on and off. Multistep controllers operate similarly to discrete controllers, but as setpoint is approached, the multistep controller takes intermediate steps. Therefore, the oscillation around setpoint can be less dramatic when multistep controllers are employed than when discrete controllers are used (Figure 7.16).

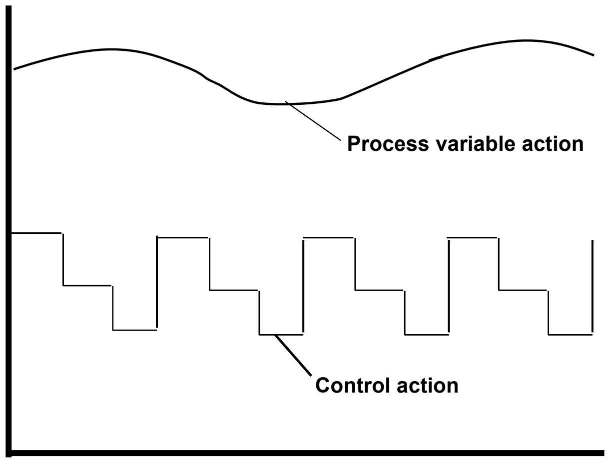


Figure 7.16: Multistep Control Profile

CONTINUOUS CONTROLLERS

Controllers automatically compare the value of the PV to the SP to determine if an error exists. If there is an error, the controller adjusts its output according to the parameters that have been set in the controller. The tuning parameters essentially determine:

How much correction should be made? The *magnitude* of the correction(change in controller output) is determined by the proportional mode of the controller.

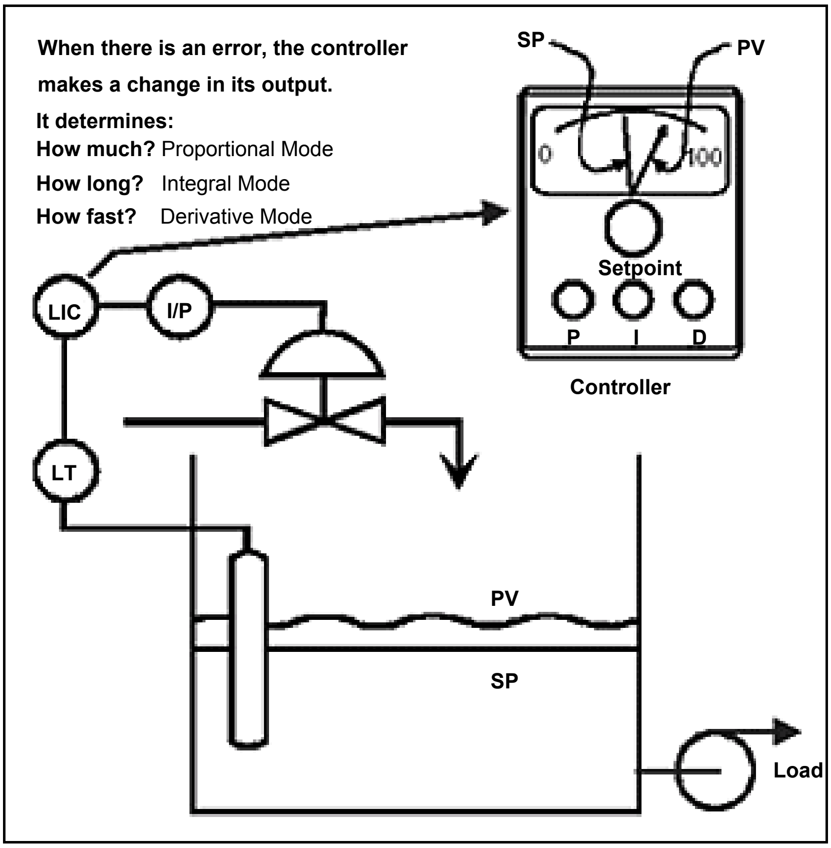
How long should the correction be applied? The *duration* of the adjustment to the controller output is determined by the integral mode of the controller

How fast should the correction be applied? The *speed* at which a correction is made is determined by the derivative mode of the controller.

Activities

2. A controller with three or more set positions is called a continuous controller. Is this statement true or false?

Controller Algorithms



Automatic Feedback Control

Activities

Why Controllers Need Tuning?

Controllers are tuned in an effort to match the characteristics of the control equipment to the process so that two goals are achieved:
is the foundation of process control measurement in that electricity:

- ❑ The system responds quickly to errors.
- ❑ The system remains stable (PV does not oscillate around the SP).

GAIN

Controller tuning is performed to adjust the manner in which a control valve (or other final control element) responds to a change in error. In particular, we are interested in adjusting the *gain* of the controller such that a change in controller input will result in a change in controller output that will, in turn, cause sufficient change in valve position to eliminate error, but not so great a change as to cause instability or cycling.

Gain is defined simply as the change in output divided by the change in input.

Examples:
Change in Input to Controller - 10%
Change in Controller Output - 20%
Gain = 20% / 10% = 2

Change in Input to Controller - 10%
Change in Controller Output - 5%
Gain = 5% / 10% = 0.5
convey measurements and instructions to other instruments in a control loop to maintain the highest level of safety and efficiency.

The next three sections in this module discuss electricity, circuits, transmitters, and signals in greater detail so you can understand the importance of electricity in process control.

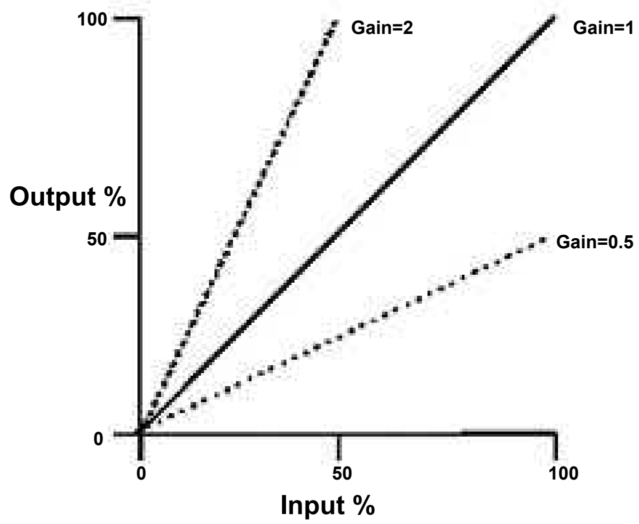
Activities

3. The change in the controller output divided by the change in the input to the controller is known as __________ .

Why Controllers Need Tuning?

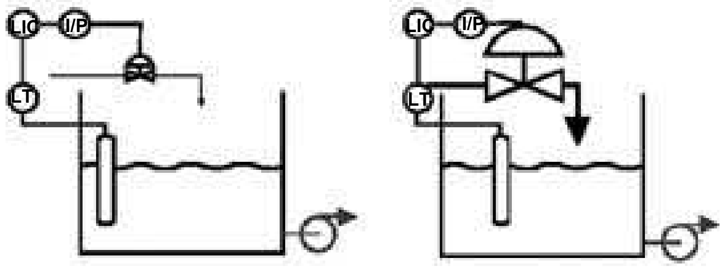
Gain Plot - The Figure below is simply another graphical way of representing the concept of gain.

Gain Kc =Δ Output % / Δ Input %

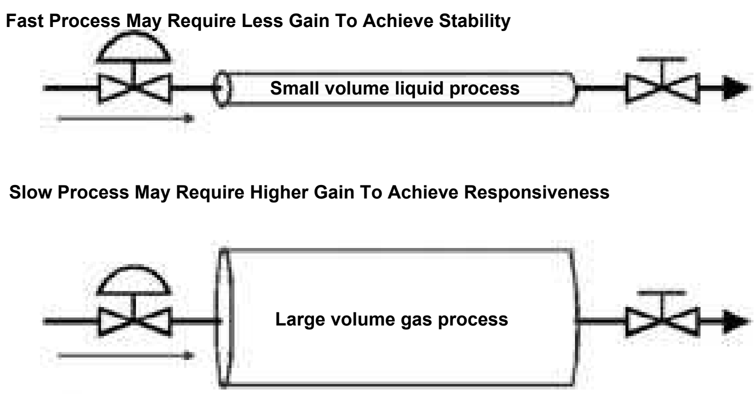


Graphical Representaion of Gain Concept

Examples - The following examples help to illustrate the purpose of setting the controller gain to different values.



