ANALYTICAL PROCESS CONTROL

9
LEARNING ACTIVITY PACKET

METHODS OF AUTOMATIC CONTROL

AMATROL®

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METHODS OF AUTOMATIC CONTROL

INTRODUCTION

This LAP covers the operation of three common automatic control methods: proportional, integral, and derivative (PID). Proportional control provides a basic automatic control method while the other two are added to it, depending on the needs of the system. PID control is used in electronic controllers, PLCs, and software packages to provide accurate process control.

ITEMS NEEDED

Amatrol Supplied
- 1 T5554 Analytical Process Control Learning System
- 1 T5554-C1-A Single-Loop PID Controller or
  T5554-C2-A Dual-Loop PID Controller

School Supplied
- 1 Water Supply
- 1 120 VAC Electrical Supply

FIRST EDITION, LAP 9, REV. A

Amatrol,Inc., 2400 Centennial Blvd., Jeffersonville, IN 47130 USA, Ph 812-288-8285, FAX 812-283-1584 www.amatrol.com

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SEGMENT 1

PERFORMANCE CONCEPTS

OBJECTIVE 1 DEFINE STEADY AND TRANSIENT CONTROL SYSTEM STATES

Read This

A control system operates in one of two states: steady or transient. A steady state is defined as when the average of the process output remains constant over time. This typically occurs when the process output settles near or reaches its setpoint. A transient state is defined as when the output continuously changes over time. A transient state occurs when the process output is changed from one setpoint to another or when a disturbance occurs.

Figure 1 shows an example of a process systems response to a change in setpoint. In time period A, the process output is in a steady state at setpoint 1 (SP1). At the beginning of time period B, the operator changes the setpoint to SP2. This causes the system to enter a transient state where the output changes to its new setpoint over a period of time. The output makes several oscillations above and below SP2 while in the transient state. Eventually, the output settles into a steady condition at or near the new setpoint in time period C.

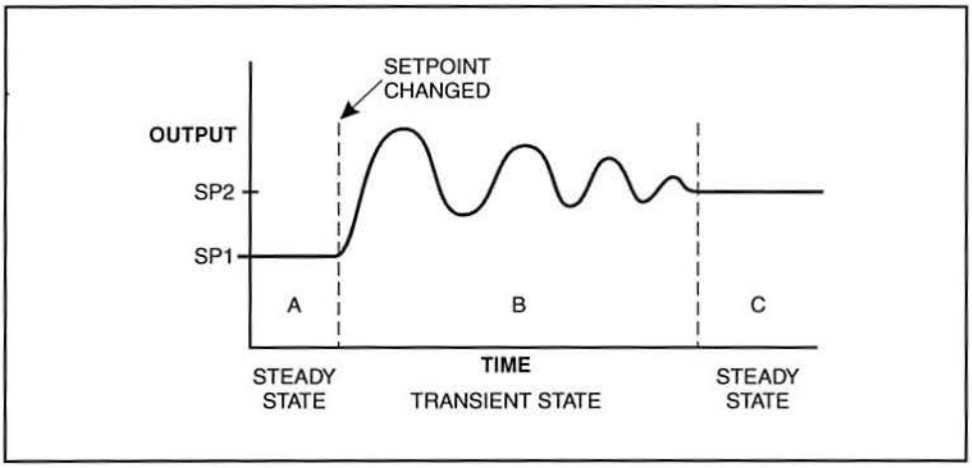

Figure 1. Process Response to a Change in Setpoint

A control system can also enter a transient state when an outside disturbance occurs. The control system must be able to return to a steady state condition at the setpoint, as shown in figure 2.

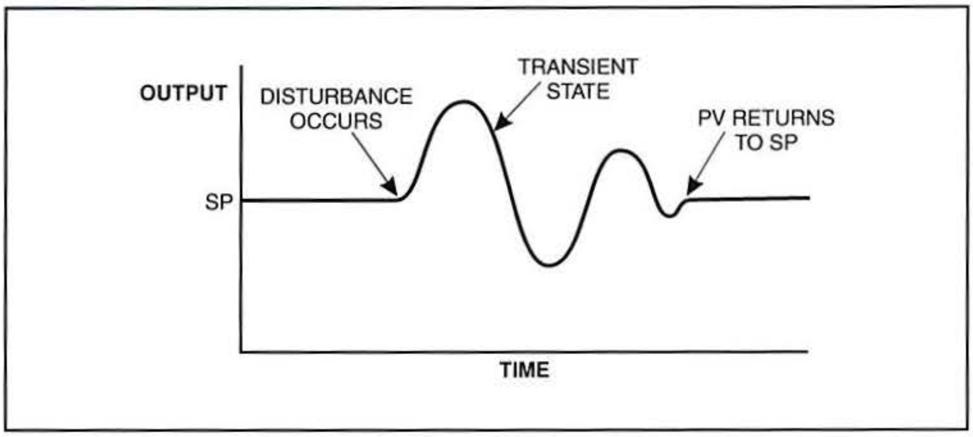

Figure 2. Process System Returns to Original SP after an Outside Disturbance

The performance of the control system during both steady and transient states is important. In a steady state, the control systems output should be as close as possible to the desired setpoint. In a transient state, the ideal control system reaches the steady state as quickly as possible with minimal overshoot.

Any adjustments made to a control system affect the steady state and transient state conditions differently. Often, one adjustment improves the steady state performance but decreases the transient state performance.

For example, figure 3 shows the response of a system before and after a change is made in the controller to shorten the amount of time that the system spends in the transient state. The dashed line shows the response of the system before the change, and the solid line shows the response after the change. After the adjustment is made in the controller, the system spends less time in the transient state (i.e. there are fewer oscillations). However, there is a larger amount of overshoot. For this reason, it is important to separately evaluate the performance of each state.

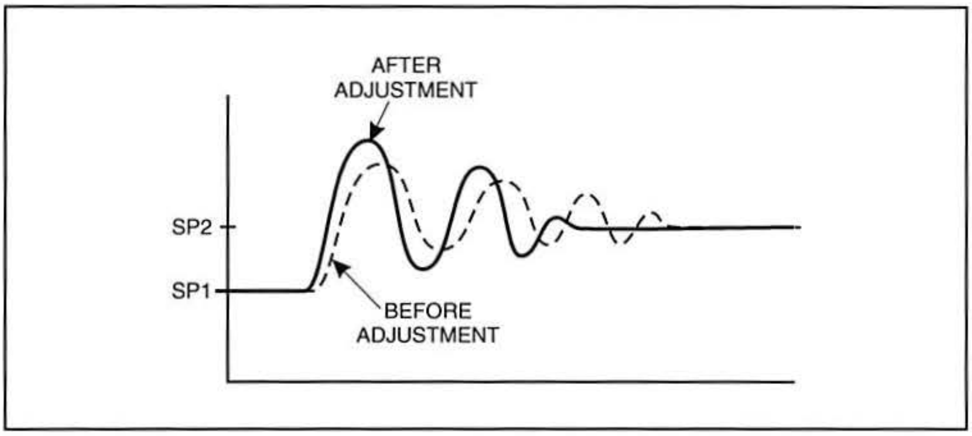

Figure 3. System Response Before and After a Controller Adjustment

OBJECTIVE 2 DEFINE GAIN AND EXPLAIN ITS IMPORTANCE

Gain is the change in output of a component or system divided by the change in input. The gain affects the value of the system output (PV) and determines how quickly a system responds to changes.

GAIN

$$Gain = \frac{\Delta\ Output}{\Delta\ Input}$$

Where:

$\Delta\ Output$ = *Change in Output*

$\Delta\ Input$ = *Change in Input*

In process control, gain represents a value by which one characteristic changes with respect to another. In figure 4, for example, a 2 mA input is amplified to a 6 mA output because the gain is 3. If the gain increases to 10, the output increases to 20 mA ($2 \times 10 = 20$).

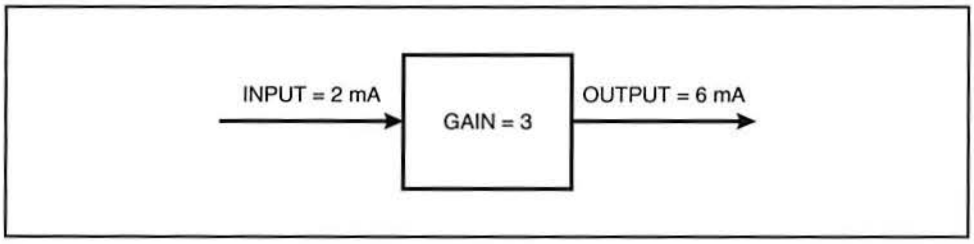

Figure 4. Device with a Gain of 3

Figure 5 shows a device with a gain of 1. The output for this device is 2 mA ($2 \times 1 = 2$). A gain of 1 is referred to as unity gain, or sometimes simply unity.

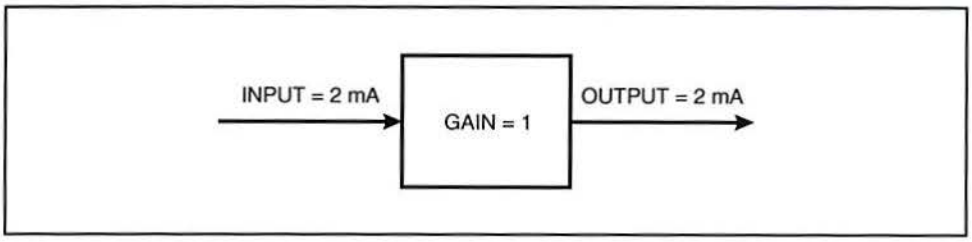

Figure 5. Device with Unity Gain

Gain can also decrease the signal if it is less than 1. For example, if a device has a gain of 0.5, a 2 mA input creates an output of 1 mA ($2 \times 0.5 = 1$), as shown in figure 6.

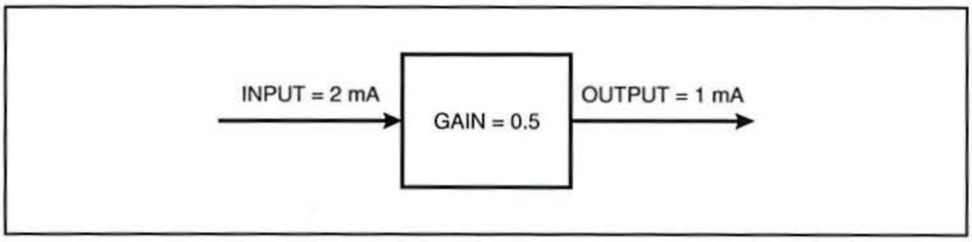

Figure 6. Device with Gain Less than 1

Notice in all of the examples thus far that gain is a dimensionless number (i.e. no units). This is because the input and output signal types have been the same. However, gain can refer to input and output signals that have different units. When gain is specified in this manner, units are necessary.

For example, the IP converter in figure 7 has a current input and a pressure output. Therefore, the gain has units of psi/mA.

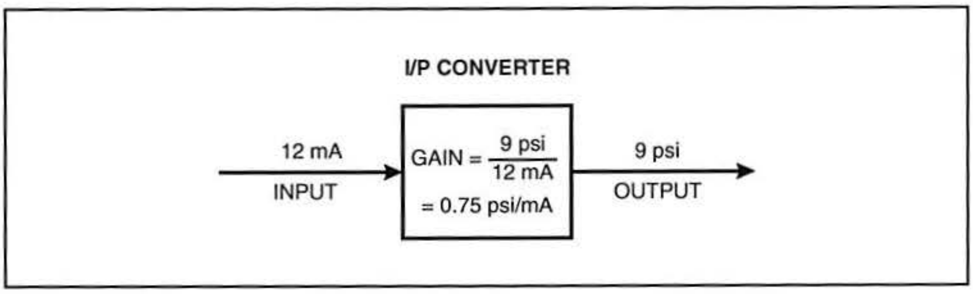

Figure 7. Gain Unit of I/P Converter

The individual gains of the components in a system combine to create an overall gain of the system. The higher the gain of one or more components, the higher the overall system gain.

In theory, a closed loop control system operates better with a higher gain because high gain increases the response of the device or system. The increased response also results in a shorter transient state. Unfortunately, if the gain is too high, the system becomes unstable, which is a condition where the system keeps oscillating past the setpoint and never settles out to a steady state.

OBJECTIVE 3 DEFINE CLOSED LOOP STABILITY AND EXPLAIN ITS IMPORTANCE

Read This

Closed loop stability refers to the ability of a process to maintain a certain value without oscillation. In stable systems, the process moves toward and settles at or near the setpoint after a disturbance, as shown in figure 8.

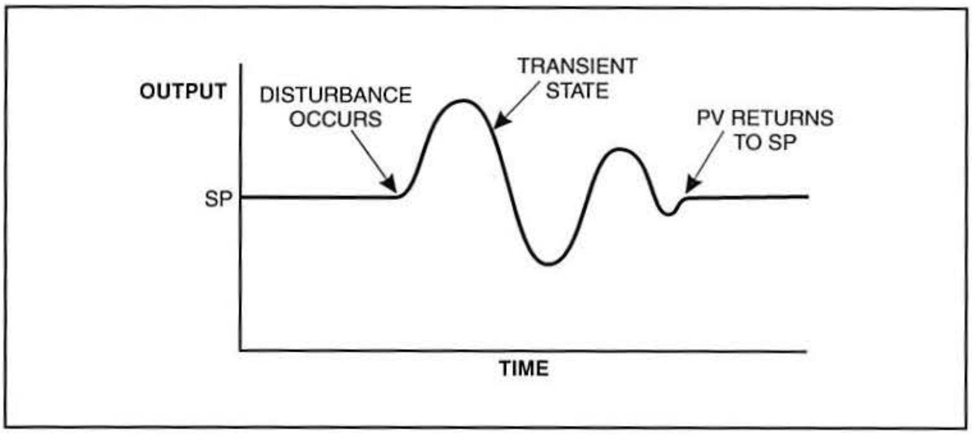

Figure 8. Stable Process System

If the combined gain of the components in a system is too high, the system becomes unstable. An unstable system overcorrects for disturbances, resulting in oscillations that increase until the maximum output limits of one of the components is reached. Figure 9 shows the output of an unstable system. A system with this type of response cannot be used to control a process.

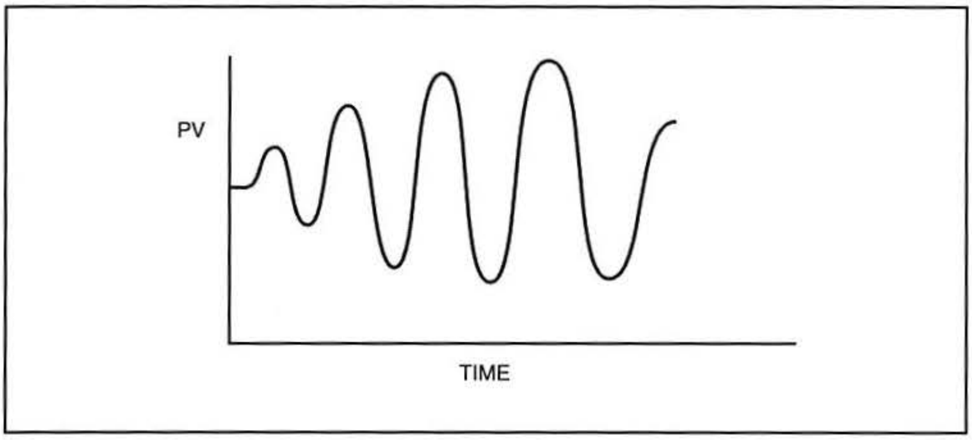

Figure 9. Output Curve for an Unstable Process

To be stable, process control systems must also use negative feedback in addition to having a gain that is not too high. A system with negative feedback resists disturbances and causes the process variable to change in the opposite direction of the disturbance.

Figure 10 shows a block diagram of a system with negative feedback. The signal from the sensor is subtracted from the SP, as indicated by the minus (-) sign at the summing junction. This results in a decrease in the magnitude of the error signal as the PV approaches the SP.

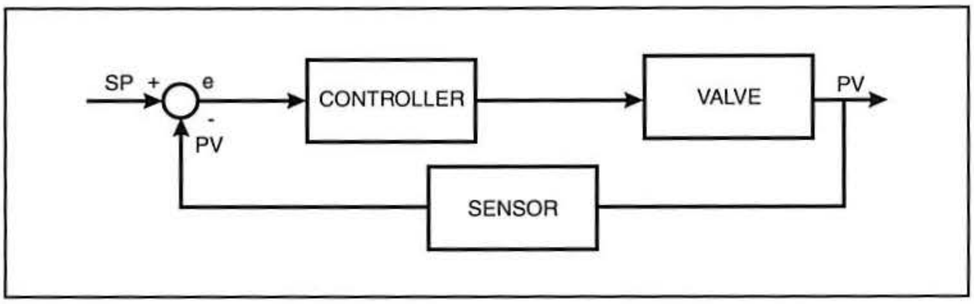

Figure 10. Negative Feedback System

In contrast, a system with positive feedback adds the feedback and setpoint together, causing the output to increase. This action causes a system to immediately become unstable regardless of the gain. Fortunately, most electronic controllers have internal programming that automatically uses negative feedback in its control scheme, regardless of how the sensor is wired to the controller. In earlier control systems, it was possible to wire the feedback sensors so that the polarity would create positive feedback.

OBJECTIVE 4 DEFINE OPEN LOOP GAIN AND EXPLAIN ITS IMPORTANCE

The gain at which a process system becomes unstable is determined by the combination of the gains of all components in the system rather than just one. This combination of gains is called the open loop gain or system gain. Open loop (system) gain is the product of the gains of all the components in the process system. Every system has a threshold value of open loop gain. Beyond this threshold, the system becomes unstable and oscillates uncontrollably past the setpoint.

OPEN LOOP GAIN

$$G_{OL} = G_1 \times G_2 \times G_3 ... \times G_n$$

Where:

G_{OL} = *Open Loop Gain*

$G_1, G_2, G_3 ... G_n$ = *Gain of Each Component in the Process System*

As an example, the system loop gain in figure 11 is 72 ($6 \times 4 \times 3 = 72$).

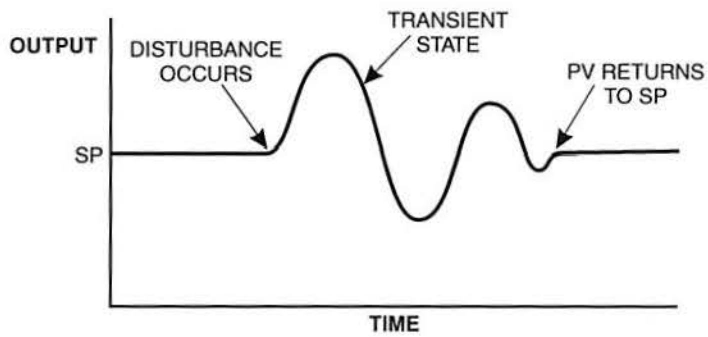

Figure 11. Process Control System Loop Gain

The system gain calculation allows you to see how changing a device in the loop can affect the loop gain. If any component in the system is replaced with a new component having a different gain, the system performance can change. A lower gain component might cause sluggish operation while a higher gain component may cause the system to react too quickly or even be unstable.

Changes to the system gain are not necessarily a problem because electronic controllers today have an adjustable gain setting that can compensate for the other component gains.

SEGMENT 1

SELF REVIEW

1. __________ state means that the output continuously changes over time.

2. ________ state occurs when the average of the process output over time remains constant.

3. In stable systems, the process moves toward and settles at or near the set point after a __________.

4. The ability of a process to maintain a certain value with as little oscillation as possible is called closed loop ________.

5. _______ is the change in output divided by the change in input.

6. A gain of 1 is referred to as _______.

7. The _____ loop gain considers the gain from all of the components in the system.

SEGMENT 2

PROPORTIONAL CONTROL

OBJECTIVE 5 DESCRIBE THE OPERATION OF A PROPORTIONAL CLOSED LOOP CONTROL SYSTEM AND GIVE AN APPLICATION

Read This

Proportional control is the fundamental method used to control a process. Its purpose is to create an immediate change in an output. In its simplest form, proportional control provides an output that is equal to the error multiplied by the controller gain. The controller gain or proportional gain causes the system to react faster than simply correcting by the amount of the error. The gain is also what makes the system proportional because it makes one characteristic (the output) change as a multiple of (i.e. in proportion to) another changing characteristic (the error).

For example, if the setpoint for a process is 5 and the process variable is 2, the error in the system is 3 (5-2=3). If the proportional gain (Kp) is 1, the initial output of the controller is 3. However, if the gain increases to 2, as shown in figure 12, the output doubles. This means that the controller reacts faster to correct the error signal (the ratio of the output to the error is 2:1).

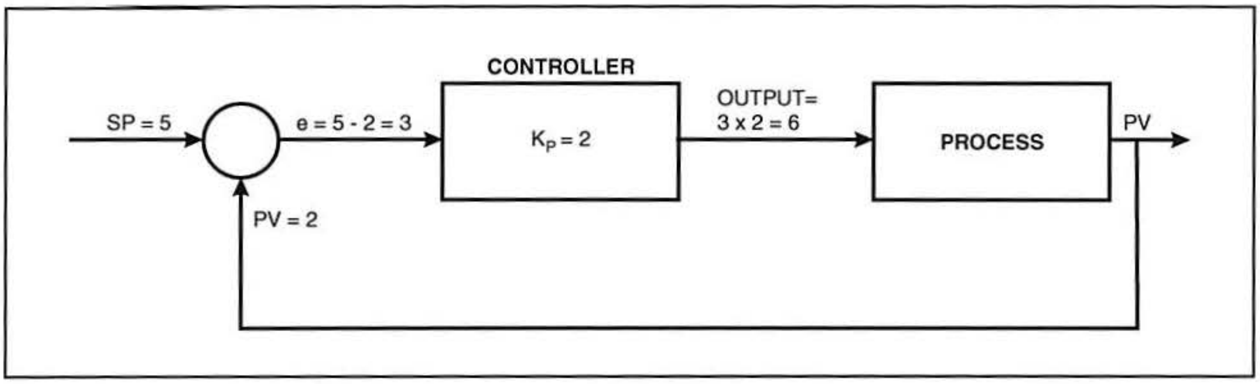

Figure 12. Block Diagram of a System Using Proportional Control with a Multiplying Factor of 2

Figure 13 shows the ideal proportional response of the system in figure 12. The response on the left is for a proportional gain (Kp) of 1, and the response on the right is for a proportional gain (Kp) of 2. Notice that the slope of the response curve increases with the gain. This occurs because increasing the gain also increases the change in output for the same error, resulting in a faster response.

Notice that in either case, the output of the proportional system steadily changes as the error decreases.

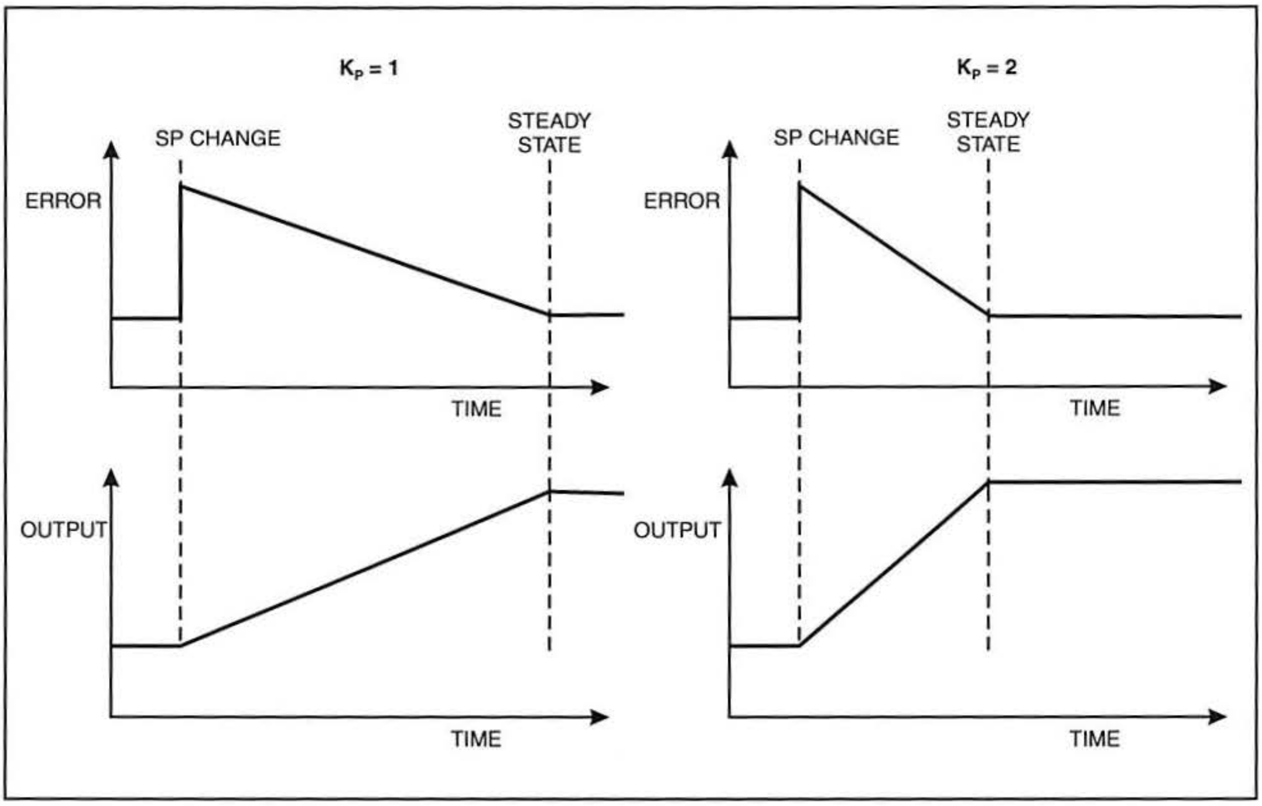

Figure 13. Ideal Proportional Response

To better understand the response of a proportional system, examine the operation of the temperature control system shown in figure 14. A proportional control valve manipulates the flow of hot liquid through one side of the heat exchanger to control the temperature of the process fluid flowing through the other side. Initially, the system is at a steady state, controlling the temperature of the process fluid at 50°C. The temperature sensor, which has a range from 0°C to 100°C, sends a feedback signal to the controller, indicating the current temperature.

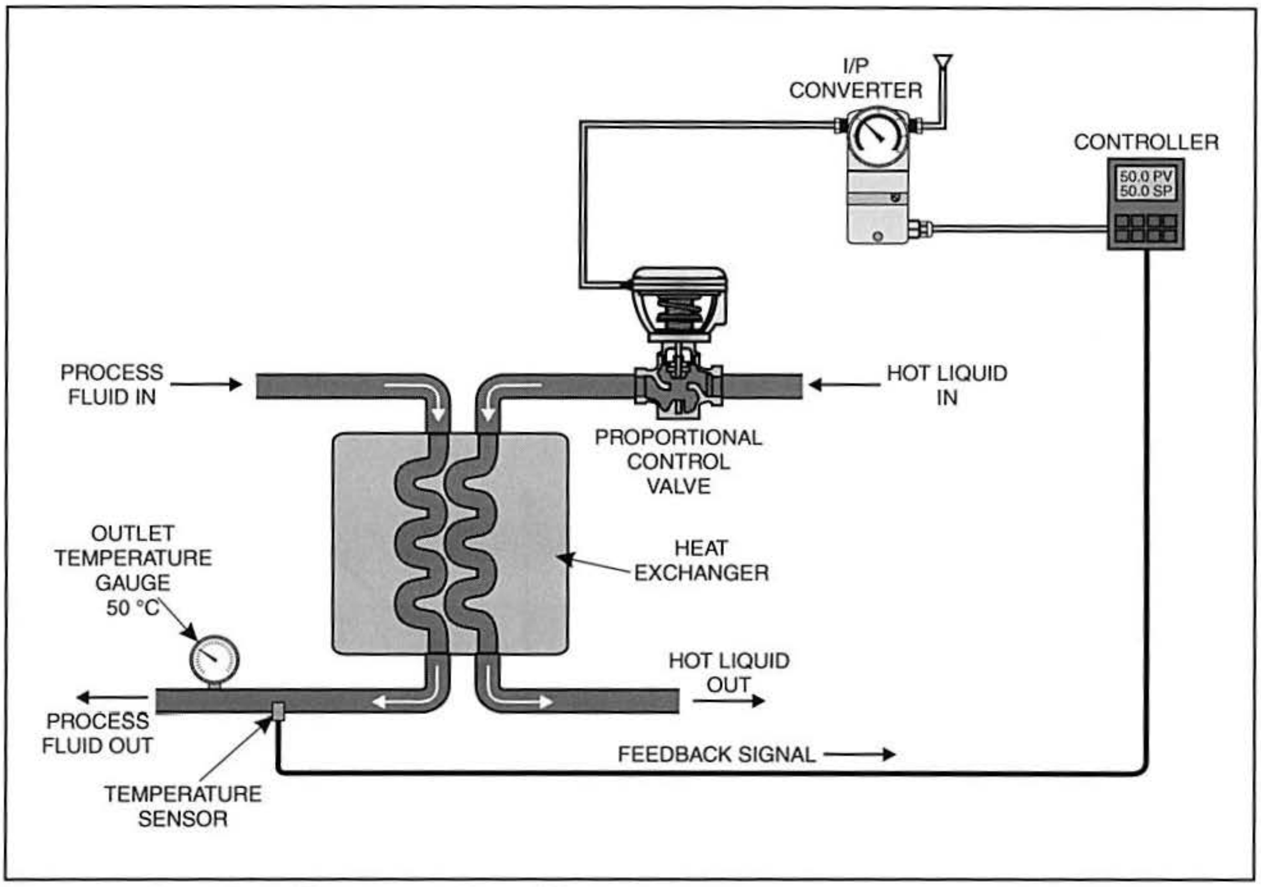

Figure 14. Proportional Temperature Control System

If the setpoint is changed to 80°C, as figure 15 shows, an error of 30°C results (80°C - 50°C = 30°C). With the gain set to 10, the controller output should be 300% ($30 \times 10 = 300$). However, the controllers internal software limits the maximum output of the controller to 100%. The maximum output from the controller causes the I/P converter to fully open the reverse acting control valve, as figure 15 shows. At this point, the control is not proportional.

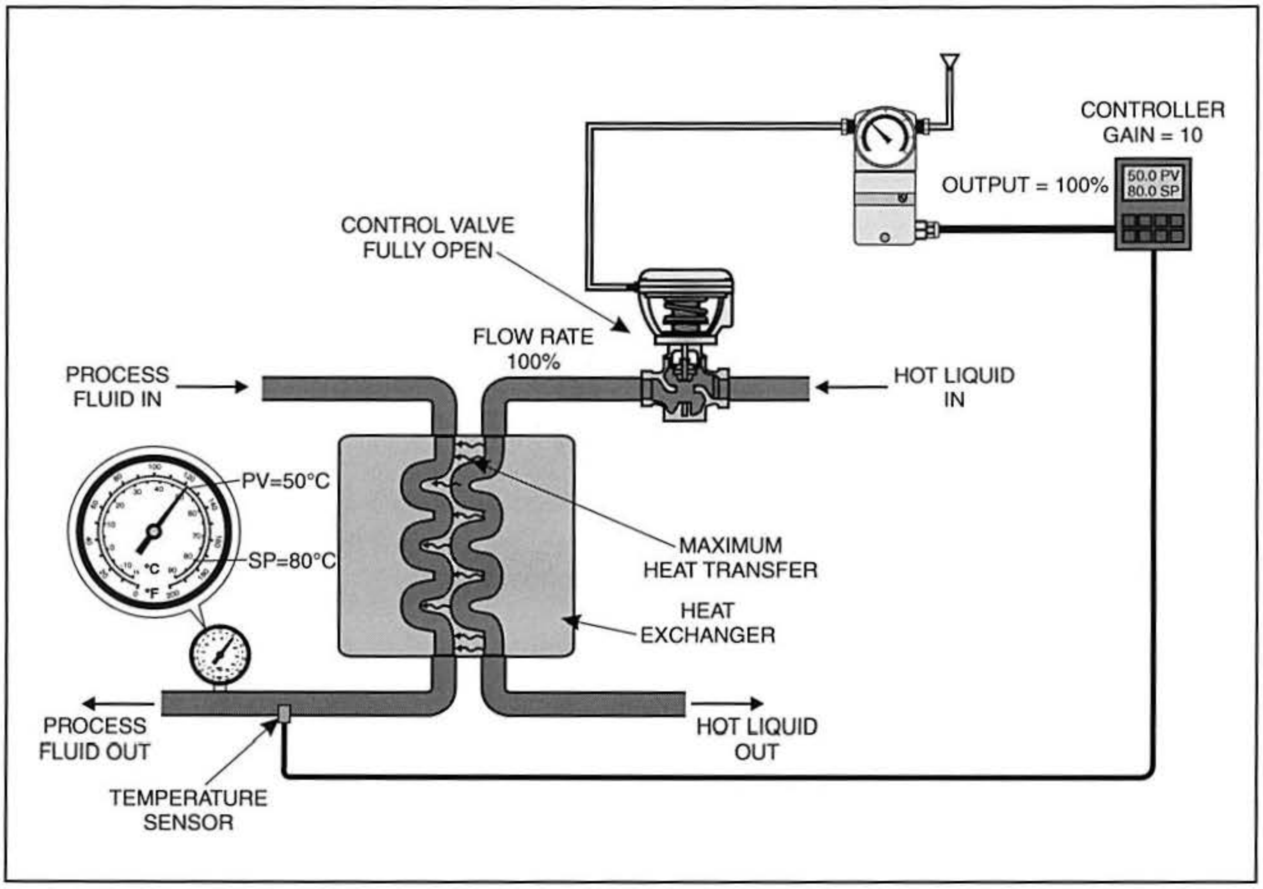

Figure 15. Proportional Control Valve Fully Open

Because the control valve is fully open, the maximum heat transfer rate to the process fluid occurs, causing its temperature to rise as fast as possible.

When the temperature increases sufficiently, the error becomes small enough so that the controller output is less than 100% and the controller therefore begins to control the valve proportionally. For example, when the process fluid temperature reaches 72°C, as figure 16 shows, the error is 8°C. This results in a controller output of 80% (10 x 8 = 80). A controller output of 80% causes the reverse-acting valve to close 20%, allowing less hot liquid to enter the heat exchanger and decreasing the rate of heat transfer.

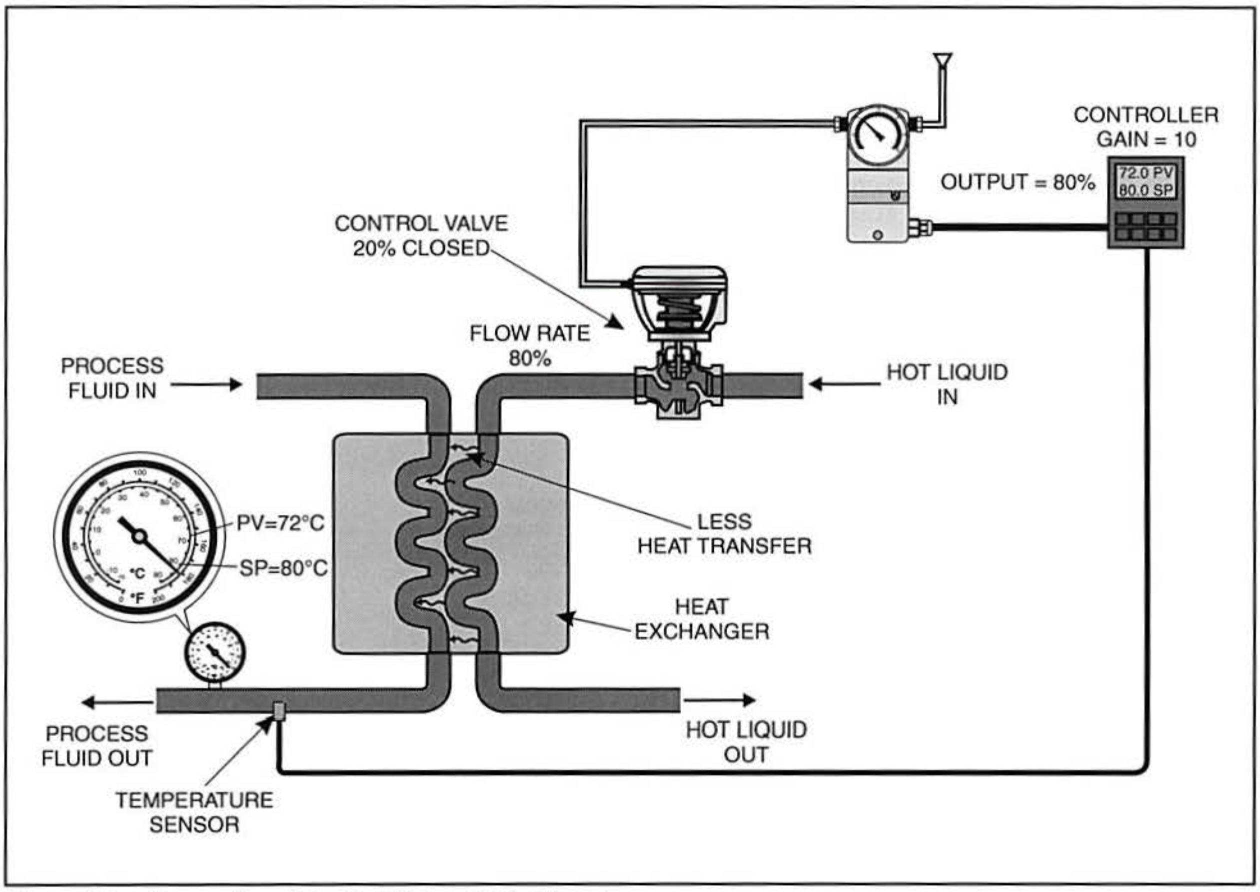

Figure 16. Proportional Control Valve 20% Closed

The controller continues to close the valve in proportion to the remaining error until the temperature settles near, but not necessarily at the new SP. When the system reaches a steady state, the controller outputs a signal that keeps the valve in a position to maintain the temperature.

Proportional control is common in industry for controlling the temperature of fuel in containers and the temperature of gases because of its simplicity and cost effectiveness.

Offset

For proportional control systems, reaching a steady state does not mean that PV equals SP. Instead, a steady state error known as offset exists.

Figure 17 shows the response of a proportional system to a change in SP. The PV never makes it to the new SP. Instead, the PV reaches a steady state at a value near the SP. Depending on the system, this value may be above or below the SP.

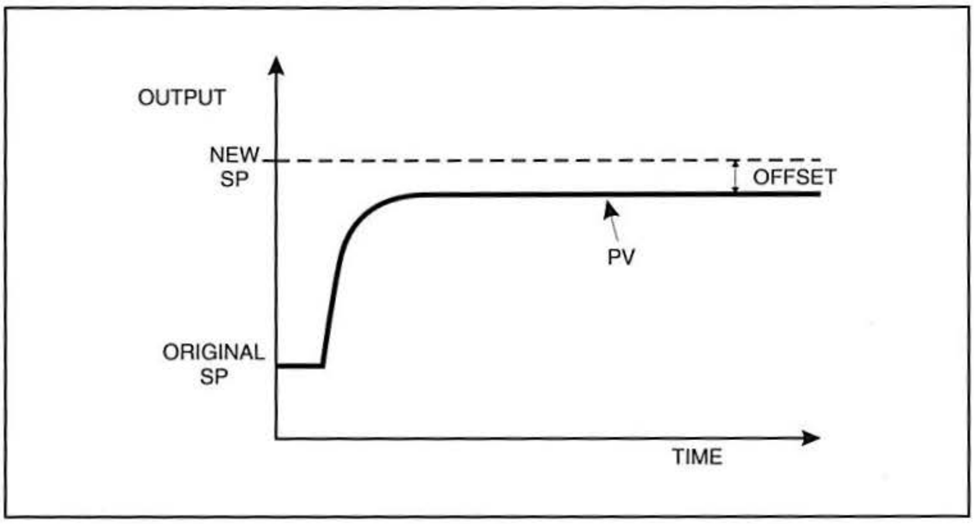

Figure 17. Example of Offset

Offset is a necessary characteristic of proportional systems because of the way that error is calculated and used. Error is the difference between the SP and the PV and is used to determine the output of the controller. An error of zero (SP = PV) results in a controller output of zero, driving the control valve either fully open or fully closed and moving the PV away from the SP. Therefore, some amount of error must exist for the system to reach a steady state.

Effects of Proportional Gain

The goal of a proportional system is to provide a quick response and achieve a steady state with minimum offset. The amount of offset depends on the proportional gain that is set in the controller. If the gain setting is low, the system eventually reaches steady state with few or no oscillations. However, there are two important consequences. First, the system reacts slowly to disturbances. Second, a large offset results, as shown in figure 18.