Controllers May be Tuned to Help Match the Valve to the Process



Fast and Slow Processes May Require Different Controller Gain Settings

Activities

4. Fast or slow processes have no impact on controller gain settings. Is this statement true or false?

Proportional Mode

PROPORTIONAL ACTION

The proportional mode is used to set the basic gain value of the controller. The setting for the proportional mode may be expressed as either:

1. Proportional Gain
2. Proportional Band

PROPORTIONAL GAIN

In electronic controllers, proportional action is typically expressed as proportional *gain*. Proportional Gain (Kc) answers the question:
"What is the percentage change of the controller output relative to the percentage change in controller input?"
Proportional Gain is expressed as:

Gain, (Kc) = ΔOutput% /ΔInput %

PROPORTIONAL BAND

Proportional Band (PB) is another way of representing the same information and answers this question:
"What percentage of change of the controller input span will cause a 100% change in controller output?"

PB = ΔInput (% Span) For 100%ΔOutput

Converting Between PB and Gain

A simple equation converts *gain to proportional Band:*
added.

PB = 100/Gain

Also recall that:

Gain = 100%/PB

Proportional Gain, (Kc) = ΔOutput% / ΔInput %

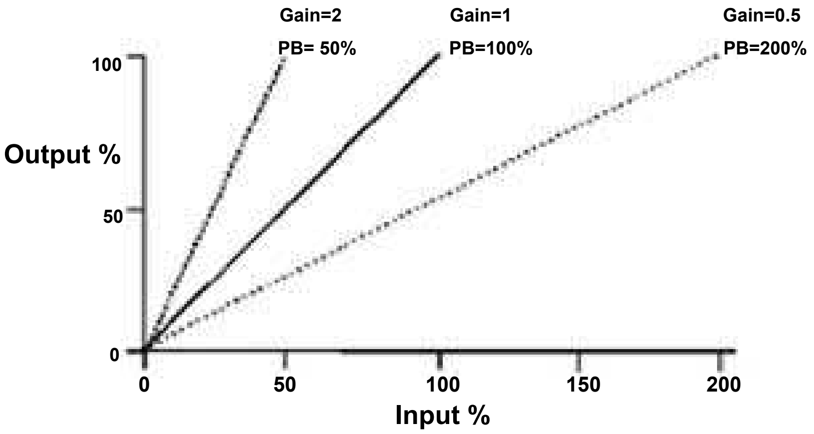
PB= ΔInput(%Span) For 100%ΔOutput

Activities

5. Identify the major disadvantage of proportional action.

1 Tends to leave an offset
2 Reset Windup during shutdown
3 Possible overshoot during startup
4 Can cause cycling in fast process by amplifying noisy signals

Proportional Mode



Relationship of Proportional Gain and Proportional Band

LIMITS OF PROPORTIONAL ACTION

Responds Only to a Change in error - Proportional action responds *only* to a *change in the magnitude* of the error.

Does Not Return the PV to Setpoint - Proportional action will *not* return the PV to setpoint. It will, however, return the PV to a value that is within a defined span (PB) around the PV.

DETERMINING THE CONTROLLER OUTPUT

Controller Output - In a proportional only controller, the output is a function of the change in error and controller gain.

Output Change, % = (Error Change, %) (Gain)

Example: If the setpoint is suddenly changed 10% with a proportional band setting of 50%, the output will change as follows:

Calculating Controller Output

ΔController Output = ΔInput, % X Gain
Gain = 100%/PB

EXAMPLE

ΔInput = 10%
PB = 50%, so Gain = 100%/50% = 2

Activities

6. If proportional gain is 0.5, and a level reading is 5% above setpoint, a proportional controller will signal the outflow control valve to open by <1 / 2.5 / 5> % of its full range.

Proportional Mode

ΔController Output = Δ Input X Gain
ΔController Output = 10% X 2 = 20%

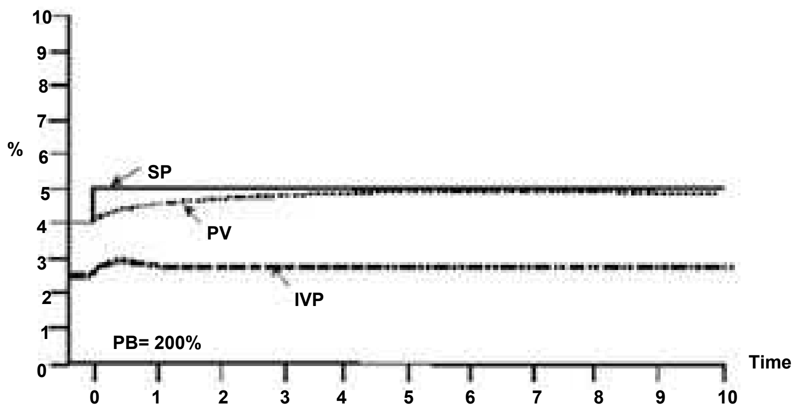
Expressed in Units:

Controller Output Change = (0.2)(12 psi span) = 2.4 psi OR
(0.2)(16 mA span) = 3.2 mA

PROPORTIONAL ACTION - CLOSED LOOP

Loop Gain - Every loop has a critical or natural frequency. This is the frequency at which cycling may exist. This critical frequency is determined by all of the loop components. If the loop gain is too high at this frequency, the PV will cycle around the SP; i.e., the process will become unstable.

Low Gain Example - In the example below, the proportional band is high (gain is low). The loop is very stable, but an error remains between SP and PV.

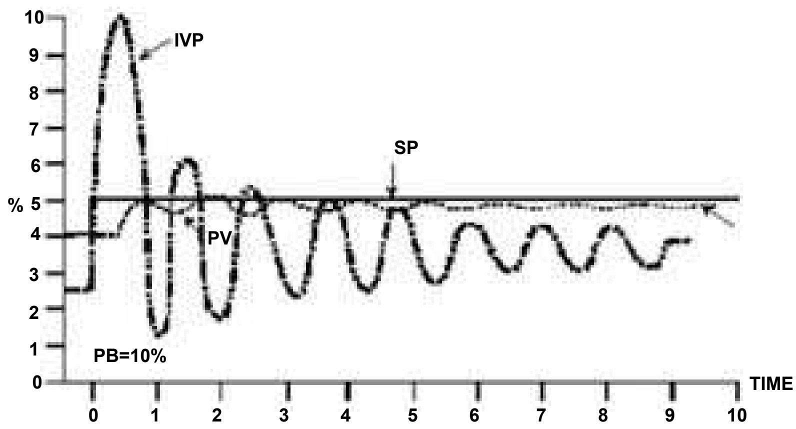


Proportional Control Closed Loop - Low Gain Example

High Gain Example - In the example, the proportional band is small resulting in high gain, which is causing instability. Notice that the process variable is still not on set point.

Activities

Proportional Mode



Proportional Control Closed Loop - High Gain example

Proportional Summary - For the proportional mode, controller output is a function of a change in error. Proportional band is expressed in terms of the percentage change in error that will cause 100% change in controller output. Proportional gain is expressed as the percentage change in output divided by the percentage change in input.

PB = (ΔInput, % / ΔOutput, %) x 100 = 100/Gain

Gain= ΔInput % / ΔOutput %

Δ Controller Output = (Change in Error)(Gain)

1. Proportional Mode Responds only to a change in error
2. Proportional mode alone will not return the PV to SP.

Advantages - Simple

Disadvantages - Error

Settings - PB settings have the following effects:

Small PB (%)	Minimize Offset
High Gain (%)	Possible cycling
Large PB (%)	Large Offset
Low Gain	Stable Loop

Tuning - reduce PB (increase gain) until the process cycles following a disturbance, then double the PB (reduce gain by 50%).

Activities

7. What will be the result if the proportional gain is set too high?

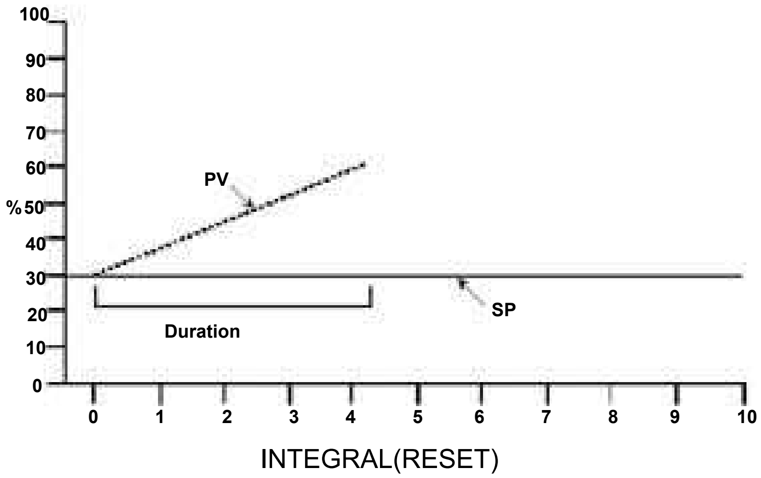
Select all options that apply.

1 Large offset
2 Minimized offset
3 Possible cycling
4 Stable loop

Integral Mode

INTEGRAL ACTION

Duration of Error and Integral Mode - Another component of error is the *duration* of the error, i.e., how long has the error existed? The controller output from the integral or reset mode is a function of the duration of the error.



OPEN LOOP ANALYSIS

Purpose- The purpose of integral action is to return the PV to SP. This is accomplished by repeating the action of the proportional mode as long as an error exists. With the exception of some electronic controllers, the integral or reset mode is always used with the proportional mode.

Setting - Integral, or reset action, may be expressed in terms of:

Repeats Per Minute - How many times the proportional action is repeated each minute.

Minutes Per Repeat - How many minutes are required for 1 repeat to occur.

Activities

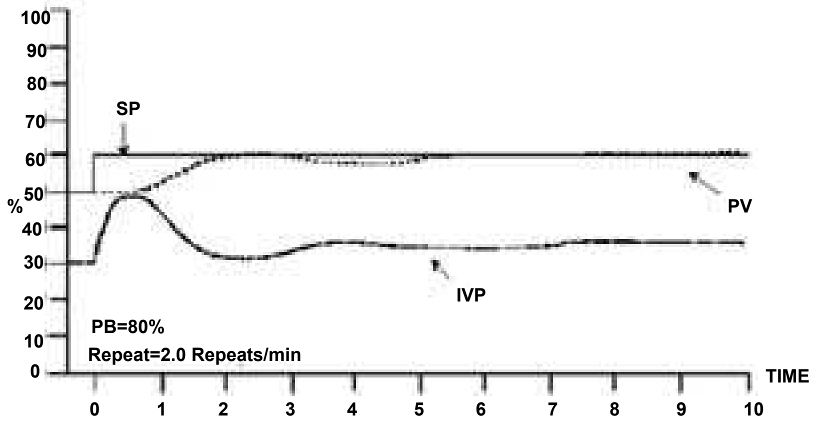
8. _____________ action is the type of control algorithm that eliminates offset.

Integral Mode

Closed Loop Analysis

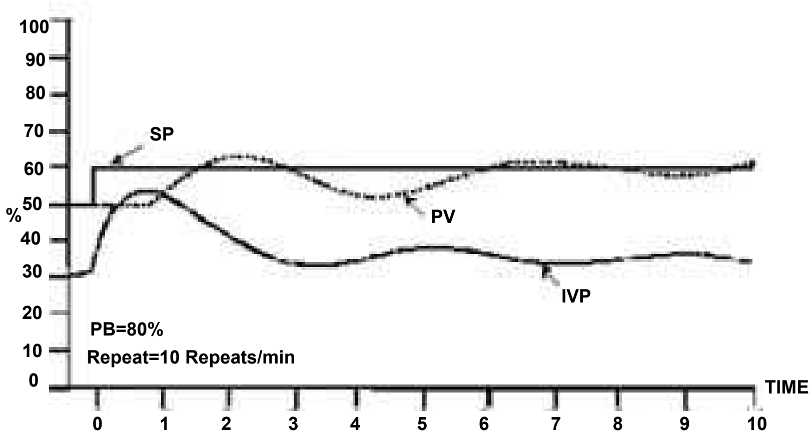
Closed Loop With Reset - Adding reset to the controller adds one more gain component to the loop. The faster the reset action, the greater the gain.

Slow Reset Example - In this example the loop is stable because the total loop gain is not too high at the loop critical frequency. Notice thatthe process variable does reach set point due to the reset action.



SLOW RESET, CLOSED LOOP

Fast Reset Example - In the example the rest is too fast and the PV is cycling around the SP.



FAST RESET, CLOSED LOOP

Activities

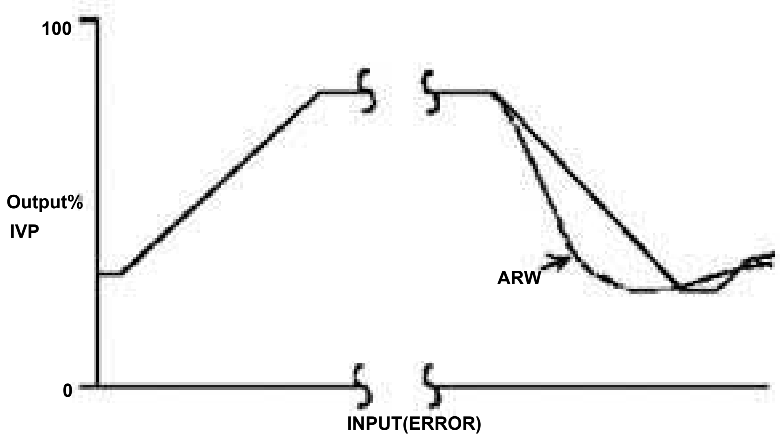
9. Which of the following are integral or reset actions expressed in terms of?
   Select all options that apply.

1 Repeats per setting
2 Repeats per minute
3 Repeats per loop
4 Minutes per repeat

Integral Mode

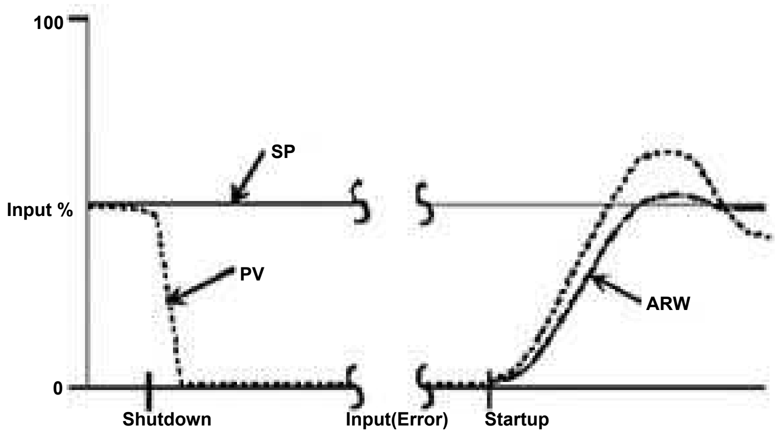
Reset Windup

Defined - Reset windup is described as a situation where the controller output is driven from a desired output level because of a large difference between the set point and the process variable.



Reset Windup - Ant-Reset Windup

Shutdown - Reset windup is common on shut down because the process variable may go to zero but the set point has not changed, therefore this large error will drive the output to one extreme.



Reset Windup - Shutdown and Startup

Startup - At start up, large process variable overshoot may occur because the reset speed prevents the output from reaching its desired value fast enough.

Anti Reset Windup - Controllers can be modified with an anti-reset

Activities

10. Identify the major disadvantages of integral action.
Select all options that apply.

1 Tends to leave an offset
2 Reset windup during shutdown
3 Possible overshoot during start up
4 Can cause cycling in fast process by amplifying noisy signals

Integral Mode

windup (ARW) device. The purpose of an anti-reset option is to allow the output to reach its desired value quicker, therefore minimizing the overshoot.

SUMMARY

Integral (Reset) Summary - Output is a repeat of the proportional action as long as error exists. The units are in terms of repeats per minute or minutes per repeat.

Advantages - Eliminates error

Disadvantages - Reset windup and possible overshoot

Fast Reset	1.High Gain
(Large Repeats/Min.,Small Min./Repeat)	2.Fast Return To Setpoint
	3.Possible Cycling
Slow Reset	1.Low Gain
(Small Repeats/Min.,Large Min./Repeats)	2.Slow Return To Setpoint
	3.Stable Loop

Trailing and Error Tuning - Increase repeats per minute until the PV cycles following a disturbance, then slow the reset action to a value that is 1/3 of the initial setting.

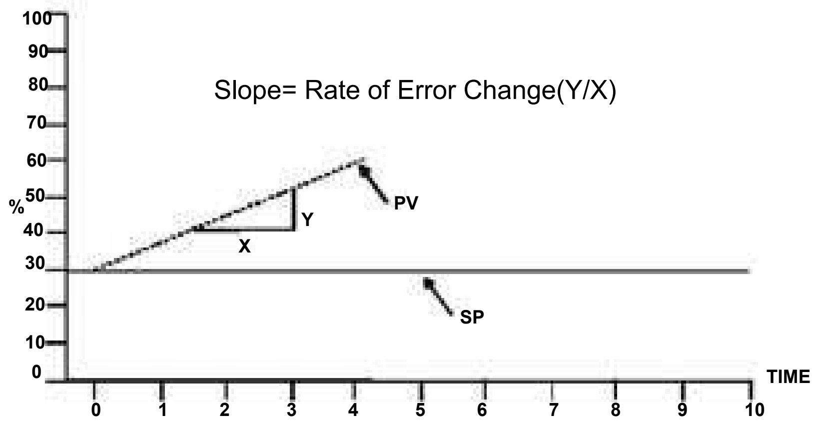
Activities

Derivative Mode

DERIVATIVE ACTION

Derivative Mode Basics - Some large and/or slow process do not respond well to small changes in controller output. For example, a large liquid level process or a large thermal process (a heat exchanger) may react very slowly to a small change in controller output. To improve response, a large initial change in controller output may be applied. This action is the role of the derivative mode.