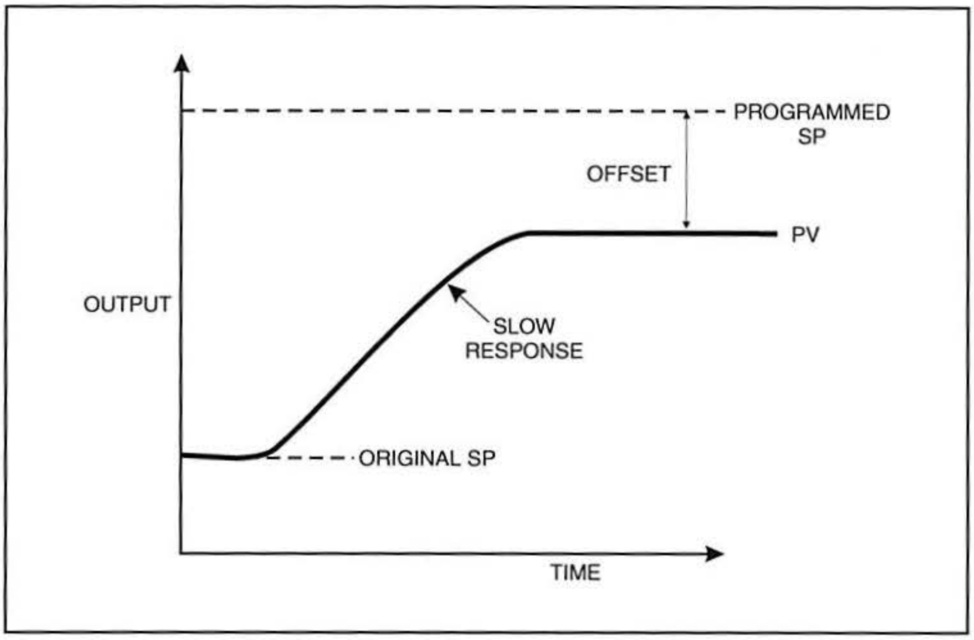

Figure 18. Process Response with a Low Gain Setting

For a high gain setting, the system reacts more quickly to disturbances. The offset is also reduced, as figure 19 shows. However, a larger gain setting also results in overshoot and oscillations before reaching steady state because the controller tends to overcorrect for the error.

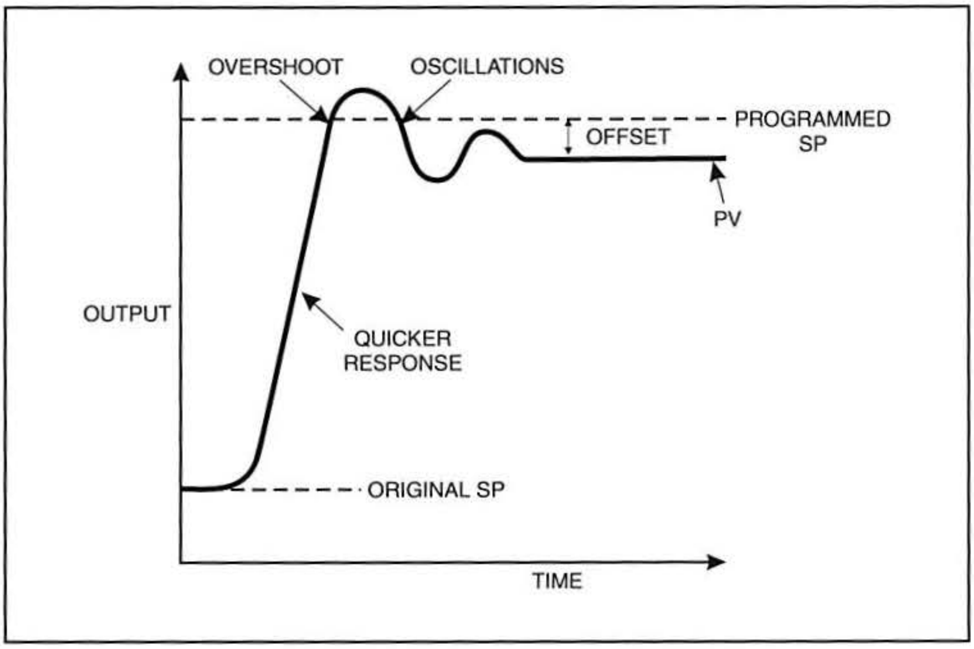

Figure 19. Process Response with a High Gain Setting

The tendency of the controller to overcorrect for the error as the gain increases is also the reason the proportional gain is not simply set as high as possible in an attempt to eliminate the offset. If the gain is increased too much, the system eventually becomes unstable. Therefore, the ideal gain setting is high enough to cause the system to respond quickly to a disturbance, such as a load change or a change in setpoint, yet low enough to prevent continuous oscillations (instability) or a long settling time to steady state.

OBJECTIVE 6 DEFINE PROPORTIONAL BAND AND EXPLAIN ITS IMPORTANCE

Read This

Proportional band (PB) is another way in which the proportional gain can be stated. Proportional band is the reciprocal of the proportional gain multiplied by 100%, as shown in the following formula:

PROPORTIONAL BAND VS. PROPORTIONAL GAIN

$$PB = \frac{1}{K_p} \times 100\%$$

Where:

$PB\%$ = *Proportional Band (Percentage)*
K_p = *Proportional Gain*

The relationship between typical values of proportional gain and proportional band are shown in figure 20. For example, a proportional gain of 2 is equal to a proportional band of 50%.

Also notice that the parameters are reciprocals of each other, so increasing the proportional gain results in a smaller proportional band, and vice versa. This means that a low proportional band is usually desirable for the same reasons a high proportional gain is desired.

PROPORTIONAL BAND VS. PROPORTIONAL GAIN	
Proportional Band	**Proportional Gain**
1%	100.0
10%	10.0
50%	2.0
100%	1.0
500%	0.2
1,000%	0.1

Figure 20. Proportional Band vs. Proportional Gain

The proportional band (PB) better quantifies what happens with the process by describing the range over which the PV is proportionally controlled. For example, figure 21 shows a temperature control system that has an operating range from 0°F to 200°F. The controller has a setpoint of 100°F and a proportional band (PB) of 20%. The PB setting of 20% results in a band of 40 degrees in which the temperature is controlled proportionally. In this case, the proportional band lies between 100°F and 140°F and the PV reaches steady state at 130°F. Because the PB is fairly large, the offset (30°F) is also relatively large.

Outside this band, control is not proportional. The valve is either fully open or fully closed.

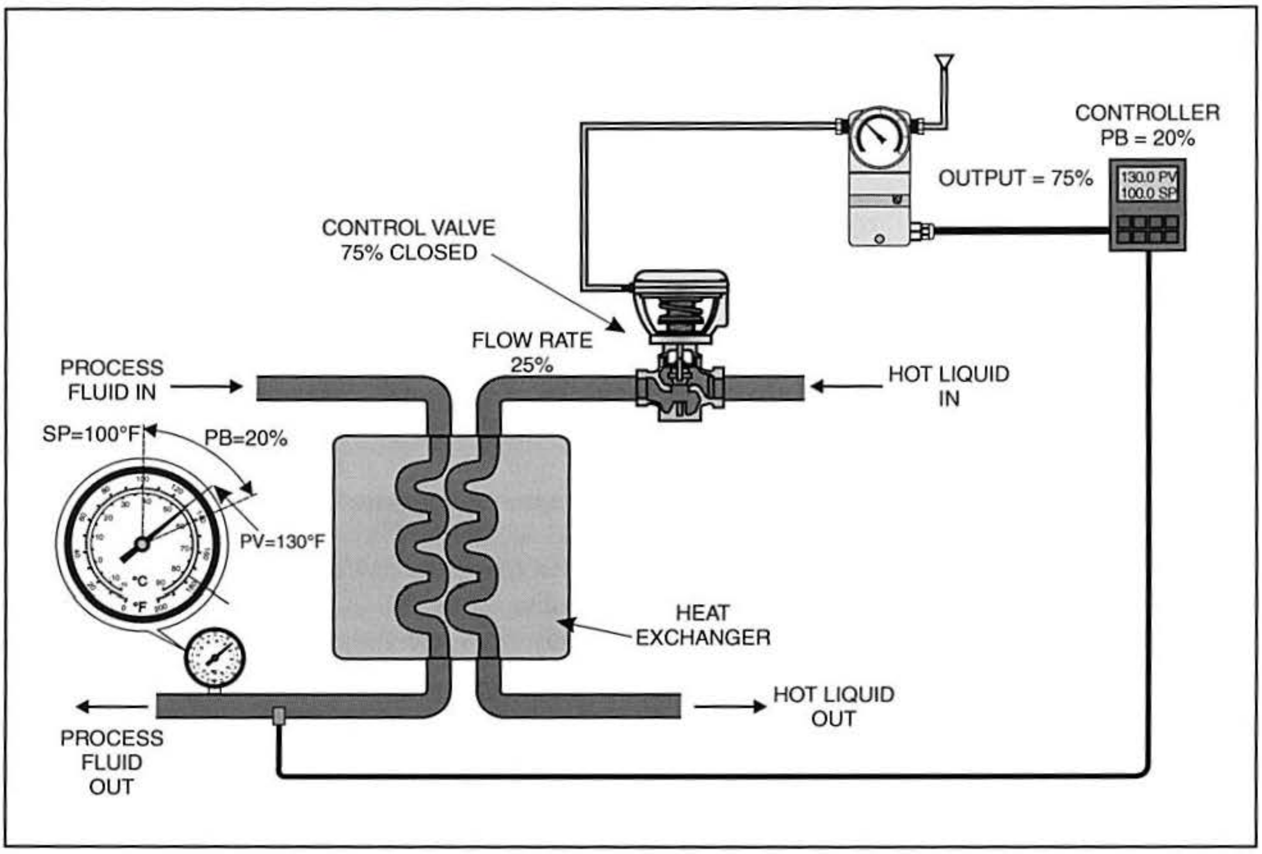

Figure 21. Temperature Control System with a PB of 20%

In processes that use a control valve, the PB identifies the range of proportional travel for the valve. A large PB means that the control valve moves proportionally through a wide range of its full travel after a disturbance, as figure 22 shows. This results in a sluggish system response and a large offset. However, the operational life of the valve is extended because the valve does not have to travel frequently between fully open and fully closed.

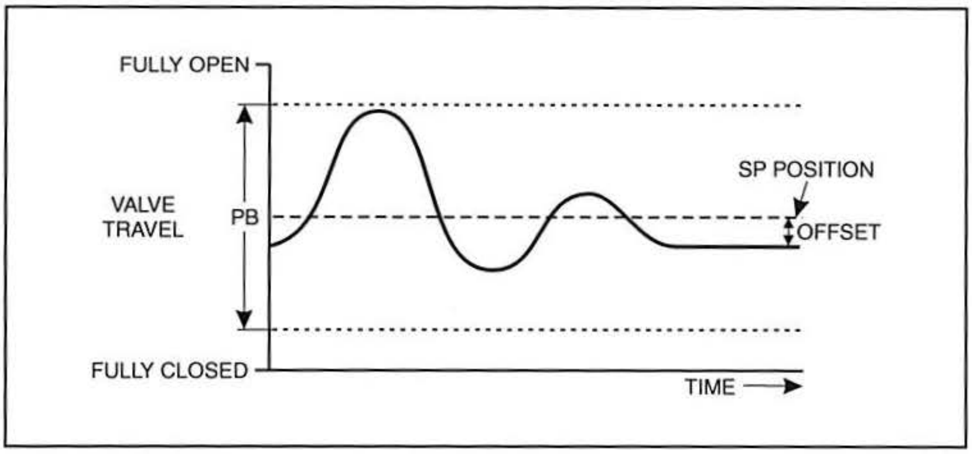

Figure 22. Valve Travel for a Large PB

A small (narrow) PB means that the valve moves proportionally only through a small range of its full travel, as figure 23 shows. This results in a fast system response and a small offset.

However, when a disturbance occurs, the system tends to oscillate more before settling into a steady state because outside the PB the valve is driven either fully open or fully closed. The increased frequency and amplitude of the oscillations reduce the operating life of the valve. If the PB is too small, the control valve continually oscillates between fully open and fully closed, making the system unstable.

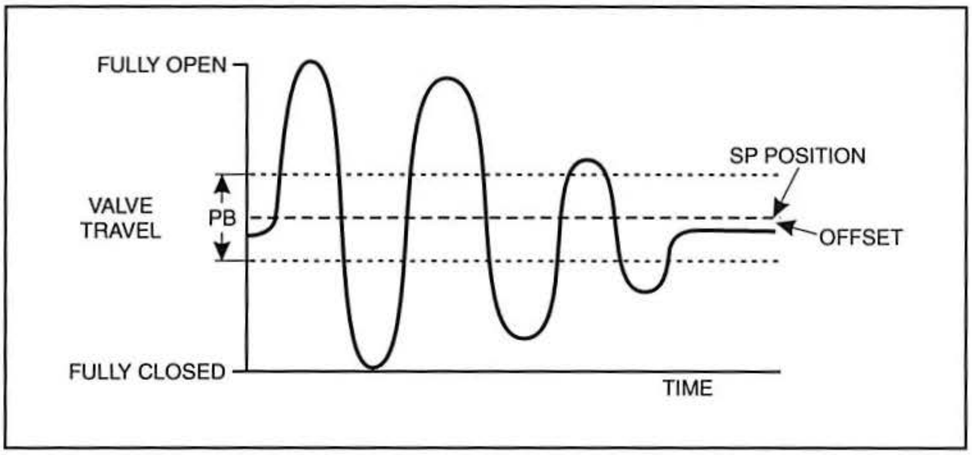

Figure 23. Valve Travel for a Small PB

Figure 24 summarizes the ideal response of a control valve in a proportional temperature control system. Initially, the system is in a steady state. At point A, the system is in a steady state when a change in setpoint creates a large error. This causes the proportional control valve to quickly begin to open, resulting in a large increase in the flow rate of the hot liquid through the heat exchanger. At point B, the flow rate reaches a maximum value, which indicates that the control valve is fully open. This allows the error to be reduced at the maximum rate.

The valve remains fully open until the temperature reaches point C at which point the temperature is close enough to allow the controller to begin closing the valve in proportion with the error that still exists. Therefore, point C indicates the start of the proportional band. Finally, the system reaches a steady state at point D. However, there is a small offset between the temperature at point D and the new setpoint (SP2).

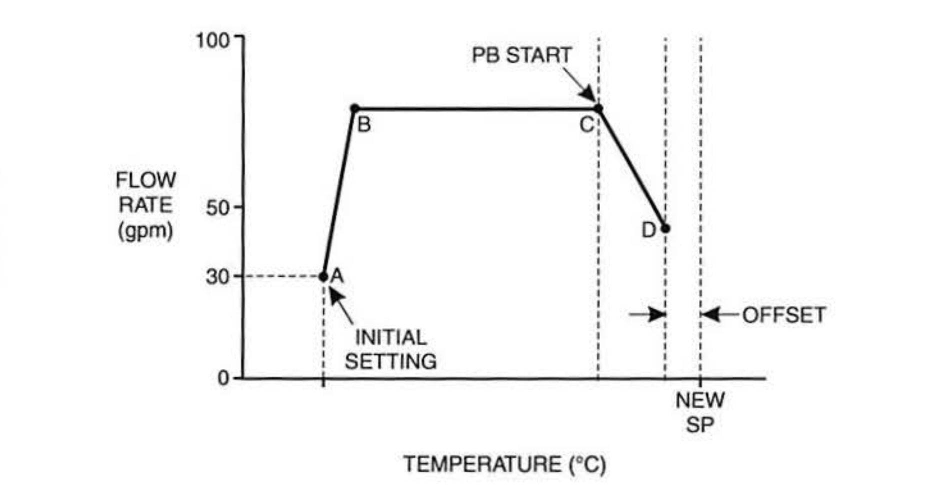

Figure 24. Response of a Proportional Temperature Control System

A stable proportional control system eventually settles at a value near the setpoint. Even if the PV is not equal to the SP when the system stabilizes, the PV falls inside the proportional band and is still considered to be in a steady state.

OBJECTIVE 7 DEFINE RESET CONSTANT

Offset in a proportional control system is not desirable if the process requires control at a specific value. The reset constant, or manual reset, is a controller setting that can be used to eliminate offset. The reset constant enables the controller to have a non-zero output when the error is zero. This causes the controller to hold the valve open at a position that eliminates offset.

For example, the temperature control system in figure 25 has a 5°C offset using a proportional controller without manual reset. This offset is what enables the controller to provide the output needed to make the heat transfer from the hot liquid side of the heat exchanger sufficient to maintain the process fluid near the setpoint. If the error goes to zero, the controller output also goes to zero because of the proportional relationship between the output and the error. This would cause the process fluid temperature (PV) to move away from the SP.

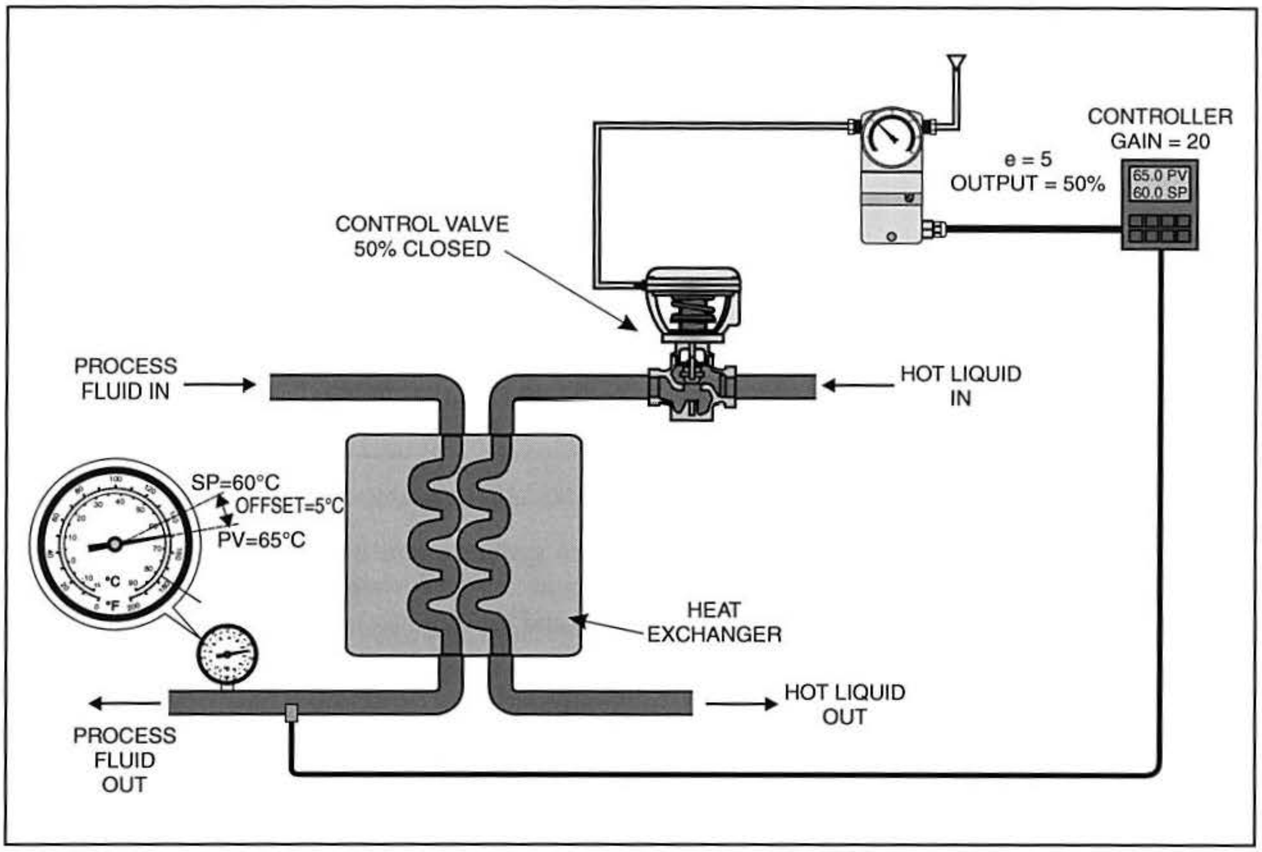

Figure 25. Offset in a Proportional System

The reset constant adds to the controller output, as figure 26 shows, so that the PV equals the SP at steady state and the controller still maintains an output. It provides a way for the valve to be at a position other than fully closed or fully open when the error is zero.

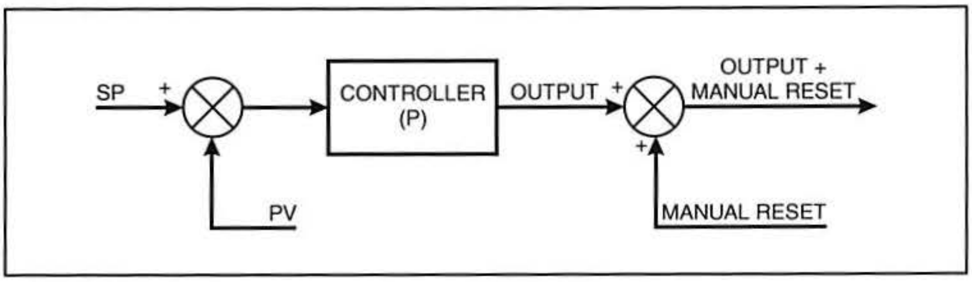

Figure 26. Manual Reset Added to Controller Output

If the manual reset is set to 55% for the system in figure 25, the control valve is closed another 5% (50 + 5 = 55%) and the offset is eliminated, as shown in figure 27.