The derivative action is initiated whenever there is a *change in the rate of change of the error* (the slope of the PV). The magnitude of the derivative action is determined by the setting of the derivative . The mode of a PID controller and the rate of change of the PV. The Derivative setting is expressed in terms of *minutes.* In operation, the the controller first compares the current PV with the last value of the PV. If there is a change in the slope of the PV, the controller etermines what its output would be at a future point in time (the future point in time is determined by the value of the derivative setting, in minutes). The derivative mode *immediately* increases the output by that amount.



Derivative Action is based on the rate of change in Error (Y/X)

Activities

11. ___________ action is a control algorithm that is tied to the rate of change in the error.

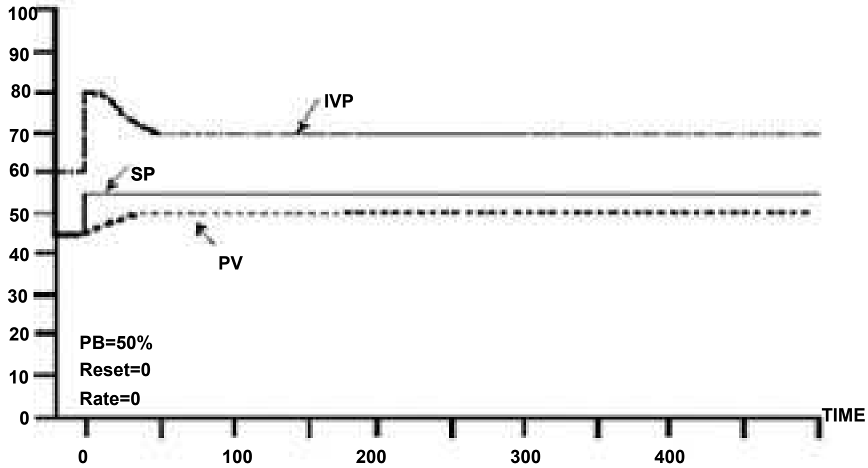
12. Which of the following are derivative or rate actions expressed in terms of?

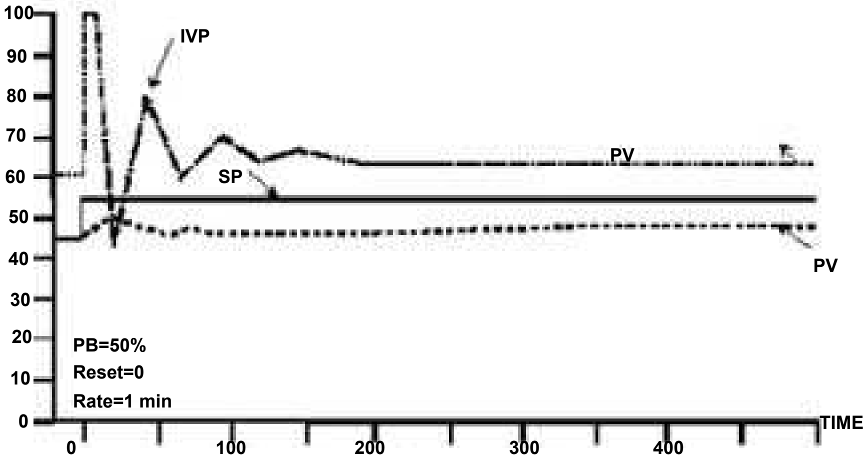
1. Repeats per minute
2. Hours
3. Seconds
4. Minutes
5. Milliseconds

Derivative Mode

Example - Let's start a closed loop example by looking at a temperature control system. IN this example, the time scale has been lengthened to help illustrate controller actions in a slow process. Assume a proportional band settingof 50%. There is no reset at this time. The proportional gain of 2 acting on a 10% change in set pint results in a change in controller output of 20%. Because temperature is a slow process the setting time after a change in error is quite long. And, in this example, the PV never becomes equal to the SP because there is no reset.

Rate Effect - To illustrate the effect of rate action, we will add the are mode with a setting of 1 minute. Notice the very large controller output at time 0. The output spike is the result of rate action. Recall that the change in output due to rate action is a function of the *speed (rate) of change of error,* which in a step is nearly infinite. The addition of rate alone will not cause the process variable to match the set point.





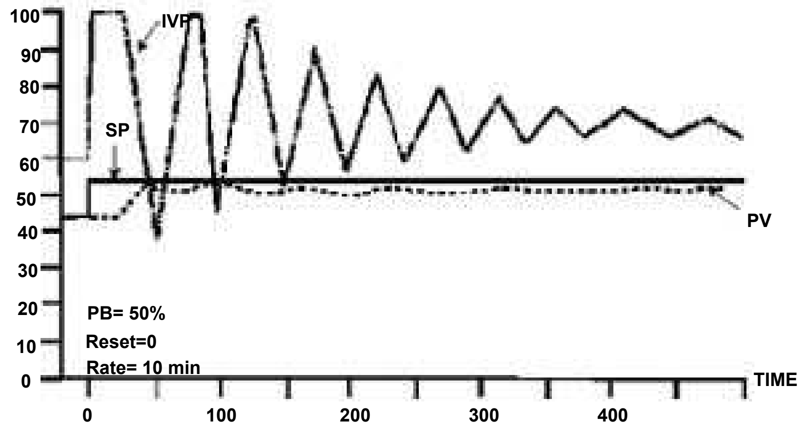
No Rate, Small Rate examples, Closed Loop

Activities

13. The addition of derivative or rate alone to a close loop control can cause the process variable to match the set point. Is this statement true or false?

Derivative Mode

Effect of Fast Rate - Let's now increase the rate setting to 10 minutes. The controller gain is now much higher. As a result, both the IVP (controller output) and the PV are cycling. The point here is that increasing the rate setting will not cause the PV to settle at the SP.



P+D, High Rate Setting, Closed Loop Analysis

Need for Reset Action - It is now clear that reset must be added to bring process variable back to set point.

Applications - Because this component of the controller output is dependent on the *speed of change* of the input or error, the output will be very erratic if rate is used on fast process or one with noisy signals. The controller output, as a result of rate, will have the greatest change when the input changes rapidly.

Controller Option to Ignore Change in SP - Many controllers, especially digital types, are designed to respond to changes in the PV only, and to ignore changes in SP. This feature eliminates a major upset upset that would occur following a change in the setpoint.

Activities

Derivative Mode

SUMMARY

Derivative (Rate) Sumary - Rate action is a function of the *speed of change* of the error. The units are *minutes.* The action is to apply an immediate response that is equal to the proportional plus reset action that would have occurred some number of minutes I the future.

Advantages - Rapid output reduces the time that is required to return PV to SP in slow process.

Disadvantage - Dramatically amplifies noisy signals; can cause cycling in fast processes.

Settings

Large (Minutes)	1.High Gain 2.Large Output Change 3.Possible Cycling
Small (Minutes)	1.Low Gain 2.Small Output Change 3.Stable Loop

Trial-and-Error Tuning

Increase the rate setting until the process cycles following a disturbance, then reduce the rate setting to one-third of the initial value.

Activities

Controller Algorithms

Proportional, PI, and PID Control

By using all three control algorithms together, process operators can:

- ❑ Achieve rapid response to major disturbances with derivative control
- ❑ Hold the process near setpoint without major fluctuations with proportional control
- ❑ Eliminate offset with integral control

Not every process requires a full PID control strategy. If a small offset has no impact on the process, then proportional control alone may be sufficient.

PI control is used where no offset can be tolerated, where *noise* (temporary error readings that do not reflect the true process variable condition) may be present, and where excessive *dead time* (time after a disturbance before control action takes place) is not a problem.

In processes where no offset can be tolerated, no noise is present, and where dead time is an issue, customers can use full PID control. Table 7.2 shows common types of control loops and which types of control algorithms are typically used.

Controlled Variable	Proportional Control	PI Control	PID Control
Flow	Yes	Yes	No
Level	Yes	Yes	Rare
Temperature	Yes	Yes	Yes
Pressure	Yes	Yes	Rare
Analytical	Yes	Yes	Rare

Table 7.2: Control Loops and Control Algorithms

Activities

14. What type of control is used in an application where noise is present, but where no offset can be tolerated?

1 P only
2 PD
3 PI
4 PID

COMPLETE WORKBOOK EXERCISE - CONTROLLER ALGORITHMS AND TUNING

Process Control Loops

In this section, you will learn about how control components and control algorithms are integrated to create a process control system. Because in some processes many variables must be controlled, and each variable can have an impact on the entire system, control systems must be designed to respond to disturbances at any point in the system and to mitigate the effect of those disturbances throughout the system.

LEARNING OBJECTIVES

After completing this section, you will be able to:

- ❑ Explain how a multivariable loop is different from a single loop.
- ❑ Differentiate feedback and feedforward control loops in terms of their operation, design, benefits, and limitations
- ❑ Perform the following functions for each type of standard process control loop (i.e., pressure, flow, level, and temperature):
  - State the type of control typically used and explain why it is used
  - Identify and describe considerations for equipment selection (e.g., speed, noise)
  - Identify typical equipment requirements
  - Diagram the loop using ISA symbology
- ❑ Explain the basic implementation process, including a description of equipment requirements and considerations, for each of the following types of control:
  - Cascade control
  - Batch control
  - Ratio control
  - Selective control
  - Fuzzy control
- ❑ Describe benefits and limitations of each type of control listed above
- ❑ Give examples of process applications in which each type of control described in this section might be used

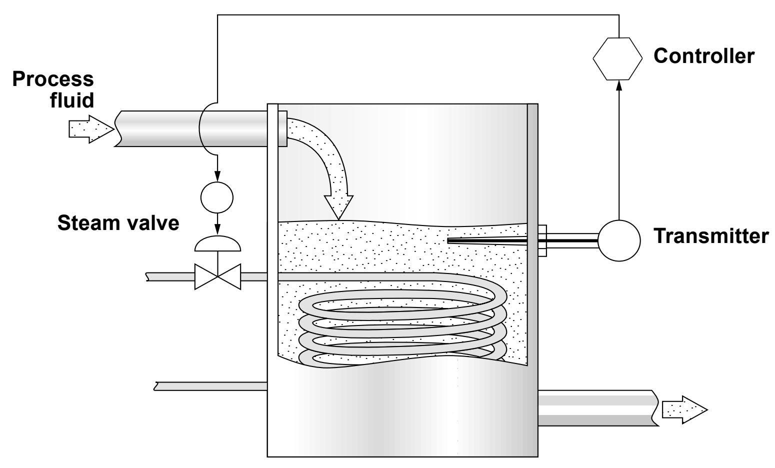
Note: To answer the activity questions the Hand Tool (H) should be activated.

Single Control Loops

Control loops can be divided into two categories: Single variable loops and multi-variable loops.

FEEDBACK CONTROL

A *feedback loop* measures a process variable and sends the measurement to a controller for comparison to setpoint. If the process variable is not at setpoint, control action is taken to return the process variable to setpoint. Figure 7.18 illustrates a feedback loop in which a transmitter measures the temperature of a fluid and, if necessary, opens or closes a hot steam valve to adjust the fluid's temperature.



Feedback Loop

An everyday example of a feedback loop is the cruise control system in an automobile. A setpoint is established for speed. When the car begins to climb a hill, the speed drops below setpoint and the controller adjusts the throttle to return the car's speed to setpoint.

Feedback loops are commonly used in the process control industry. The advantage of a feedback loop is that it directly controls the desired process variable. The disadvantage to feedback loops is that the process variable must leave setpoint for action to be taken.

Activities

1. What type of control loop takes action in response to measured deviation from setpoint?

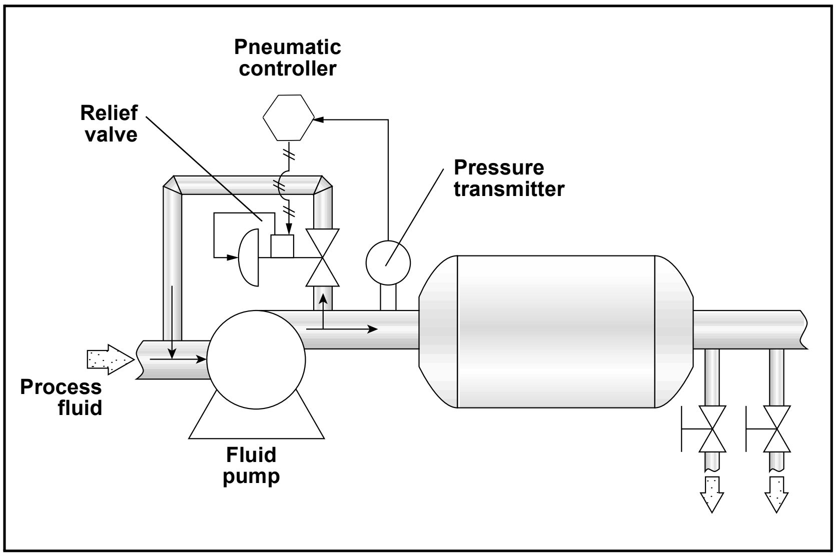
1 Discrete control loop
2 Multi-step control loop
3 Open loop
4 Feedback control loop

Examples of Single Control Loops

While each application has its own characteristics, some general statements can be made about pressure, flow, level, and temperature loops.

PRESSURE CONTROL LOOPS

Pressure control loops vary in speed—that is, they can respond to changes in load or to control action slowly or quickly. The speed required in a pressure control loop may be dictated by the volume of the process fluid. High-volume systems (e.g., large natural gas storage facilities) tend to change more slowly than low-volume systems (Figure 7.21).



A Pressure Loop

Activities

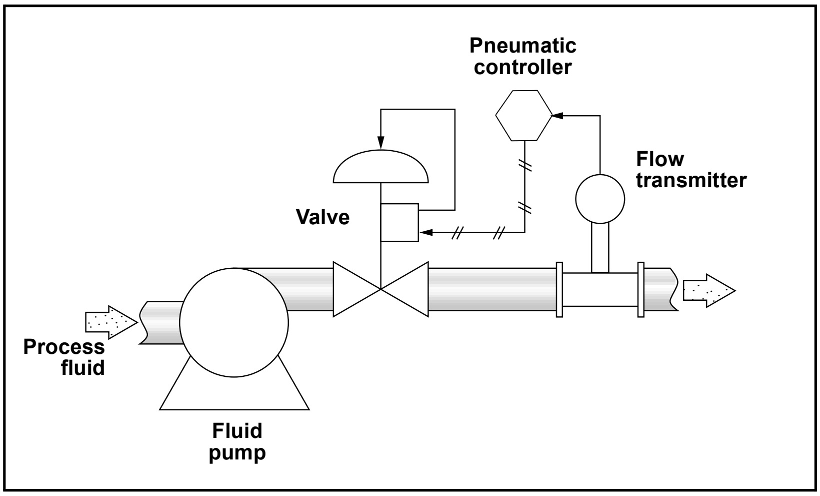
2. How does a high-volume pressure control loop react as compared to a small-volume pressure control loop?

1 Same rate
2 Quicker
3 Slower
4 Extremely fast

Examples of Single Control Loops

FLOW CONTROL LOOPS

Generally, flow control loops are regarded as fast loops that respond to changes quickly. Therefore, flow control equipment must have fast sampling and response times. Because flow transmitters tend to be rather sensitive devices, they can produce rapid fluctuations or noise in the control signal. To compensate for noise, many flow transmitters have a damping function that filters out noise. Sometimes, filters are added between the transmitter and the control system. Because the temperature of the process fluid affects its density, temperature measurements are often taken with flow measurements and compensation for temperature is accounted for in the flow calculation. Typically, a flow sensor, a transmitter, a controller, and a valve or pump are used in flow control loops (Figure 7.22).