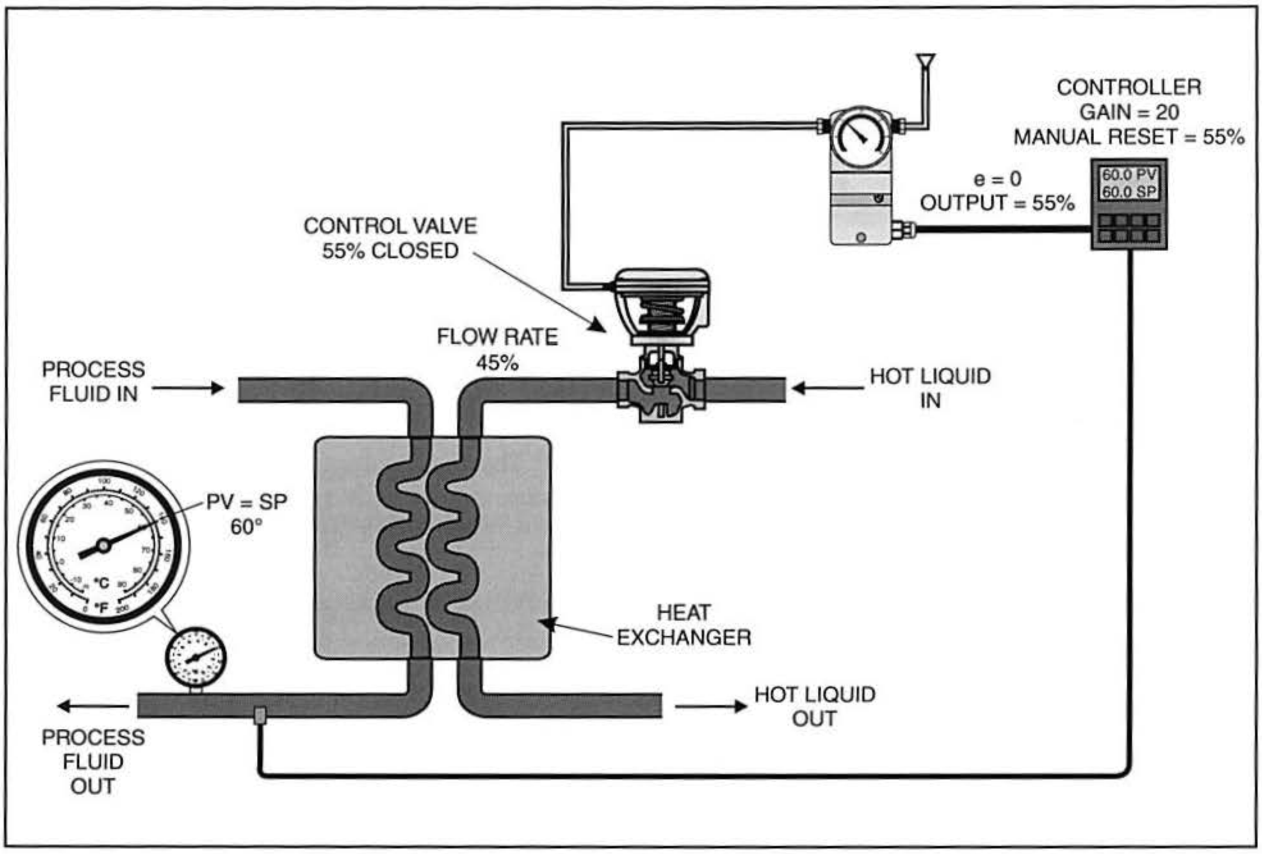

Figure 27. Proportional System with Manual Reset

Unfortunately, the manual reset value is only good as long as conditions do not change. If the SP is increased, as shown in figure 28, a new offset results. To eliminate the new offset, a new manual reset value is required, as figure 28 also shows.

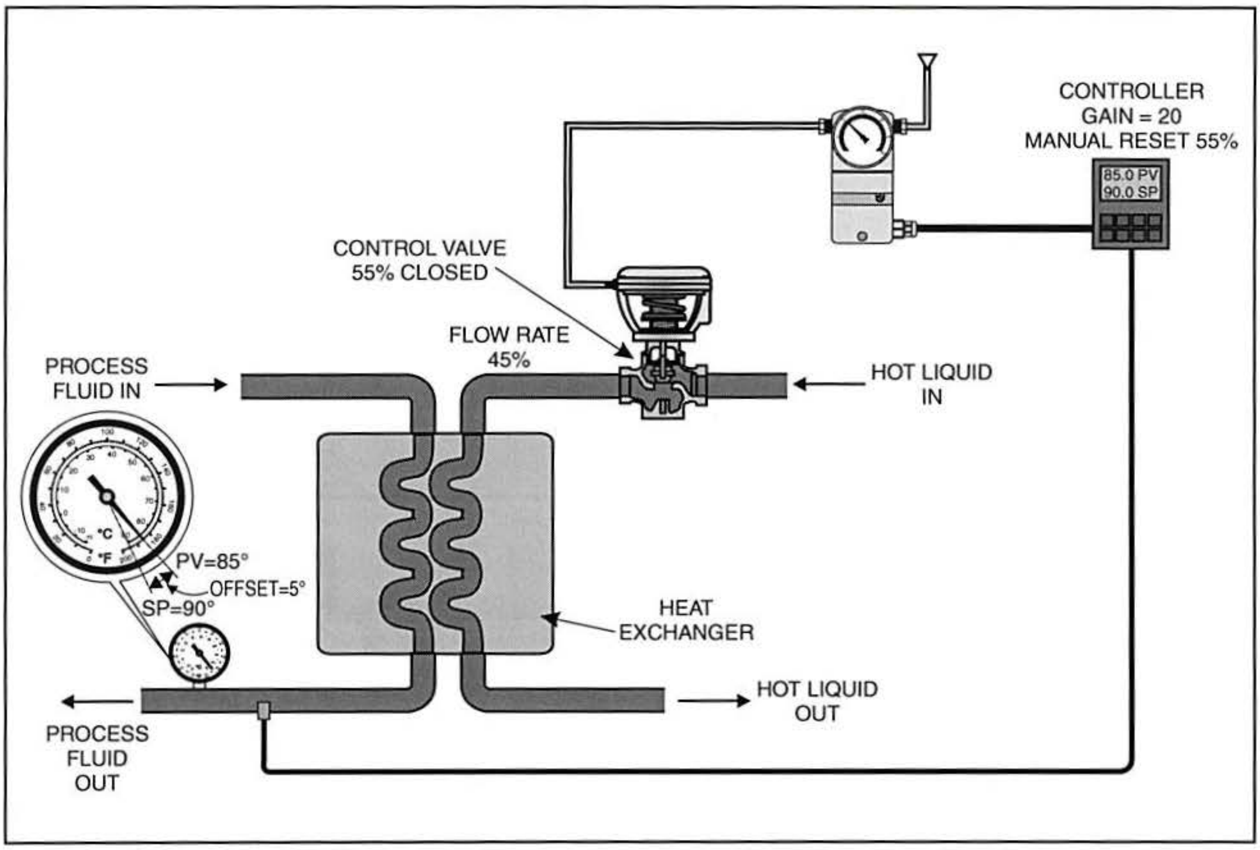

Figure 28. Change in the SP Requires a New Manual Reset

The advantage of the manual reset is that it provides a way for a proportional controller to control the PV at the SP. The disadvantage is that the manual reset has to be readjusted each time a disturbance or change in setpoint occurs.

OBJECTIVE 8 DESCRIBE HOW TO USE A HONEYWELL CONTROLLER TO CONTROL A PROCESS USING CLOSED LOOP CONTROL

Read This

An electronic controller-based closed loop system includes a Proportional-Integral-Derivative (PID) controller, a control element (e.g. a valve), and a feedback element, as shown in figure 29. The PID controller receives a feedback signal from a sensor that indicates the value of the process variable. It then uses its microprocessor to create the proportional, integral, and derivative outputs using computer software. The P, I, and D outputs are combined and converted to a 4-20 mA analog output using a digital-to-analog converter. The analog output of the controller then feeds a chemical pump that injects the reagent into the process to adjust the pH of the fluid in the reactor tank.

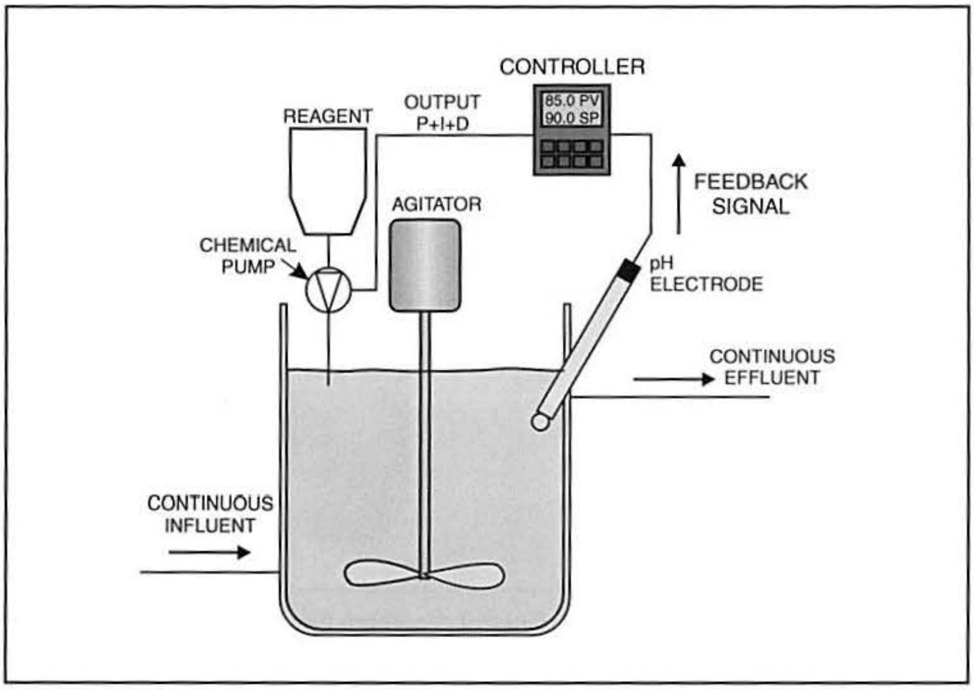

Figure 29. Electronic Controller Based Closed Loop pH System

In an electronic controller-based closed loop system, the operator determines which control method the process requires and enters the parameters into the controller. These parameters include the settings for proportional, integral, and derivative gain, the setpoint, input parameters, and several others, depending on the complexity of the system. The parameters entered determine how well the system performs. As the process is running, the controller continuously makes output adjustments based on feedback from the sensor.

The following steps describe how to program a Honeywell controller for closed loop control:

- **Enter the setup menu.**
- **Locate the INPUT programming group and enter the required parameters.**

  These parameters should include:

  IN 1 TYPE

  IN 1 HIGH

  IN 1 LOW

- **Locate the ALGORITHM function group and select the desired control algorithm for the process.**

  Scroll to the CONT ALG parameter, as shown in figure 30, which stands for Control Algorithm.

Figure 30. Control Algorithm Parameter in a Honeywell Controller

This common settings for this parameter are:

ALGORITHM	DESCRIPTION
PID A	Selecting this algorithm activates each of the three control methods (i.e. proportional, integral, derivative) and allows each to respond to changes in setpoint and process variable. This algorithm is used when the operator desires full PID control of a process. An operator may also choose to use this algorithm exclusively and set the integral and/or derivative terms so that they have minimal effect on the process.
PID B	Selecting this algorithm also activates each of the three control methods. However, only integral control responds to changes in setpoint, while the proportional and derivative modes only respond to changes in the process variable. This algorithm is used in processes with a high proportional gain setting, which can have adverse effects if a step change occurs.
PD+MR	Selecting this algorithm eliminates the integral control and allows the operator to adjust the manual reset to eliminate offset. This algorithm is used for proportional and proportional plus derivative control applications.

- **Locate the CONTROL function group and enter the required parameters.**

  Select GAIN or PB PCT (proportional band percent) for the proportional action when the upper display indicates GAIN and the lower display indicates PBorGAIN, as shown in figure 31.

Figure 31. PB or Gain Selection on a Honeywell Controller

Scroll to the next parameter and select either RPM (integral rate as repeats per minute) or MIN (integral time as minutes), as shown in figure 32. These parameters determine the integral action.

Figure 32. MIN or RPM Selection on a Honeywell Controller

- **Locate the TUNING function group and enter the required parameters.**

  Depending on the chosen algorithm, each of the three control methods may be active in the controller. Therefore, you must set each to the proper value to optimize or eliminate its effect, depending on the level of control desired.

  Set the GAIN or PB PCT parameter (whichever was chosen in the CONTROLS group) to the desired value.

  Scroll to the next parameter, RATE MIN, and set it to the desired value. This parameter determines the derivative time in minutes. A setting of 0.0 eliminates its effectiveness.

  Scroll to the next parameter, either RSET RPM or RSET MIN (whichever was chosen in the CONTROL group) and set it to the desired value. These parameters determine the integral rate and the integral time, respectively.

- **Exit the setup mode.**
- **Set the setpoint (SP).**
- **Place the controller in automatic mode and run the process.**

SKILL 1 USE A HONEYWELL CONTROLLER TO CONTROL A PROCESS USING PROPORTIONAL CONTROL

Procedure Overview

In this procedure, you will control a chemical process using a Honeywell PID controller. You will use only proportional control and note the effects on the process as you increase and decrease the GAIN setting.

☐ 1. Perform the following substeps to make sure the T5554 Analytical Process Control System is set up as shown in figure 33.

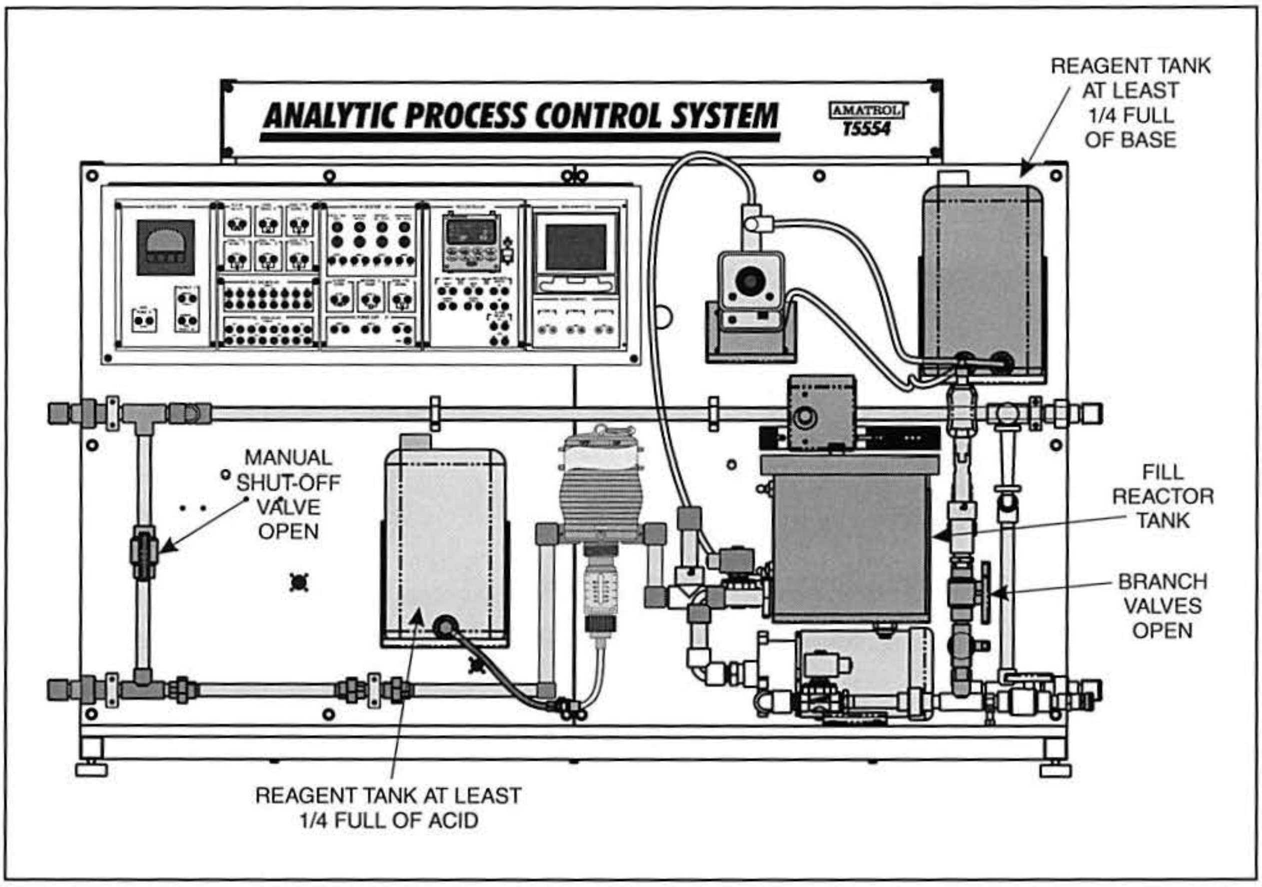

Figure 33. T5554 Setup

A. Fill the reactor tank with fresh water.

If the reactor tank includes a pressure sensor in the bottom of the tank, do not pour water directly over the sensor to avoid possible damage to the sensor.

Be sure to keep the water level below the high level switch, as shown in figure 34. If the water actuates the high level switch, the inlet solenoid valve is closed to stop flow into the tank.

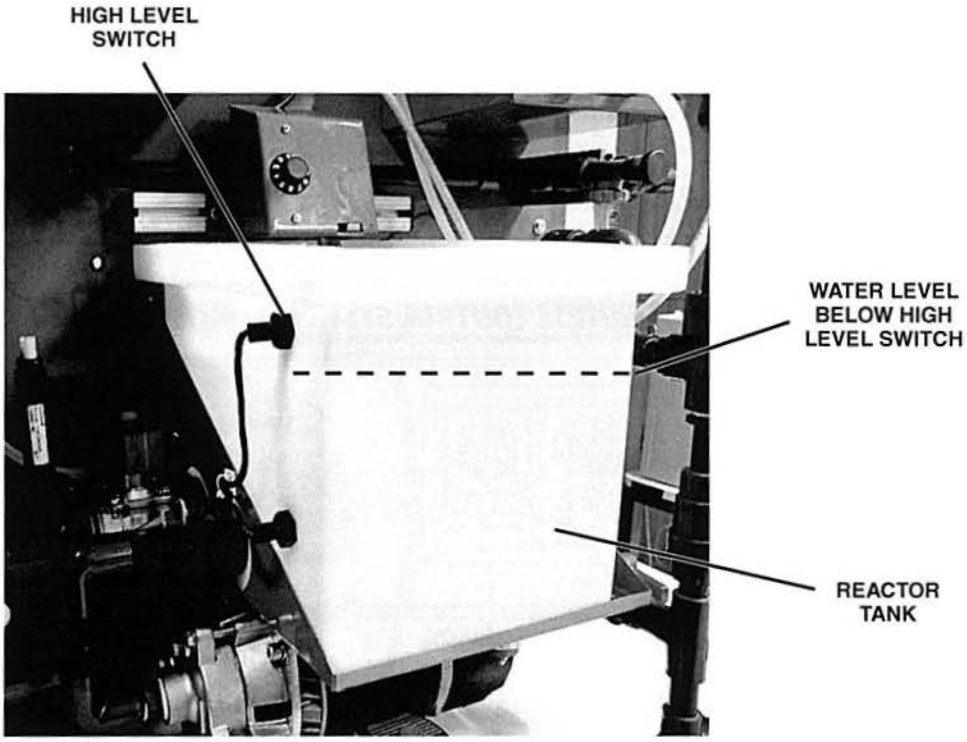

Figure 34. Water Below the High Level Switch

B. Make sure the drain shutoff hand valve is closed (shut) and the drain cap is in place.

C. Make sure the main shutoff valve and the two branch valves are open.

D. Make sure the reagent tanks are filled at least 1/4 full.

E. Make sure the bypass hand valve is closed.

❑ 2. Connect the circuit shown in figure 35.

This allows the controller to continuously monitor and control the pH of the process fluid. Make sure a 250-Ohm resistor module is connected to the Loop 1 input on the controller.