A Flow Loop

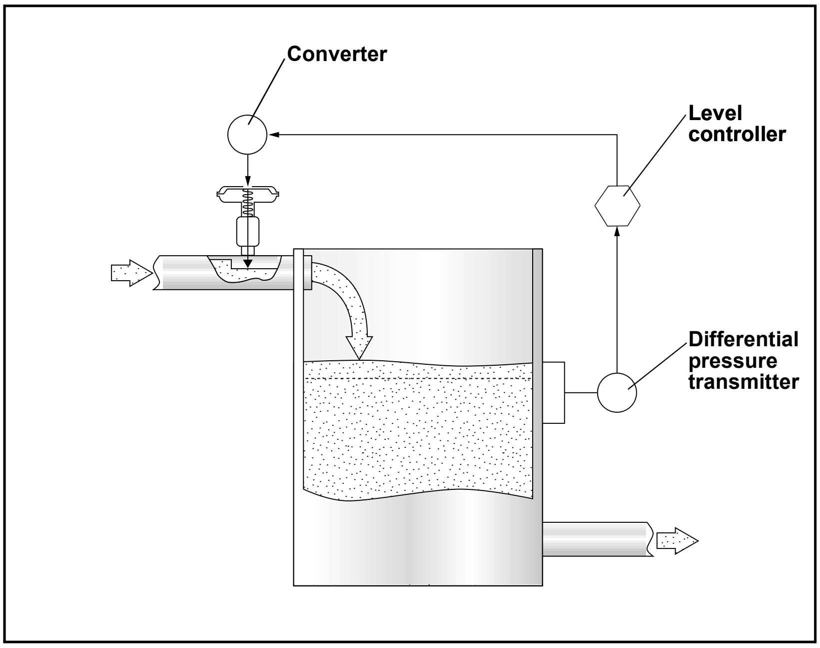
Activities

3. Flow control loops are generally considered to be slow responding loops. Is this statement true or false?

Examples of Single Control Loops

LEVEL CONTROL LOOPS

The speed of changes in a level control loop largely depends on the size and shape of the process vessel (e.g., larger vessels take longer to fill than smaller ones) and the flow rate of the input and outflow pipes. Manufacturers may use one of many different measurement technologies to determine level, including radar, ultrasonic, float gauge, and pressure measurement. The final control element in a level control loop is usually a valve on the input and/or outflow connections to the tank (Figure 7.23). Because it is often critical to avoid tank overflow, redundant level control systems are sometimes employed.



A Level Loop

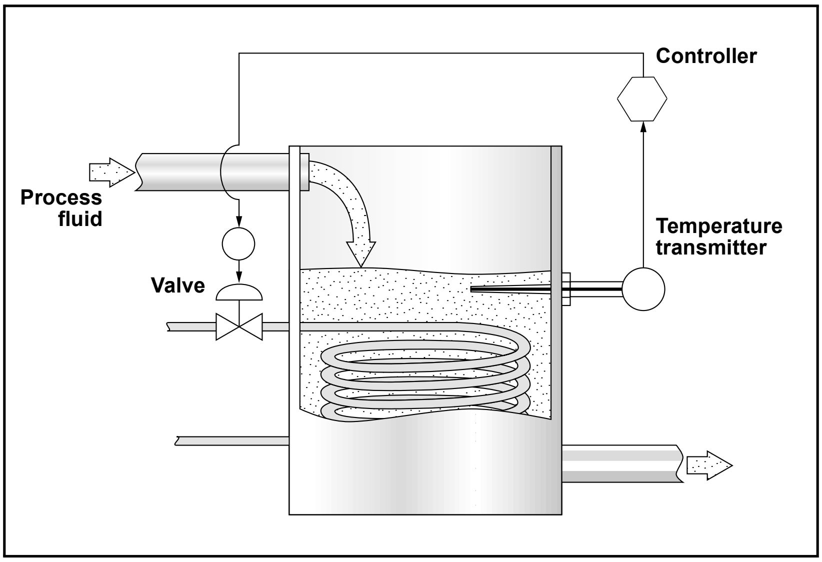
Activities

4. Redundant control systems are sometimes used in level applications because preventing tank overflow is often critically important. Is this statement true or false?

Examples of Single Control Loops

TEMPERATURE CONTROL LOOPS

Because of the time required to change the temperature of a process fluid, temperature loops tend to be relatively slow. Feedforward control strategies are often used to increase the speed of the temperature loop response. RTDs or thermocouples are typical temperature sensors. Temperature transmitters and controllers are used, although it is not uncommon to see temperature sensors wired directly to the input interface of a controller. The final control element for a temperature loop is usually the fuel valve to a burner or a valve to some kind of heat exchanger. Sometimes, cool process fluid is added to the mix to maintain temperature (Figure 7.24).



A Temperature Loop

Activities

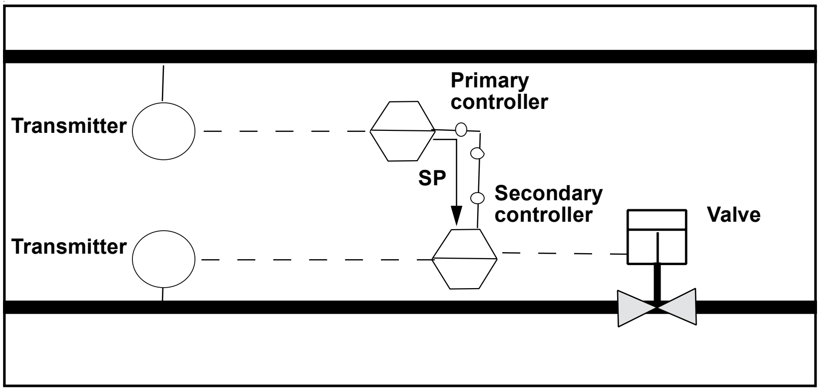
5. What type of control strategy is often used to increase the speed of a temperature control loop?

1 Feedforward control
2 Feedback control
3 Cascade control
4 Ratio control

Multi-Variable / Advanced Control Loops

MULTIVARIABLE LOOPS

Multivariable loops are control loops in which a primary controller controls one process variable by sending signals to a controller of a different loop that impacts the process variable of the primary loop. For example, the primary process variable may be the temperature of the fluid in a tank that is heated by a steam jacket (a pressurized steam chamber surrounding the tank). To control the primary variable (temperature), the primary (master) controller signals the secondary (slave) controller that is controlling steam pressure. The primary controller will manipulate the setpoint of the secondary controller to maintain the setpoint temperature of the primary process variable (Figure 7.17).



Multivariable Loop

When tuning a control loop, it is important to take into account the presence of multivariable loops. The standard procedure is to tune the secondary loop before tuning the primary loop because adjustments to the secondary loop impact the primary loop. Tuning the primary loop will not impact the secondary loop tuning.

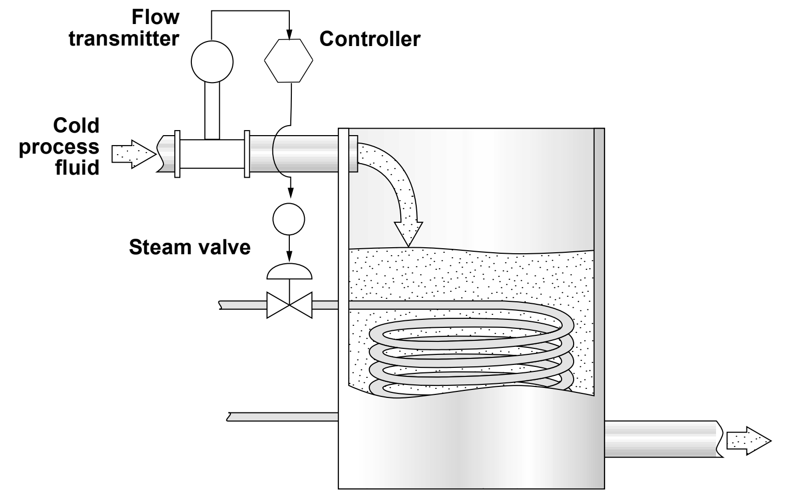
Activities

6. A multivariable control loop contains a primary and secondary controller assigned to different process variables? Is this statement true or false?

Multi-Variable / Advanced Control Loops

FEEDFORWARD CONTROL

Feedforward control is a control system that anticipates load disturbances and controls them before they can impact the process variable. For feedforward control to work, the user must have a mathematical understanding of how the manipulated variables will impact the process variable. Figure 7.19 shows a feedforward loop in which a flow transmitter opens or closes a hot steam valve based on how much cold fluid passes through the flow sensor.



Feedforward Control

An advantage of feedforward control is that error is prevented, rather than corrected. However, it is difficult to account for all possible load disturbances in a system through feedforward control. Factors such as outside temperature, buildup in pipes, consistency of raw materials, humidity, and moisture content can all become load disturbances and cannot always be effectively accounted for in a feedforward system.

In general, feedforward systems should be used in cases where the controlled variable has the potential of being a major load disturbance on the process variable ultimately being controlled. The added complexity and expense of feedforward control may not be equal to the benefits of increased control in the case of a variable that causes only a small load disturbance.