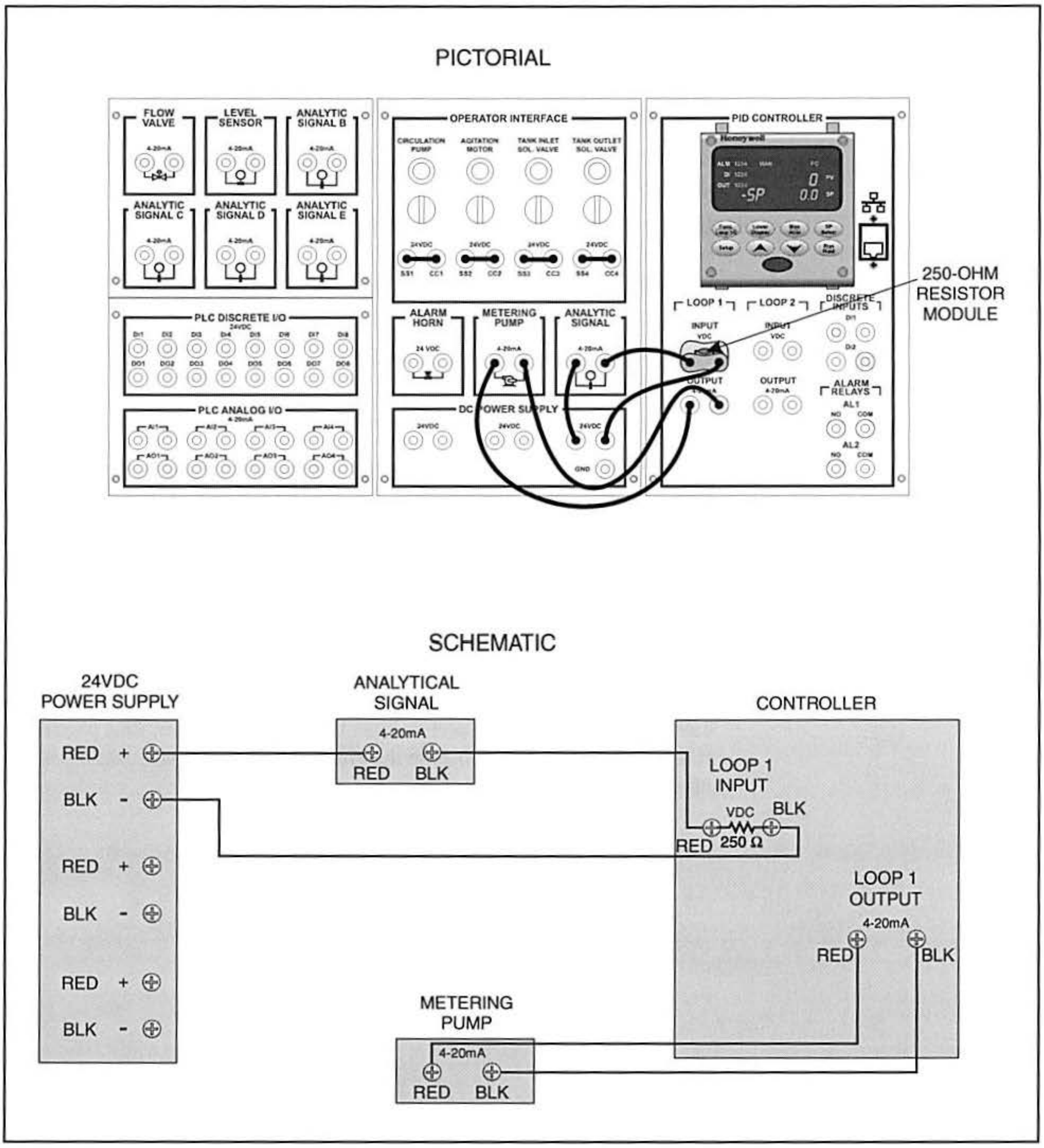

Figure 35. Continuous pH Control Circuit

❑ 3. Perform the following substeps to start up the system and set the controller for proportional control.

A. Turn on the main circuit breaker.

B. Use the **Setup** key on the controller to enter the setup menu and scroll through the groups until ALGORITHM appears on the display.

C. In the ALGORITHM group, set the CONT ALG parameter to **PD+MR**.

CONT ALG is the control algorithm parameter. It identifies the type of control method(s) (i.e. proportional, integral, and derivative) the process uses. The setting PD+MR prevents the controller from using any integral control and allows you to adjust the manual reset if desired, to eliminate any offset that occurs.

D. Use the **Setup** key to scroll through the groups until CONTROL appears on the display.

E. In the CONTROL group, set the PBorGAIN parameter to **GAIN** and the ACTION parameter to **REVERSE**.

F. Use the **Setup** key to scroll through the groups until TUNING appears on the display.

G. Set the following parameters in the TUNING function group:

PARAMETER	SETTING
GAIN	30.0
RATE MIN	0.0
MAN RSET	0.0

The GAIN parameter sets the controllers proportional gain. The RATE MIN parameter refers to the derivative control method. This parameter is set to zero to eliminate its effect on the process. The MAN RSET parameter refers to the manual reset and can be set from 0-100%. This parameter is set to zero so you can observe the effects of proportional control with no reset capability.

H. Program the remaining parameters shown in figure 36.

PARAMETER GROUP	PARAMETER	VALUE OR SELECTION
OUTPUT ALG	OUT ALG C1 RANGE	CURRENT 4-20
INPUT 1	IN1 TYPE XMITTER1 IN1 HIGH IN1 LOW	1-5 VLINEAR 14.0 0.0
INPUT 2	IN2 TYPE	DISABLE
CONTROL	PV SOURC SP HiLIM SP LoLIM ACTION I Hi LIM I Lo LIM	INPUT 1 14.0 0.0 REVERSE 100.0 0.0
OPTIONS	DIG IN 1 DIG IN 2	NONE NONE
COM	ComSTATE	DISABL
ALARMS	A1S1TYPE A1S2TYPE A2S1TYPE A2S2TYPE	NONE NONE NONE NONE
DISPLAY	DECIMAL TEMPUNIT PWR FREQ	TWO NONE 60 HZ

Figure 36. Remaining Controller Settings for Continuous pH Control

❑ 4. Exit the setup mode by pressing the **Lower Display** key.

❑ 5. Toggle to the setpoint (SP) display and set it to **7.0**.

❑ 6. Make sure the On/Off switch on the eductor pump, shown in figure 37, is in the On position.

❑ 7. Set the ratio control or the eductor pump to a ratio of 1:100 (1%).

This allows the eductor pump to inject the acid reagent into the process flow to create a disturbance in the system.

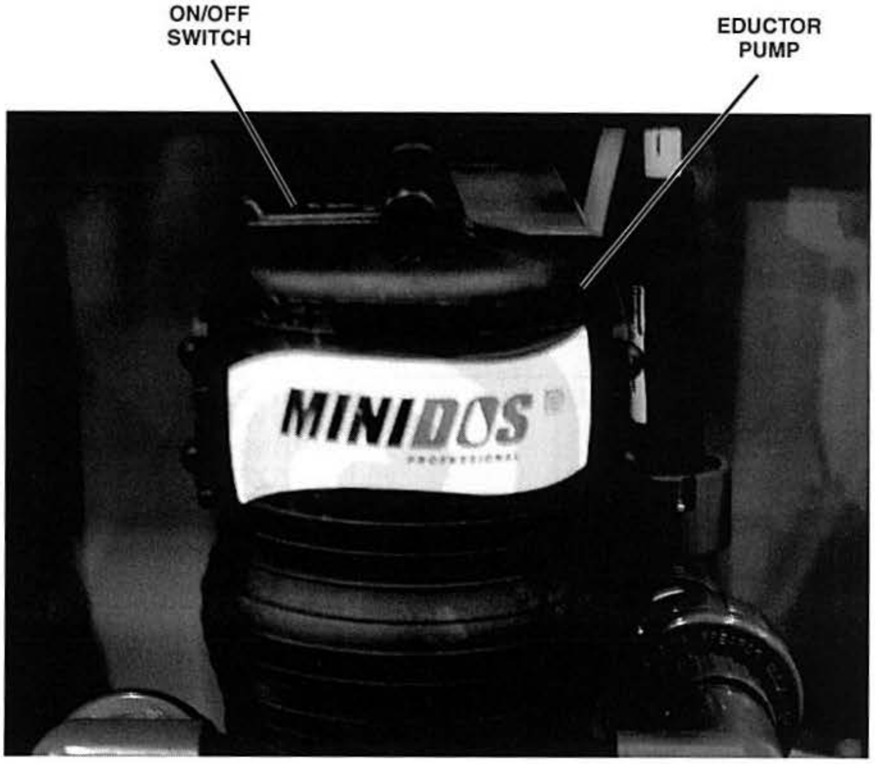

Figure 37. On/Off Switch on Eductor Pump

❑ 8. Place the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches in the **ON** (CW) position.

❑ 9. Set the **Agitator Speed** control to **6**.

This allows the eductor pump to begin injecting the acid reagent into the process flow. Allow this to continue until the pH reading on the display of the controller indicates 6.50 pH.

❑ 10. Once the measured pH reaches 6.50, perform the following substeps to set the metering pump controls.

A. Set the **Mode** selector switch to the **Automatic** position (turn CW).

B. Unlock the locking lever on the Percentage Stroke Length dial.

C. Set the Percentage Stroke Length dial to **50%**.

The setting of the Stroke Rate Percentage dial does not matter. The stroke rate will be controlled by the output of the controller.

❑ 11. Perform the following substeps to operate the continuous pH control system.

A. Place the controller in the automatic mode using the **Man/Auto** key.

B. Set the flow rate to **1.2 gpm** using the adjustment valve on the rotameter, shown in figure 38.

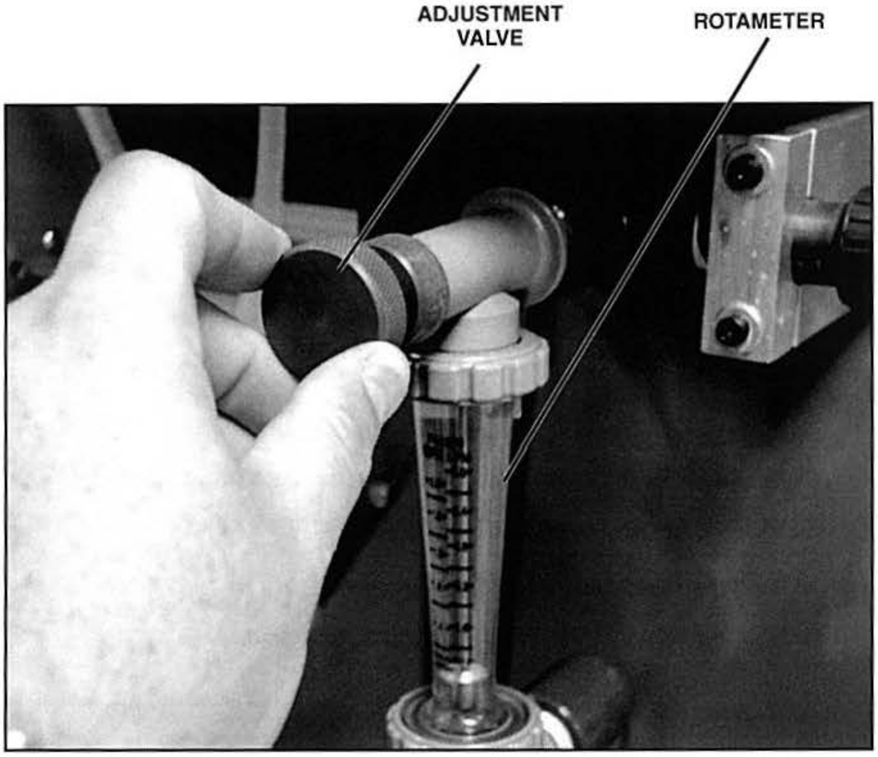

Figure 38. Adjustment Valve on Rotameter

C. Observe the operation of the system.

The controller should cause the metering pump to inject the base reagent into the water to neutralize the pH, measured at the outlet of the reactor tank. It will take several minutes for the system to reach steady state.

D. Determine the pH at which the process reaches steady state.

Steady State pH ______________________________

You should find that the process reaches steady state at a pH level that is not at the neutral point (pH = 7.0).

This represents an offset due to using only proportional control.

E. Turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

F. Place the **Mode** selector switch on the metering pump in the **Standby** position.

G. Set the **Agitator Speed** control fully CCW.

H. Place the controller in the manual mode.

❑ 12. Enter the Setup Menu on the controller and change the GAIN parameter in the TUNING group to **40**.

❑ 13. Turn on the CIRCULATION PUMP and **AGITATOR MOTOR** selector switches.

❑ 14. Set the **Agitator Speed** control to **6** and allow the pH reading on the controller display to fall to 6.50.

❑ 15. Once the measured pH reaches 6.50, perform the following substeps to operate the continuous pH control system.

A. Place the controller in the automatic mode.

B. Place the **Mode** selector switch on the metering pump in the **Automatic** position.

C. Observe the operation of the system and determine the pH at which the process reaches steady state.

Steady State pH ______________________________

You should find that the process again reaches steady state. The offset is smaller, but still exists. This is due to the increased proportional gain.

D. Turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

E. Place the **Mode** selector switch on the metering pump in the **Standby** position.

F. Set the **Agitator Space** control fully CCW.

G. Place the controller in the manual mode.

❑ 16. Turn off the main circuit breaker for the T5554.

❑ 17. Leave the circuit connected.

You will use it again in the next skill.

SEGMENT 2

SELF REVIEW

1. __________ control is the fundamental method used to control a process.

2. The value of the manual _____________ constant enables the controller to have a non-zero output when the error is zero.

3. When the proportional gain is increased, the proportional band __________.

4. The steady state error that almost always occurs when using proportional control is called ______________.

5. If you increase the gain, the offset will ________________.

6. A PID controller contains a(n) ______________ that uses computer software to generate the proportional, integral, and derivative controls.

7. A Honeywell controller can control a process using proportional control if you program the proper _________, algorithm, control, and tuning group parameters.

8. Outside the proportional (PB), control is not ________.

SEGMENT 3

PROPORTIONAL-INTEGRAL CONTROL

OBJECTIVE 9 DESCRIBE THE OPERATION OF INTEGRAL (RESET) CONTROL

Read This

In most applications, the offset that naturally occurs in a proportional system is not desirable. Although the operator can adjust the manual reset setting in the controller to eliminate the offset, the setting only works for a specific demand level. If the demand changes (i.e. new SP), the offset reappears.

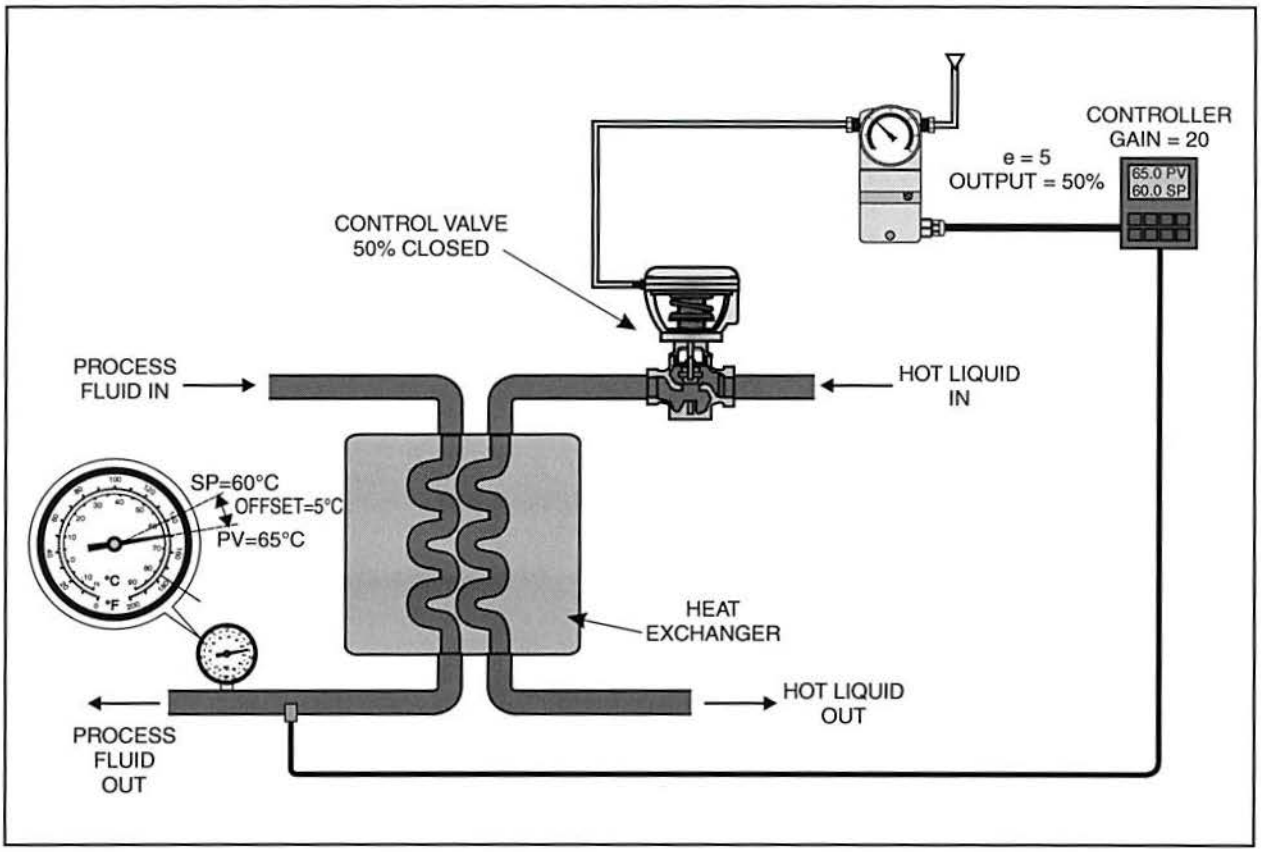

Figure 39. Response of Proportional System with Manual Reset

Offset can automatically be eliminated for all conditions by adding integral control to the proportional control. Integral control is added by setting the integral gain in the PID controller. It also has the benefit of eliminating steady state error due to other influences such as valve stiction (a combination of hysteresis and friction).

The integral control element is able to eliminate offset because it creates an increasing output signal as long as there is an error. The output is linear and the rate of increase is proportional to the size of the error.

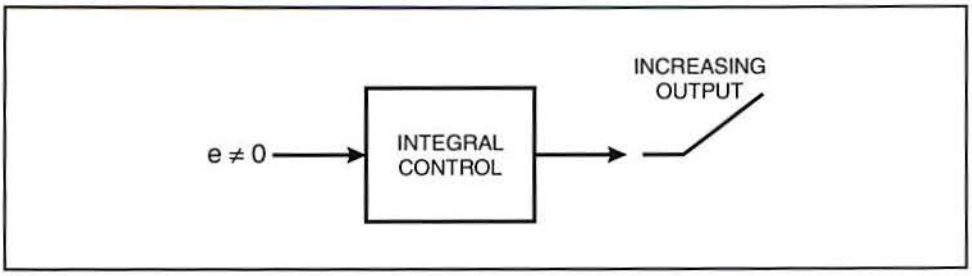

Figure 40. Linear Output Resulting from a Non-Zero Error

When the error is equal to zero, as shown in figure 41, the output remains at a non-zero constant value that holds the error signal at zero. This characteristic differs from proportional control where the output is always zero (assuming there is no manual reset) if the error is zero.

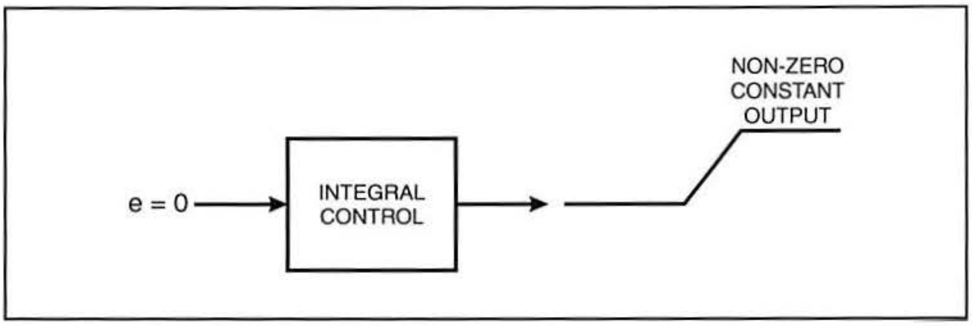

Figure 41. Constant Output Resulting from a Zero Error Signal

Figure 42 shows an example of a controllers output response to error because of integral control. Initially, the error is zero. Therefore, the controller output is constant (i.e. unchanging, this does not imply that it is equal to zero). If a step change occurs (e.g. a change in setpoint), the integral gain causes the controller to increase the output signal at a constant rate as long as the error is present. When the error returns to zero (SP = PV), the controller output becomes constant, holding the system at the new setpoint.

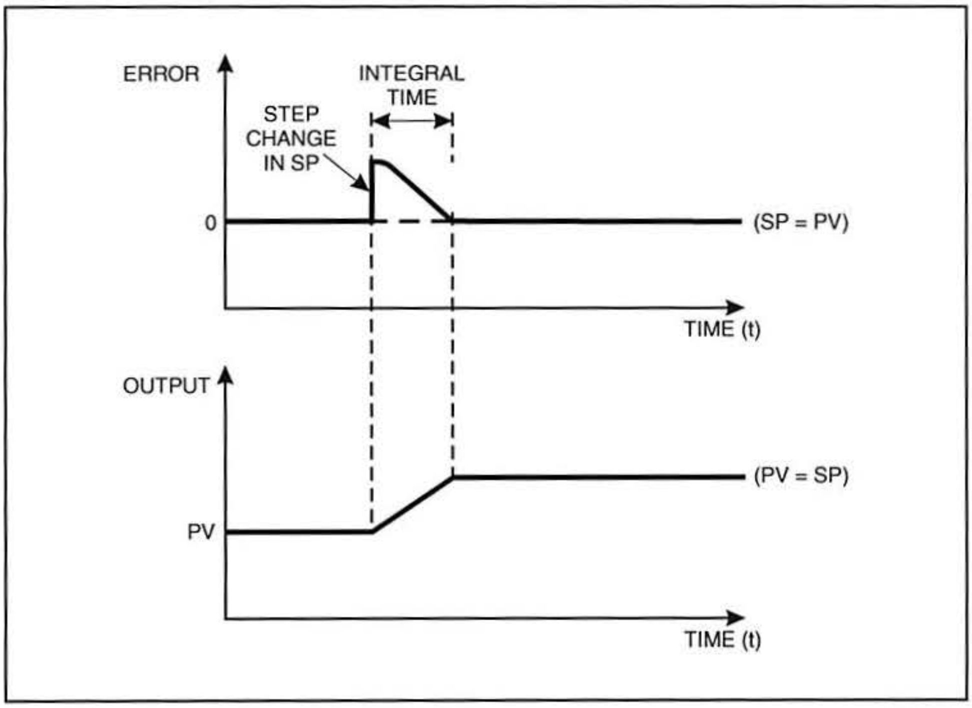

Figure 42. Controller Response to Error Due to Integral Control

A disadvantage of using integral control alone is that an error that is large or exists for a long period of time can cause the final control element (e.g. valve) to reach its fully open or fully closed position before the error is eliminated. If this occurs, the final control element remains at the extreme position (either fully open or fully closed) because the integral control continues to increase the output. The process can not react quickly enough, so the valve stays in the position until it is reset manually. Because of this, integral control is seldom used alone but is combined with proportional control.

OBJECTIVE 10 DEFINE RESET TIME AND RESET RATE AND EXPLAIN THEIR IMPORTANCE

Read This

Reset time refers to the amount of time it takes for the integral action to cause the same amount of change in valve position that proportional control causes after a disturbance or change in the setpoint. Reset time is also referred to as the integral time.

Figure 43 shows an example of reset time. The time begins at the first change in output and ends when the output that the integral control creates equals the proportional control output. In addition, the slope of the line represents the reset rate.

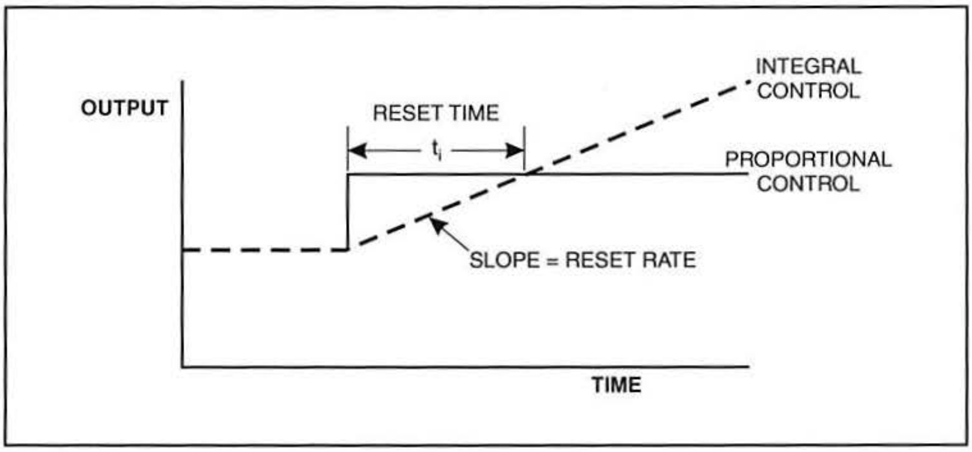

Figure 43. Reset Time and Reset Rate

The objective of any control method is to quickly respond to error with minimal oscillations. Therefore, the reset time should be as small as possible without causing the system to become unstable. The reset time is often given in minutes (MIN).

Reset rate is the inverse of reset time, as shown in the following formula. It refers to the number of times the integral action resets the valve position in a specified amount of time. Therefore, the reset rate is set as high as possible without causing the system to become unstable. The reset rate is usually given in repeats per minute (RPM).

RESET RATE

$$RPM = \frac{1}{t_i}$$

Where:

RPM = Reset Rate as Repeats per Minute

t_i = *Reset Time*

Properly setting the integral action results in no offset, as shown in figure 44.

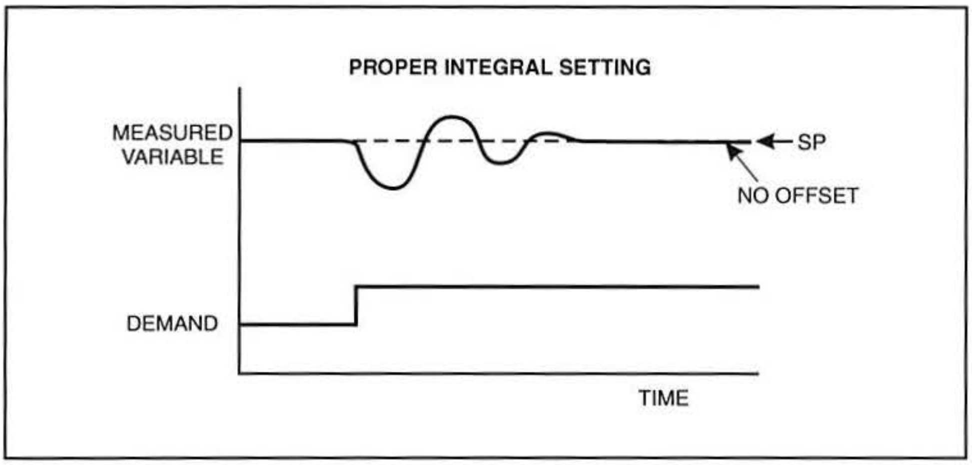

Figure 44. Proper Integral Setting

An integral setting that is either too high or too low has a negative effect on the system. For example, if the integral setting is specified as reset time, setting it too high (reset rate too low) results in a slow response because the controller takes more time to adjust the valve position. Figure 45 shows the effect of a high integral time (low integral rate) setting.

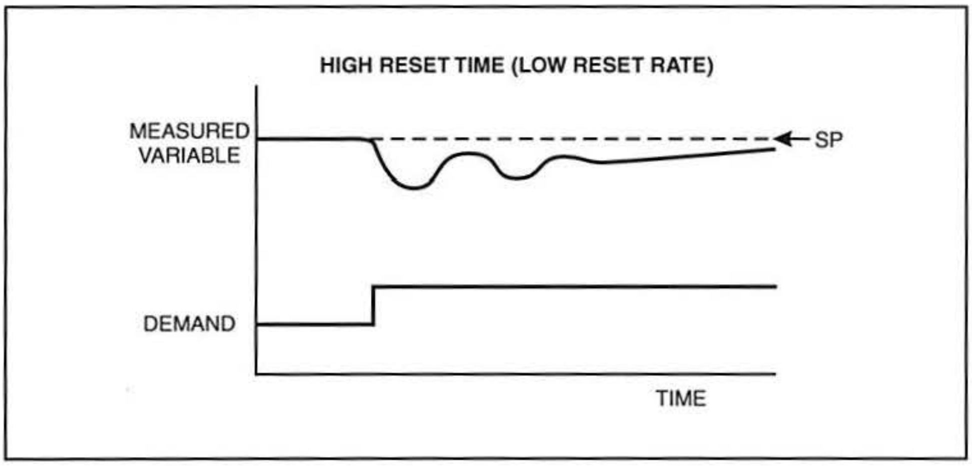

Figure 45. Effect of a High Reset Time or Low Reset Rate Setting

If the reset time is set too low (i.e. if it is set faster than the process is able to respond), the process oscillates because the controller overcorrects for the error. The same result occurs if the reset rate is set too high. Figure 46 shows how a low reset time or high reset rate setting results in an unstable system.

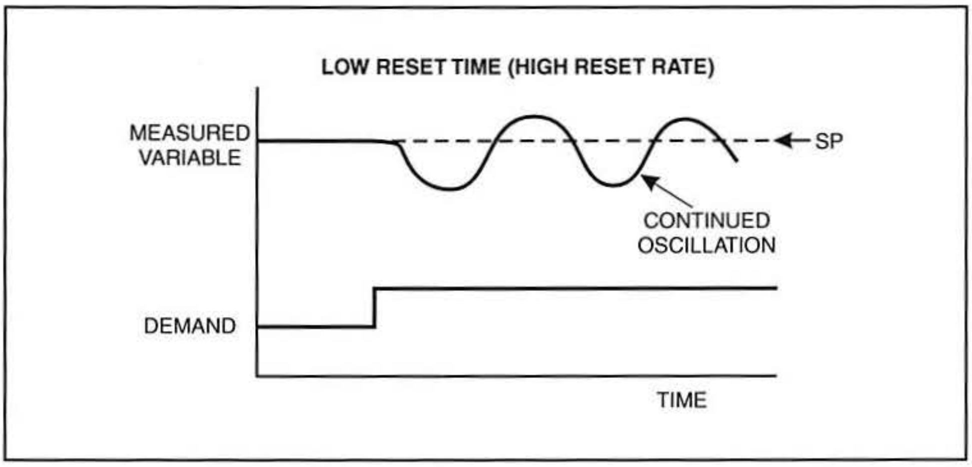

Figure 48. A Low Reset Time (High Reset Rate) Results in an Unstable System

OBJECTIVE 11 DEFINE RESET WIND-UP AND EXPLAIN ITS IMPORTANCE

Read This

Reset wind-up refers to the oscillation in a system that occurs when the integral control tries to correct an error by attempting to adjust the valve beyond its full open or full closed position. It occurs when an error exists for a long period of time. The error builds up over time and the integral control output is based on that time. If there are large delays in the process, the output continues to increase because the controller continues to detect an error. Eventually, the valve reaches its limit, but the integral control output continues to increase. In this case the integral control is said to be wound-up or saturated, as shown in figure 47.

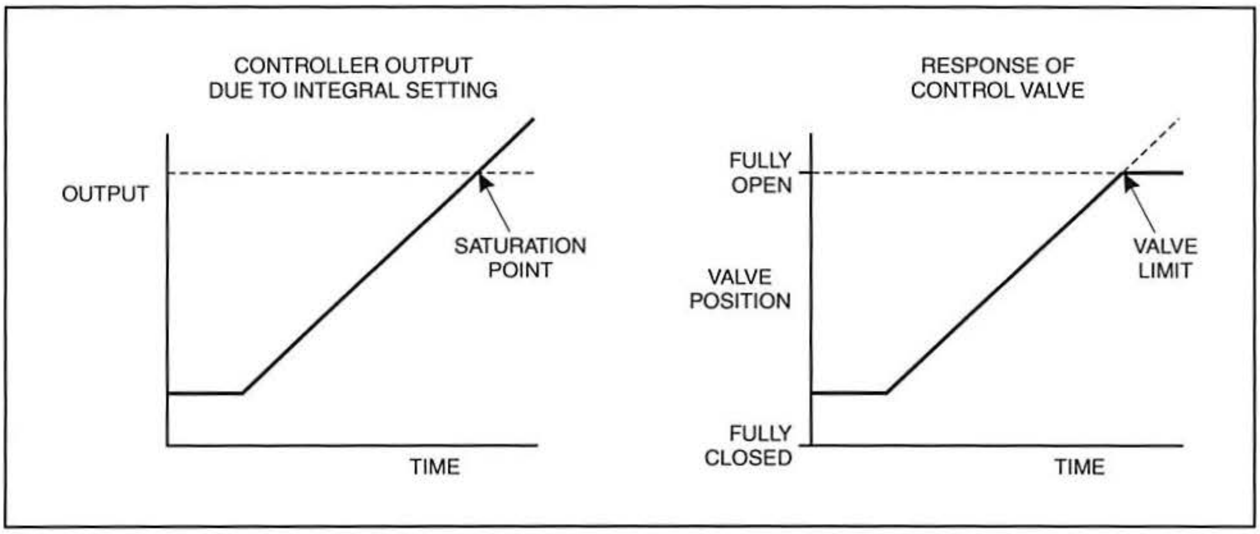

Figure 47. Integral Control Saturated

Temperature control processes often experience problems with reset windup. For example, figure 48 shows a temperature control process that has a problem with reset wind-up. Steam heats a process liquid as it flows through the heat exchanger. The system can maintain the fluid at 50°C for a fluid flow of 100 gallons per minute (gpm).

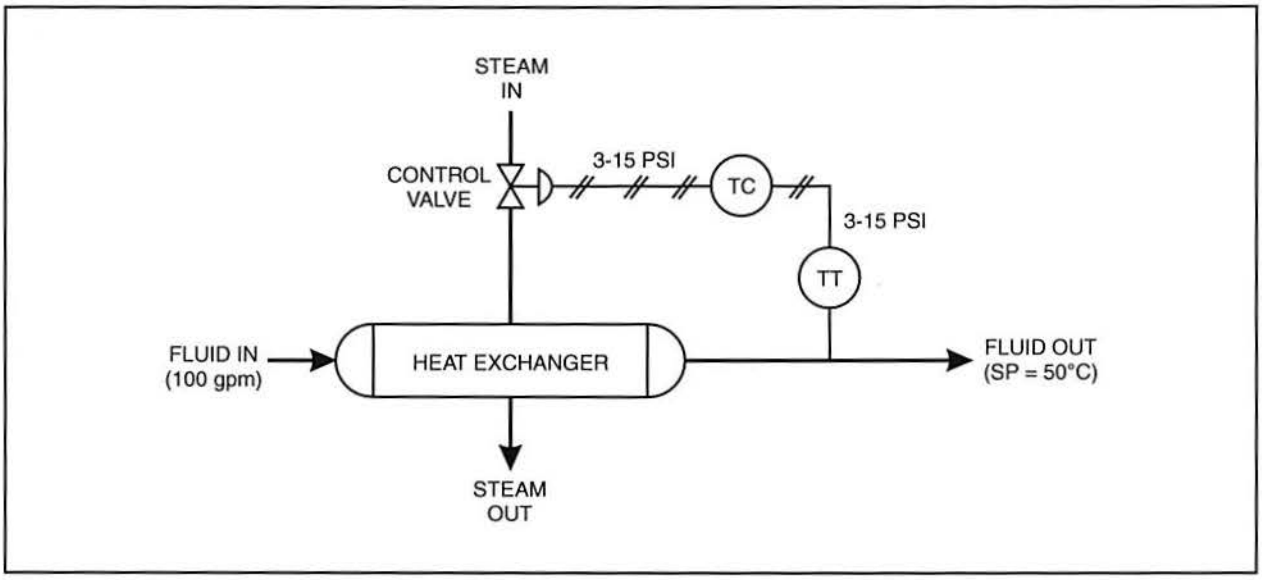

Figure 48. Temperature Control Process

If the fluid input flow increases to 150 gpm, the system cannot maintain the setpoint temperature (50°C) because there is too much fluid entering for the steam to heat. The integral control causes the controller to increase its output until the valve is fully open. Initially, error exists because it takes time for the system to respond. The error continues to exist even after the system responds because, even with the valve fully open, the flow of steam cannot overcome the added process flow. As a result, the integral control continues to perform mathematical calculations on the existing error to increase its output, despite having no effect on the process because the valve is already fully open.

Only an increasing error on the opposite side of the setpoint can bring the integral output back down so that the valve can close. As a result, the process cycles, possibly for a long time. The cycling process creates unusable product, which is very costly to the company.

Most controllers are designed with a function that prevents the integral control output from increasing outside the proportional band. This function creates boundaries in the integral control algorithm so that the controller cannot integrate outside the 4-20 mA output signal range.

OBJECTIVE 12 DESCRIBE THE OPERATION OF PROPORTIONAL-INTEGRAL CONTROL AND GIVE AN APPLICATION

Read This

Proportional-Integral (PI) control combines proportional and integral control to provide an immediate response to error with no offset. Figure 49 shows a block diagram of a process system that uses PI control. The controller receives the feedback signal and determines the required combination of proportional control and integral control necessary to eliminate the error. The output is then sent to the final control element (valve) to control the process.

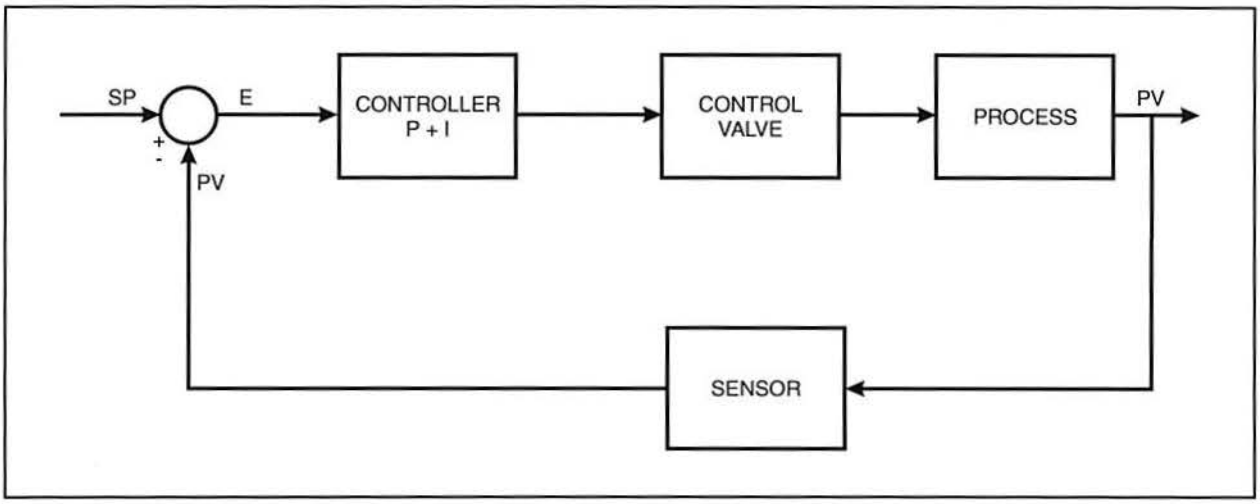

Figure 49. Block Diagram of a Process System Using PI Control

Figure 50 shows a controller response to a change in setpoint using proportional control versus PI control. Using proportional control only, there is the initial response to the error before the system stabilizes, which results in offset. Using PI control, there is a large immediate response to an error due to proportional control. After this initial response, the integral action becomes dominant to eliminate offset.

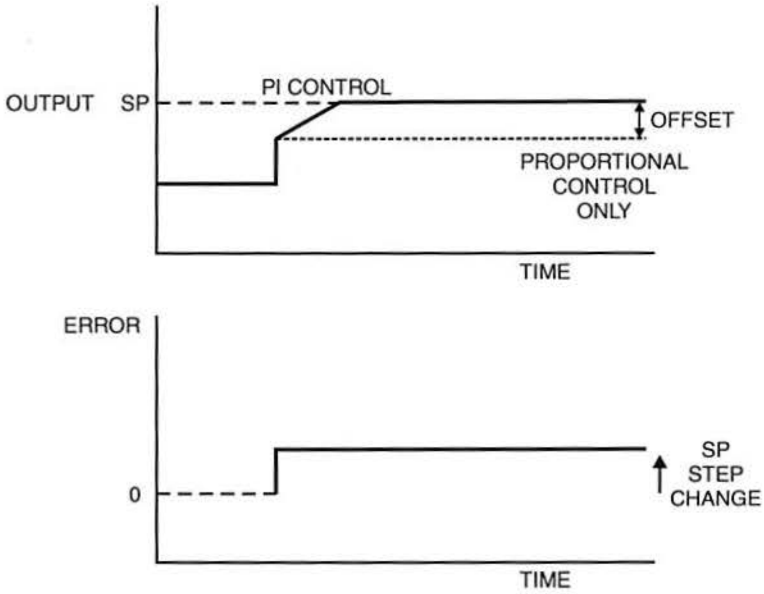

Figure 50. Controller Response Using Proportional Control vs. PI Control

It is more difficult to program a controller for PI control than proportional control because both methods must be considered. Changing one setting can have an undesired effect on the other setting.