Activities

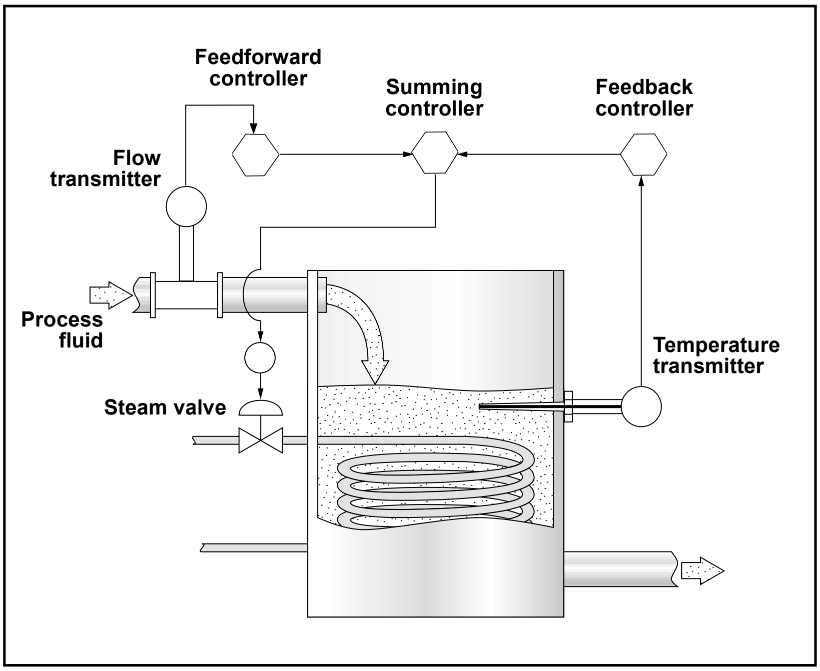
7. What type of control loop anticipates and controls load disturbances before they can impact the process variable?

1 Feedback control loop
2 Feedforward control loop
3 Ratio control loop
4 Single variable loop

Multi-Variable / Advanced Control Loops

FEEDFORWARD PLUS FEEDBACK

Because of the difficulty of accounting for every possible load disturbance in a feedforward system, feedforward systems are often combined with feedback systems. Controllers with summing functions are used in these combined systems to total the input from both the feedforward loop and the feedback loop, and send a unified signal to the final control element. Figure 7.20 shows a feedforward-plus-feedback loop in which both a flow transmitter and a temperature transmitter provide information for controlling a hot steam valve.



Feedforward Plus Feedback Control System

Activities

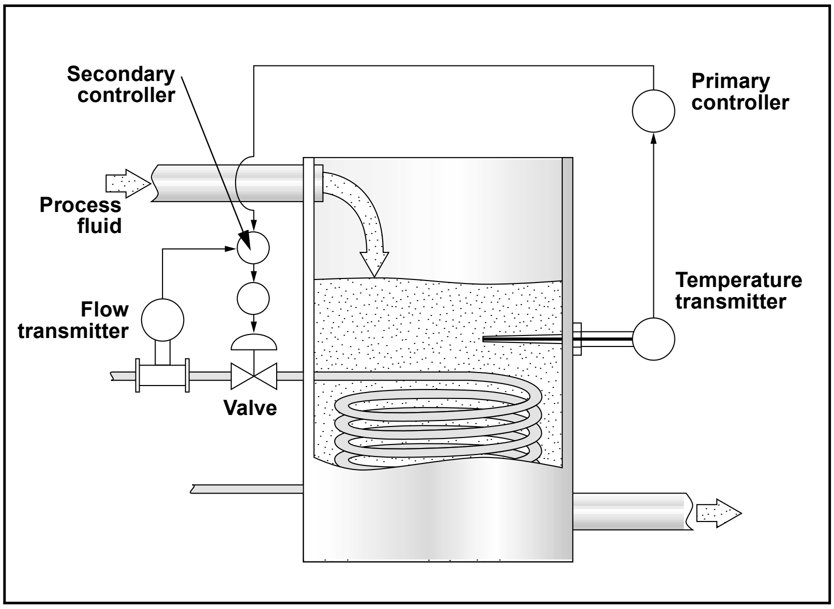
8. A controller with a summing function totals the input from both the feedforward loop and the feedback loop and sends a unified signal to the final control element. This is how a single control signal is sent to the final control element in a feedforward plus feedback system. Is this statement true or false?

Multi-Variable / Advanced Control Loops

This module has discussed specific types of control loops, what components are used in them, and some of the applications (e.g., flow, pressure, temperature) they are applied to. In practice, however, many independent and interconnected loops are combined to control the workings of a typical plant. This section will acquaint you with some of the methods of control currently being used in process industries.

CASCADE CONTROL

Cascade control is a control system in which a secondary (slave) control loop is set up to control a variable that is a major source of load disturbance for another primary (master) control loop. The controller of the primary loop determines the setpoint of the summing contoller in the secondary loop (Figure 7.25).



Cascade Control

Activities

9. Ratio control is the term used to describe a system in which the controller of the primary loop determines the setpoint of a secondary loop. Is this statement true or false?

Multi-Variable / Advanced Control Loops

Batch Control

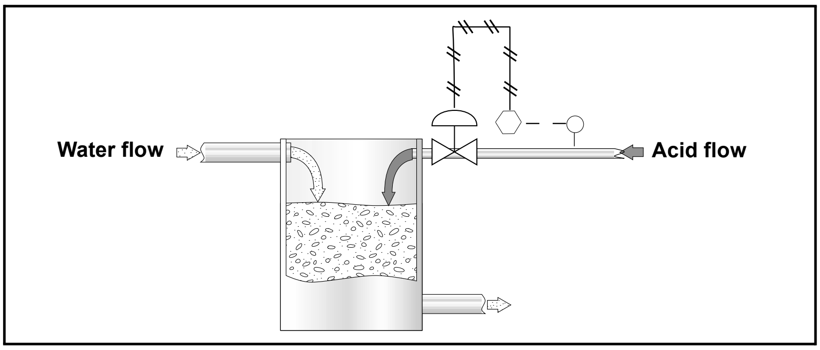
Batch processes are those processes that are taken from start to finish in batches. For example, mixing the ingredients for a juice drinks is often a batch process. Typically, a limited amount of one flavor (e.g., orange drink or apple drink) is mixed at a time. For these reasons, it is not practical to have a continuous process running. Batch processes often involve getting the correct proportion of ingredients into the batch. Level, flow, pressure, temperature, and often mass measurements are used at various stages of batch processes.

A disadvantage of batch control is that the process must be frequently restarted. Start-up presents control problems because, typically, all measurements in the system are below setpoint at start-up. Another disadvantage is that as recipes change, control instruments may need to be recalibrated.

Ratio Control

Imagine a process in which an acid must be diluted with water in the proportion two parts water to one part acid. If a tank has an acid supply on one side of a mixing vessel and a water supply on the other, a control system could be developed to control the ratio of acid to water, even though the water supply itself may not be controlled. This type of control system is called *ratio control (*Figure 7.26). Ratio control is used in many applications and involves a contoller that receives input from a flow measurement device on the unregulated (wild) flow. The controller performs a ratio calculation and signals the appropriate setpoint to another controller that sets the flow of the second fluid so that the proper proportion of the second fluid can be added.

Ratio control might be used where a continuous process is going on and an additive is being put into the flow (e.g., chlorination of water).



Ratio Control

Activities

10. Which term describes a control system in which controlled flow is added proportionately to an uncontrolled flow?

1 Selective control
2 Cascade control
3 Ratio control
4 Fuzzy control

Multi-Variable / Advanced Control Loops

SELECTIVE CONTROL

Selective control refers to a control system in which the more important of two variables will be maintained. For example, in a boiler control system, if fuel flow outpaces air flow, then uncombusted fuel can build up in the boiler and cause an explosion. Selective control is used to allow for an air-rich mixture, but never a fuel-rich mixture. Selective control is most often used when equipment must be protected or safety maintained, even at the cost of not maintaining an optimal process variable setpoint.

FUZZY CONTROL

Fuzzy control is a form of adaptive control in which the controller uses fuzzy logic to make decisions about adjusting the process. *Fuzzy logic* is a form of computer logic where whether something is or is not included in a set is based on a grading scale in which multiple factors are accounted for and rated by the computer. The essential idea of fuzzy control is to create a kind of artificial intelligence that will account for numerous variables, formulate a theory of how to make improvements, adjust the process, and learn from the result.

Fuzzy control is a relatively new technology. Because a machine makes process control changes without consulting humans, fuzzy control removes from operators some of the ability, but none of the responsibility, to control a process.

Activities

11. In which type of control system will the more important of two variables be maintained?

    1 Fuzzy control
    2 Cascade control
    3 Ratio control
    4 Selective control

12. ______________ control is the term used to describe a control system in which the controller uses computer logic to make decisions about adjusting the process.