Typically, it is not good practice to add integral control to a system that is configured for proportional control only without first lowering the proportional gain. Remember that for a proportional system, the gain is set as high as possible without causing the system to go unstable. Because adding integral control increases the total gain of the controller, failure to lower the proportional gain can cause the system to become unstable.

PI control is common in temperature control systems because they are susceptible to frequent disturbances. The added integral control improves the system response, even for small disturbances and also eliminates the offset associated with proportional systems.

SKILL 2 USE A HONEYWELL CONTROLLER TO CONTROL A PROCESS USING PI CONTROL

Procedure Overview

In this procedure, you will control a temperature loop using a Honeywell PID controller programmed for PI control. You will adjust the integral setting and note the affects on offset and stability.

❑ 1. Perform the following substeps to make sure the T5554 Analytical Process Control System is set up as shown in figure 51.

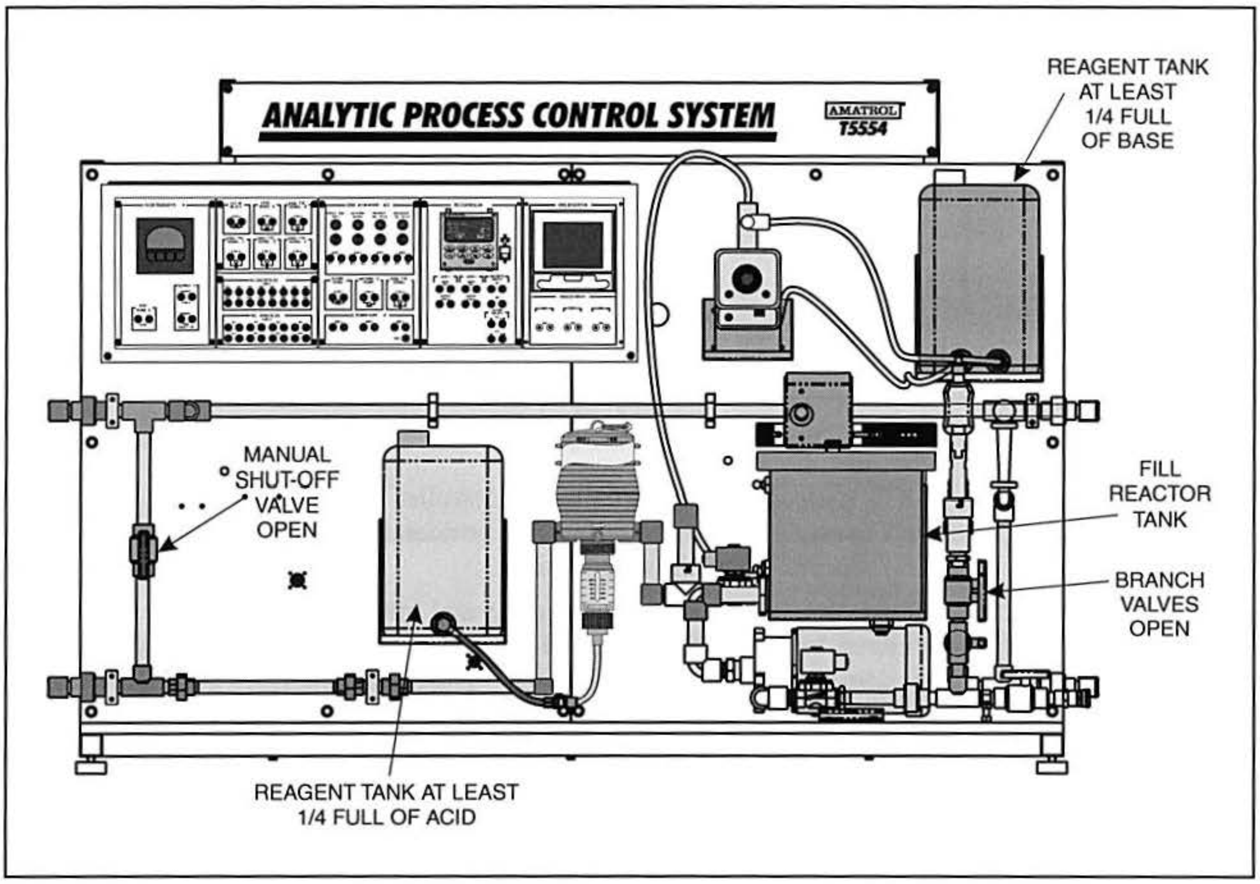

Figure 51. T5554 Setup

A. Make sure the water level in the reactor tank is between the level switches.

Be sure to keep the water level below the high level switch, as shown in figure 52. If the water actuates the high level switch, the inlet solenoid valve is closed to stop flow into the tank. If the water level is too high, drain some of the water from the tank.

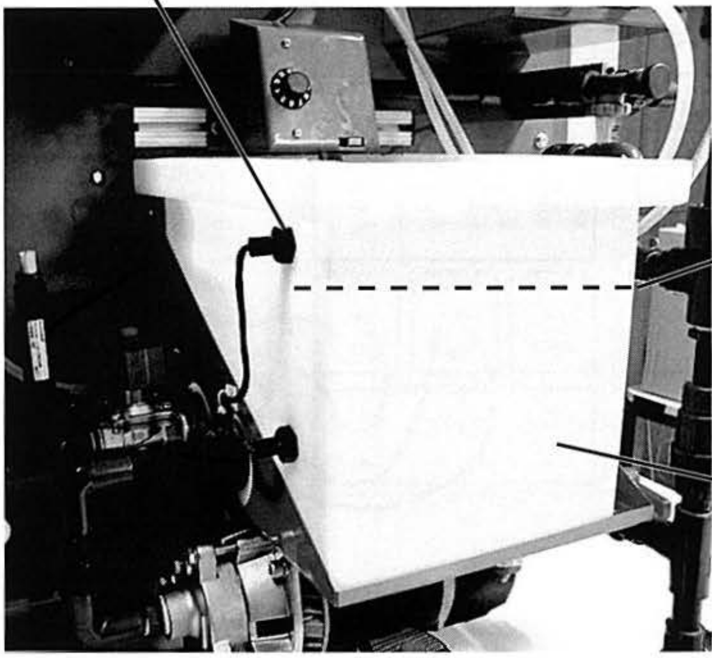

Figure 52. Water Below the High Level Switch

B. Make sure the drain shutoff hand valve is closed (shut) and the drain cap is in place.

C. Make sure the main shutoff valve and the two branch valves are open.

D. Make sure the reagent tanks are filled at least 1/4 full.

E. Make sure the bypass hand valve is closed.

❑ 2. Make sure the circuit shown in figure 53 is still connected. If not, connect it now.

This allows the controller to continuously monitor and control the pH of the process fluid. Make sure a 250-Ohm resistor module is connected to the Loop 1 input on the controller.

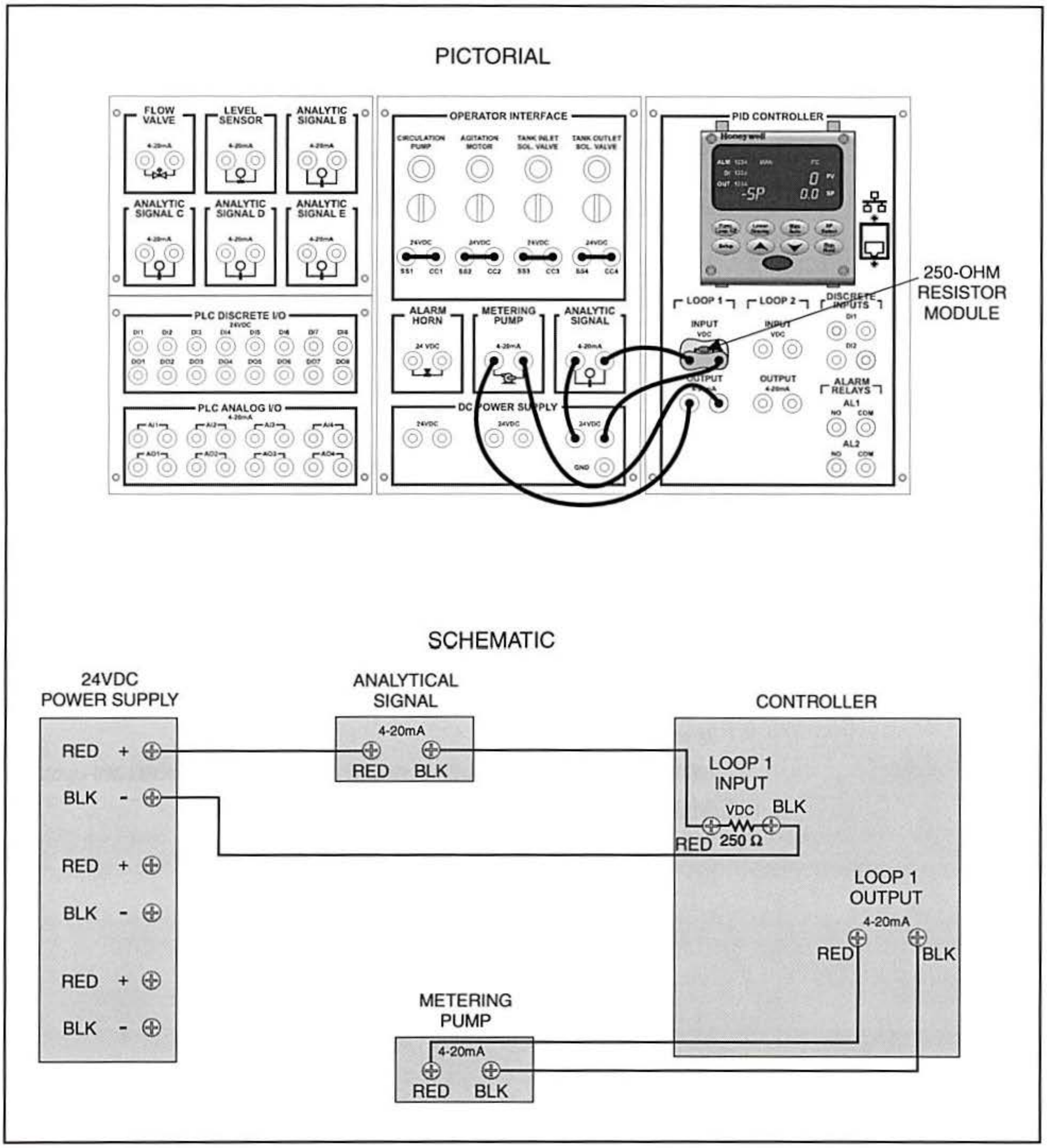

Figure 53. Continuous pH Control Circuit

❑ 3. Perform the following substeps to program the controller for proportional-integral control.

A. Use the **Setup** key on the controller to enter the setup menu and scroll through the groups until ALGORITHM appears on the display.

B. In the ALGORITHM group, set the CONT ALG parameter to **PID A**.

The setting PID A allows the operator to enter an integral control value so that the controller adjusts the manual reset automatically to eliminate any offset.

C. Use the **Setup** key to scroll through the groups until CONTROL appears on the display.

D. Set the following parameters in the CONTROL group.

PARAMETER	SETTING
PBorGAIN	GAIN
MINorRPM	MIN

The PB or GAIN setting selects GAIN as the proportional control parameter and the MIN setting selects integral time (in minutes) as the integral control parameter. These may already be set from a previous skill.

E. Use the **Setup** key to scroll through the groups until TUNING appears on the display.

F. Set the following parameters in the TUNING group:

PARAMETER	SETTING
GAIN	40
RATE MIN	0.0
RSET MIN	0.25

The GAIN parameter sets the controllers proportional gain. The RATE MIN parameter refers to the derivative control method. This parameter is set to zero to eliminate its effect on the process. The RSET MIN parameter refers to the integral time in minutes. Therefore, a setting of 0.25 indicates a reset time of 1/4 minute or 15 seconds.

❑ 4. Program the remaining parameters shown in figure 54.

NOTE

The T5554 only has one reagent pump for the reactor tank. Therefore, you will only need one control loop.

PARAMETER GROUP	PARAMETER	VALUE OR SELECTION
OUTPUT ALG	OUT ALG C1 RANGE	CURRENT 4-20
INPUT 1	IN1 TYPE XMITTER1 IN1 HIGH IN1 LOW	1-5 VLINEAR 14.0 0.0
INPUT 2	IN2 TYPE	DISABLE
CONTROL	PV SOURC SP HiLIM SP LoLIM ACTION I Hi LIM I Lo LIM	INPUT 1 14.0 0.0 REVERSE 100.0 0.0
OPTIONS	DIG IN 1 DIG IN 2	NONE NONE
COM	ComSTATE	DISABL
ALARMS	A1S1TYPE A1S2TYPE A2S1TYPE A2S2TYPE	NONE NONE NONE NONE
DISPLAY	DECIMAL TEMPUNIT PWR FREQ	TWO NONE 60 HZ

Figure 54. Controller Settings for Continuous pH Control

❑ 5. Exit the setup mode by pressing the **Lower Display** key.

❑ 6. Toggle to the setpoint (SP) display and set it to **7.0**.

- ❑ 7. Make sure the bypass valve on the eductor pump is fully closed (knob turned fully clockwise).
- ❑ 8. Set the ratio control or the eductor pump to a ratio of **1:100 (1%)**.

  This allows the eductor pump to inject the acid reagent into the process flow to create a disturbance in the system.
- ❑ 9. Place the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches in the **ON** position.
- ❑ 10. Set the **Agitator Speed** control to **6**.

  Allow the eductor pump to inject the acid reagent into the process flow until the pH reading on the controller display is 6.50.
- ❑ 11. Once the measured pH reaches 6.50, perform the following substeps to set the metering pump controls.

  A. Set the **Mode** selector switch to the **Automatic** position (turn CW).

  B. Unlock the locking lever on the Percentage Stroke Length dial.

  C. Set the Percentage Stroke Length dial to **50%**.

  The setting of the Stroke Rate Percentage dial does not matter. The stroke rate will be controlled by the output of the controller.
- ❑ 12. Perform the following substeps to operate the continuous pH control system.

  A. Place the controller in the automatic mode using the **Man/Auto** key.

  B. Make sure the flow rate is set to **1.2 gpm**. If not, use the adjustment valve on the rotameter to adjust the flow rate.

  C. Observe the operation of the system.

  The controller should cause the metering pump to inject the base reagent into the water to neutralize the pH, measured at the outlet of the reactor tank. It will take several minutes for the system to reach steady state.

  D. Determine the pH at which the process reaches steady state.

  Steady State pH ______________________________

  You should find that the process reaches steady state very close to or at the setpoint (7.0 pH). The addition of the integral gain helps to eliminate the offset that occurred when only proportional gain was used.

  E. Turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

  F. Place the **Mode** selector switch on the metering pump in the **Standby** position.

  G. Set the **Agitator Speed** control fully CCW.

  H. Place the controller in the manual mode.

❑ 13. Enter the Setup menu on the controller and change the RSET MIN parameter setting to **0.1**.

This changes the reset time to 1/10 of a minute or 6 seconds.

❑ 14. Turn on the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

❑ 15. Set the **Agitator Speed** control to **6** and allow the pH reading on the controller display to fall to 6.50.

❑ 16. Once the pH reaches 6.50, perform the following substeps to operate the continuous pH control system.

A. Place the controller in the automatic mode.

B. Set the **Mode** selector switch on the metering pump to the **Automatic** position.

C. Observe the operation of the system and determine the pH at which the process reaches steady state.

Steady State pH ______________________________

You should find that the pH reading oscillates above and below the neutral pH level of 7.0. The pH may eventually settle at the setpoint or it may continue to oscillate. This is an indication that the integral gain is too high (integral time too short).

D. Turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

E. Place the metering pump in the standby mode.

F. Set the **Agitator Speed** control fully CCW.

G. Place the controller in the manual mode.

❑ 17. Turn off the main circuit breaker for the T5554.

❑ 18. Leave the circuit connected.

You will use it again in the next skill.

SEGMENT 3

SELF REVIEW

1. In a system that uses integral control, when the error is ________, the output remains at a non-zero constant value.

2. There are two different ways of expressing the setting of the integral action: reset time and reset __________.

3. If the integral rate is too high, reset ___________ may occur.

4. When using proportional and integral (PI) control, the integral action eliminates __________.

5. Reset rate is the inverse of _________.

6. Before adding integral control to a system for proportional control only, the _________ should be lowered.

SEGMENT 4

PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL

OBJECTIVE 13 DESCRIBE THE OPERATION OF DERIVATIVE OR RATE CONTROL

Read This

Derivative control, or rate control, adjusts the controller output according to the rate at which the error is changing. This causes the controller to anticipate what the error will become and try to prevent it. Derivative control is very useful in applications such as temperature control, where the system tends to respond very slowly.

Derivative control is often added to P and PI control to reduce overshoot and dampen oscillations. It reduces overshoot by anticipating the error and applying the needed correction before the error becomes large. Figure 55 shows the response of a system using PI control and a system using PID control.

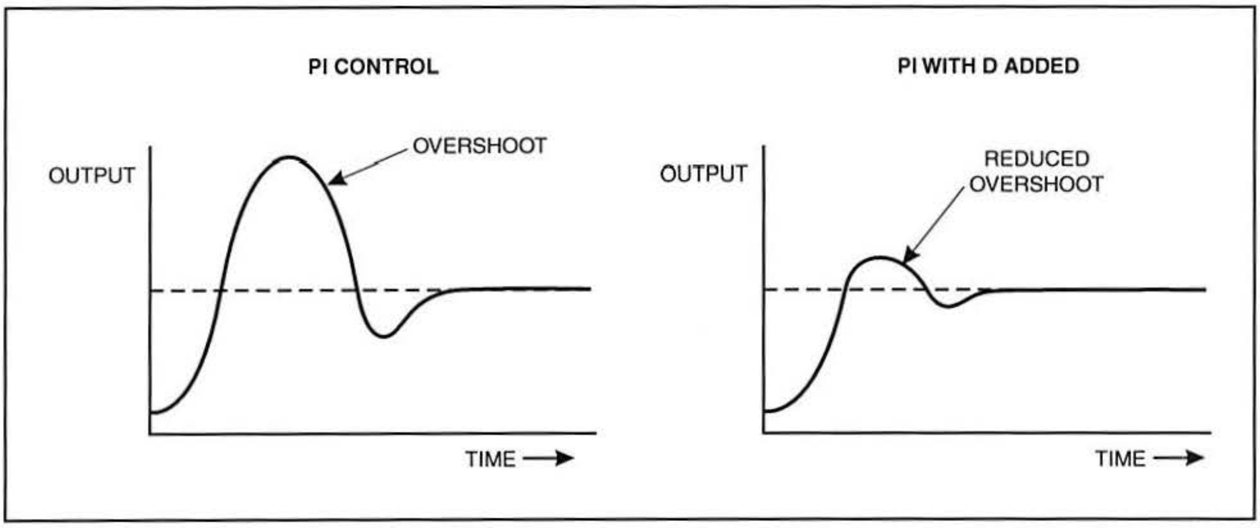

Figure 55. PI Control vs. PID Control

Figure 56 shows a block diagram of a process system that uses only derivative control. When a controller receives a changing error signal (i.e. an error signal that does not hold the same value over time), the derivative gain (D) in the controller increases the controller output according to how fast the signal is changing.

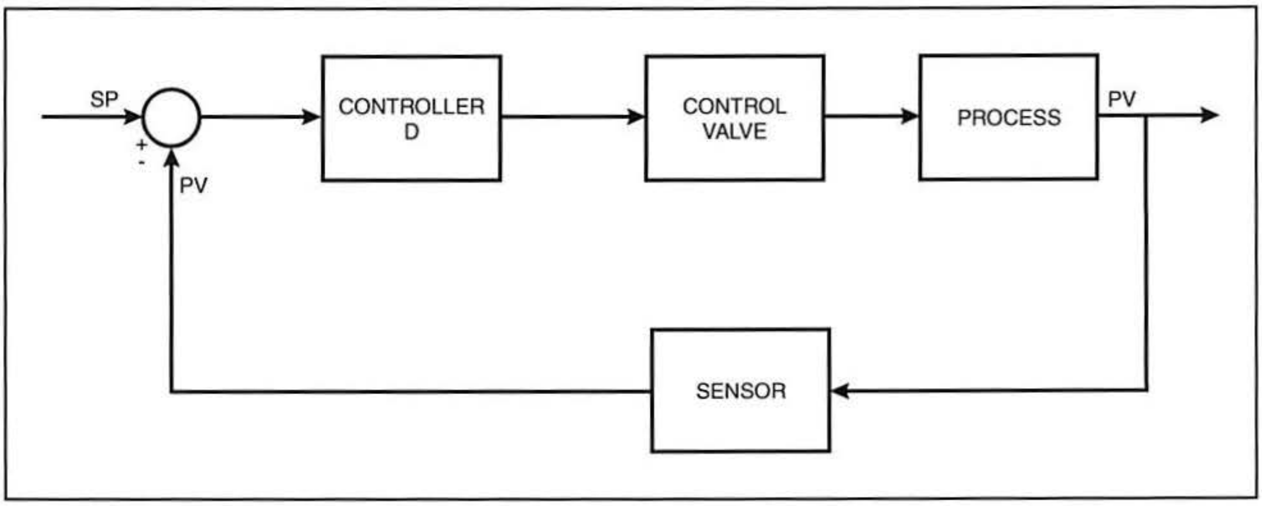

Figure 56. Block Diagram of a Process System Using Derivative Control

If the error is changing quickly, the derivative element increases the controller output by a large amount, as figure 57 shows.