COMPLETE WORKBOOK EXERCISE - PROCESS CONTROL LOOPS

Module 7: Workbook Exercises

EXERCISE 7.1— THE IMPORTANCE OF PROCESS CONTROL

1. Which of the following options best represents the reasons to control a process? (Select three options that apply)

   (1) Reduce variability
   (2) Increase productivity
   (3) Increase efficiency
   (4) Reduce cost
   (5) Ensure safety

2. Process is defined as the method of changing or refining raw materials to create end products. Is this statement true or false?

   (1) True
   (2) False

3. Which of the following are advantages of reducing variability in a process application?

   (1) Helps ensure a consistently high-quality end product.
   (2) Helps ensure an increase in the reaction rate of the process.
   (3) Helps ensure increase in efficiency of the process.
   (4) Helps ensure safety

Module 7: Workbook Exercises

EXERCISE 7.2 — CONTROL THEORY BASICS

1. Which of the following tasks is associated with process control? (Select three options that apply)

   (1) Measurement
   (2) Comparison
   (3) Quality Analysis
   (4) Adjustment
   (5) Calculation

2. Which of the following variables are commonly measured or monitored in process control applications? (Select three options that apply)

   (1) Pressure
   (2) Viscosity
   (3) Nitrogen content
   (4) Flow rate
   (5) Temperature

3. A process liquid level needs to be held within 5 ft of 150 ft in a large tank. A pressure transmitter monitors the liquid's level using a pressure reading and sends the result to a controller. The controller compares the level reading to the set point and opens or closes an inflow or outflow pipe depending on the liquid level. Keeping in mind the given scenario, match the terms in Column A with their values in Column B.

(1)	Inferred process variable	(A)	150 ft
(2)	Manipulated variable	(B)	Pressure
(3)	Measured variable	(C)	Flow of liquid to the tank
(4)	Set point	(D)	Level

Module 7: Workbook Exercises

4. Match each term to its correct definition.

(1) Load disturbance
(2) Control algorithm
(3) Manual control
(4) Manipulated variable
(5) Set point

(A) The factor that is changed to keep a measured variable at set point.
(B) An undesired change in a factor that can affect the process variable.
(C) A value or range of values for a process variable that must be maintained to keep the process running properly.
(D) A control operation that directly involves human action.
(E) A mathematical expression of a control function

5. Match each term to its correct description.

(1) Closed-loop, automatic control _____
(2) Closed-loop, manual control _____
(3) Open-loop, automatic control _____

(A) An operator turns off the heater coil when the temperature transmitter outputs a certain reading.
(B) A controller turns off the heater coil at set intervals, regardless of the process temperature.
(C) A temperature sensor measures process temperature, sends the result to a controller to compare to the setpoint, and the controller turns off the heater coil.

6. __________ is a deviation from set point due to load disturbance.

(1) Error
(2) Offset
(3) Rate of change

7. __________ is a continuing error due to the inability of a control system to keep the measured variable at set point.

(1) Load disturbance
(2) Offset
(3) Pressure

Module 7: Workbook Exercises

EXERCISE 7.3 — COMPONENTS OF CONTROL LOOPS AND ISA SYMBOLOGY

1. The basic function of a __________ is to convert a reading from a transducer into a standard signal and transmit that signal to a controller or computer monitor.

   (1) recorder
   (2) transmitter
   (3) converter

2. 4–20 m*A* is the most common standard analog signal used in the process control industry today. Is this statement true or false?

   (1) True
   (2) False

3. Match the signal type in Column A with its example/application in Column B.

(1)	Analog signal	(A)	3 –15 psig
(2)	Pneumatic signal	(B)	Fieldbus, Profibus and Modbus
(3)	Digital signal	(C)	4-20 m*A* and 1 – 5 *V*

4. A customer would use __________to read the temperature of a process fluid on a display.

   (1) an indicator
   (2) a volt-meter
   (3) an actuator

5. Match each control loop equipment to its correct description.

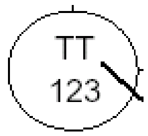
   (1) Recorder _____
   (2) Controller _____
   (3) Final control element _____
   (4) Actuator _____

6. A pump motor is the most commonly used final control element. Is this statement true or false?

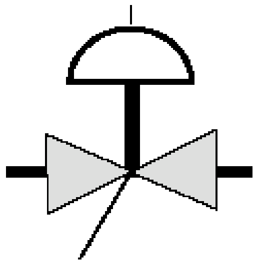
   (1) True
   (2) False

Module 7: Workbook Exercises

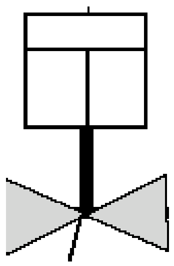
7. Match the ISA symbols in Column A with its respective description in Column B.

(1)


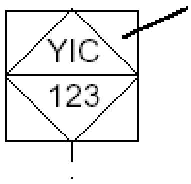
(A) Programmable logic control

(2)


(B) Temperature transmitter

(3)


(C) Pneumatically actuated valve

(4)


(D) Electrically actuated valve

Module 7: Workbook Exercises

EXERCISE 7.4 — CONTROL ALGORITHMS AND TUNING

1. Match each term to its correct definitions.

   (1) Proportional band
   (2) Proportional/integral (PI) control
   (3) Proportional control
   (4) Derivative control
   (5) Integral control

   (A) A type of control that corrects error and eliminates offset.
   (B) A type of control that produce erratic output in noisy applications.
   (C) The percent change in error that will cause a 100% change in controller output.
   (D) A type of control that is prone to leaving an offset.
   (E) A type of control that repeats the action of the proportional mode as long as an error exists.

2. Identify the two effects on a process variable if the proportional gain (Pgain) is set too high? (Select all that apply)

   (1) Minimize offset
   (2) Large offset
   (3) Stable loop
   (4) Possible cycling

3. Derivative gain (Dgain) is typically set to zero in flow applications since flow applications are usually noisy and derivative control will react to readings that are in fact noise, thus preventing the process from holding set point. Is this statement true or false?

   (1) True
   (2) False

Module 7: Workbook Exercises

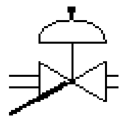
EXERCISE 7.5 — PROCESS CONTROL LOOPS

1. Which control system anticipates load disturbances and controls them before they can impact the process variable?

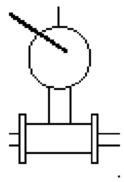
   (1) Selective control
   (2) Fuzzy control
   (3) Feed forward control
   (4) Cascade control

2. Match the component label in Column A to its ISA symbol representation in Column B.

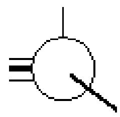
   (1) Flow transmitter — (A)



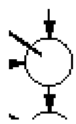
   (2) Temperature transmitter — (B)



   (3) Flow controller — (C)



   (4) Valve — (D)



3. If $R_1 = 60\ \Omega$, $R_2 = 100\ \Omega$, and $R_3 = 100\ \Omega$, what is the equivalent resistance (R_{eq}) in the circuit?

   (1) slow
   (2) fast
   (3) variable speed

Module 7: Workbook Exercises - Answers

Exercise 7.1 – The Importance of Process Control

1. 1, 3, 5
2. 1
3. 1

Exercise 7.2 – Control Theory Basics

1. 1, 2, 4
2. 1, 4, 5
3. D, C, B, A
4. B, E, D, A, C
5. C, A, B
6. 1
7. 2

Exercise 7.3 – Components of Control Loops and ISA Symbology

1. 2
2. 1
3. C, A, B
4. 1
5. C, D, B, A
6. 2
7. B, C, D, A

Exercise 7.4 – Control Algorithms and Tuning

1. C, A, D, B, E
2. 1, 4
3. 1

Exercise 7.5 – Process Control Loops

1. 3
2. B, C, D, A
3. 1

Module 7: Activity Answers

The Importance of Process Control

1. True
2. 1,3,5
3. 1,2,4

Control Theory Basics

1. True
2. True
3. True
4. 4
5. 3
6. False
7. False
8. 2,4

Components of Control Loops and ISA Symbology

1. 1,2,5
2. False
3. 3
4. True
5. 2,3,4
6. 1
7. 1,4
8. 2
9. 4
10. 3
11. 1
12. 2
13. 1
14. 2
15. 3
16. True
17. 4
18. True
19. True
20. 1
21. 3

Module 7: Activity Answers

Controller Algorithms and Tuning

1. 1,2,3,4
2. False
3. 2
4. False
5. 1
6. 2.5
7. 2,3
8. 3
9. 2,4
10. 2,3
11. 2
12. 4
13. False
14. 3

Process Control Loops

1. 4
2. 3
3. False
4. True
5. 1
6. True
7. 2
8. True
9. False
10. 3
11. 4
12. 1