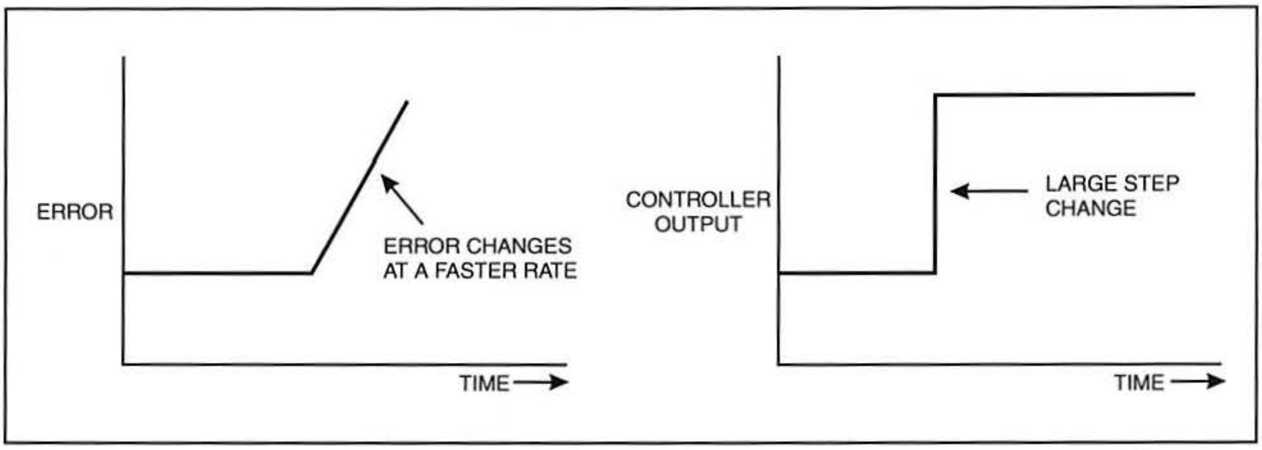

Figure 57. Derivative Response to an Error Changing at a Fast Rate

If the signal changes slowly, the derivative element increases the controller output by a smaller amount, as figure 58 shows.

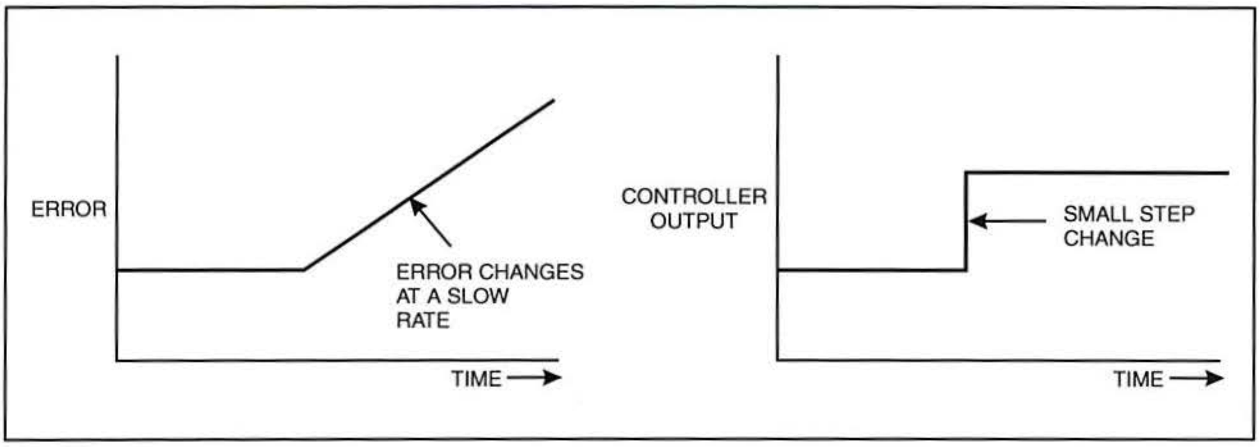

Figure 58. Derivative Response to an Error Signal Changing at a Slow Rate

Derivative control is not used alone because it only contributes to the response if the error is changing. Just because an error exists does not mean that there will be a derivative output. Even if the error is very large, no derivative action occurs if the error remains constant, as shown in figure 59. The error must be changing for derivative control to have any effect.

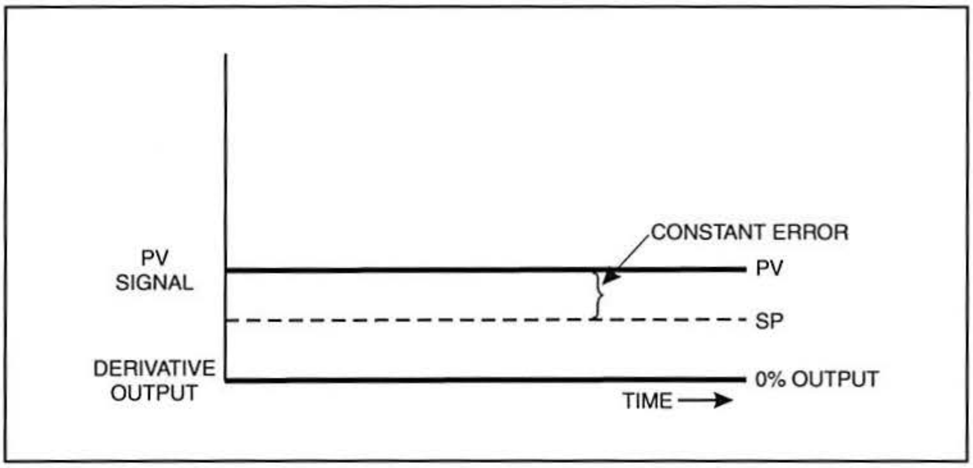

Figure 59. Derivative Response to Constant Error

Derivative Response with a Filter

Because the derivative response increases as the errors rate of change increases, a step change in error (e.g. change in setpoint) causes the output to go infinitely high and immediately return to zero, as shown in figure 60. This type of response occurs because for a step change, the rate of change initially equals infinity. When the step reaches its maximum value, the rate of change goes to zero, so the derivative output is zero.

This type of response can have negative effects on the process because the output overcorrects for the error and causes the system to become unstable. To prevent this negative effect, most controllers include a filter that smooths out step changes in error.

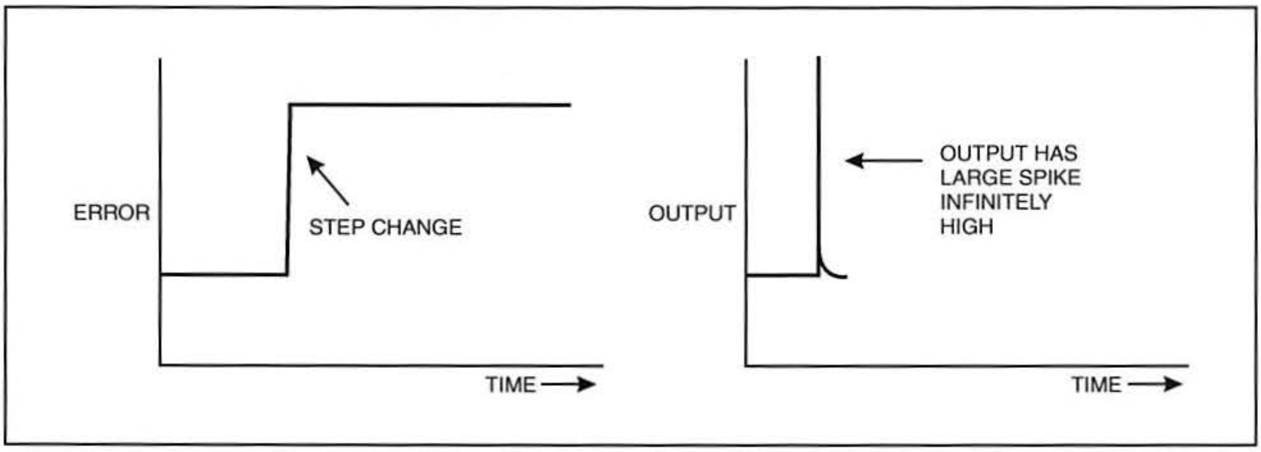

Figure 60. Derivative Response to a Step Change in Error

In figure 61, the graph on the left shows a step change without a filter and the graph on the right shows a step change with a filter. Notice that the graph on the right is slightly curved as it reaches the maximum value, which indicates a slower rate of change than the graph on the left.

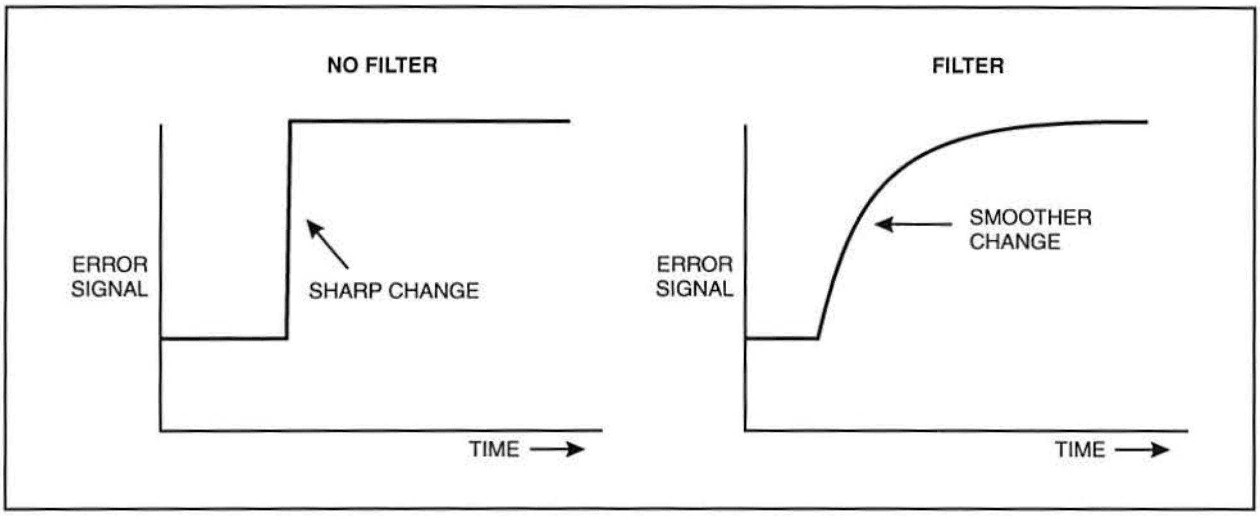

Figure 61. Step Change with and without a Filter

Figure 62 shows the derivative response to a step change with a filter. The initial output is still large and still comes down to zero as the error becomes constant. However, the output does not become infinitely large because the rate of change in the error is not infinitely large (as it would be in an unfiltered step change).

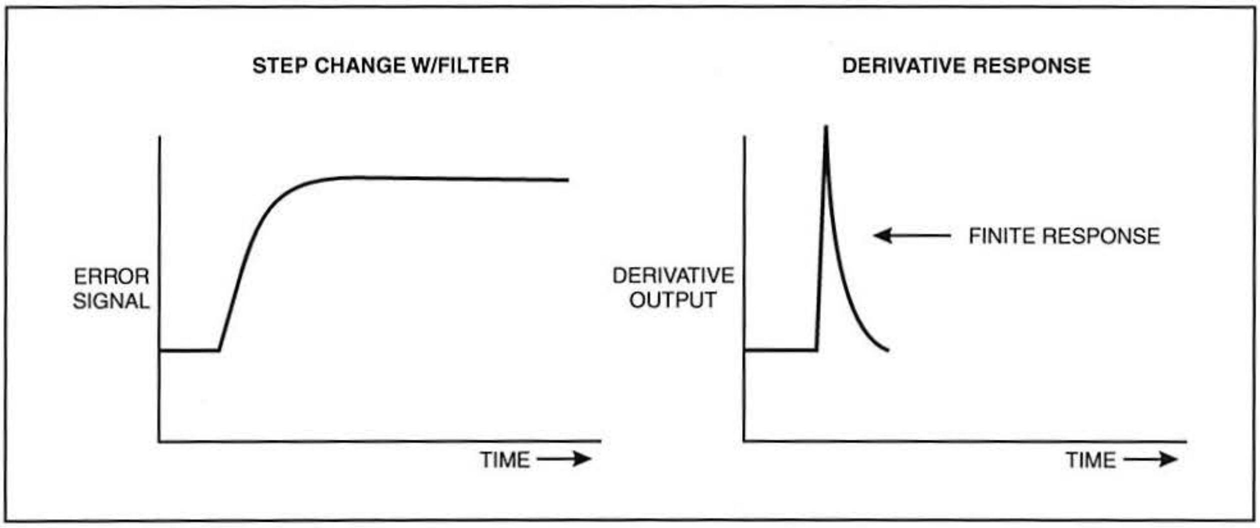

Figure 62. Derivative Response to a Step Change with a Filter

OBJECTIVE 14 DESCRIBE THE OPERATION OF PROPORTIONAL-DERIVATIVE CONTROL AND GIVE AN APPLICATION

Read This

Proportional-Derivative (PD) control combines the proportional and derivative actions to provide an immediate response that is not only proportional to the error but also anticipates the error based on how quickly the error is changing. Figure 63 shows a block diagram of a process control system that uses PD control. The controller calculates the error and determines the required combination of proportional action and derivative action necessary to correct the error. The output is then sent to the valve to control the process.

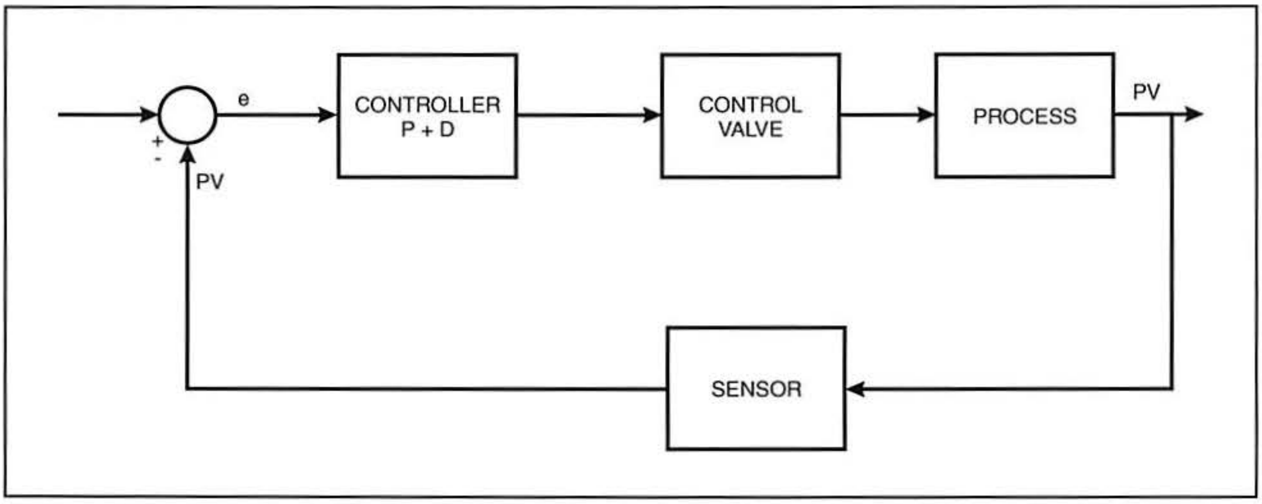

Figure 63. Block Diagram of a Process Control System Using PD Control

During operation, the derivative control action leads the proportional control action by a certain amount of time called the derivative time (td). Derivative time is a value programmed into the controller. Its value determines how much derivative action occurs. As td increases, the derivative action increases. Figure 64 shows a graph of a proportional and derivative response to error.

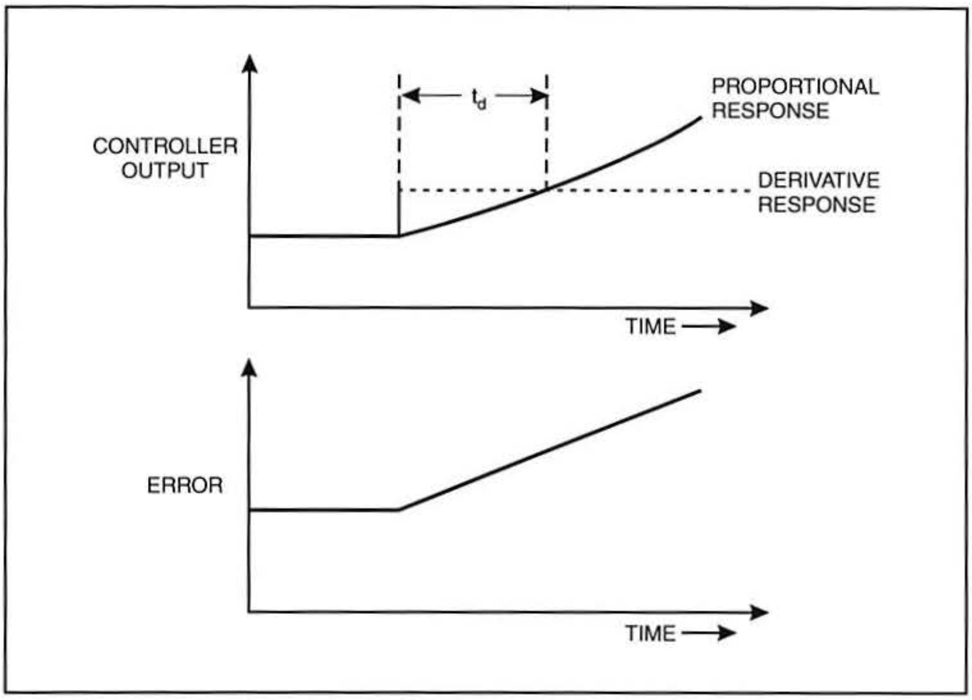

Figure 64. Graph of Proportional and Derivative Response to Error

The addition of derivative control to proportional control provides the process with a faster reaction to an error than is provided with proportional control alone. Figure 65 shows a comparison of the response of a system using only proportional control to the response of a system using PD control. The initial output from the controller increases to 20% using PD control. This allows the system to respond faster to the error. The figure also shows that the derivative time (td) equals one minute. Therefore, the proportional-only control system requires one extra minute to match the output of the PD system.

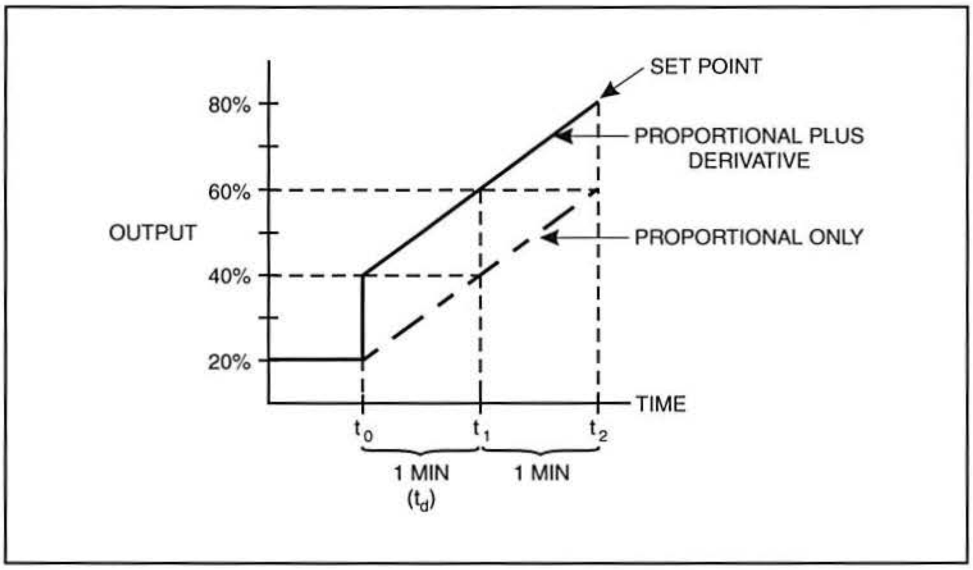

Figure 65. Proportional Response vs. PD Response

The derivative time should be set high enough so that it adjusts the controller output immediately when an error occurs. However, if the action is set too high, the system becomes unstable because the response overcorrects the error, as shown in figure 66. The figure also shows that derivative control does not eliminate offset.

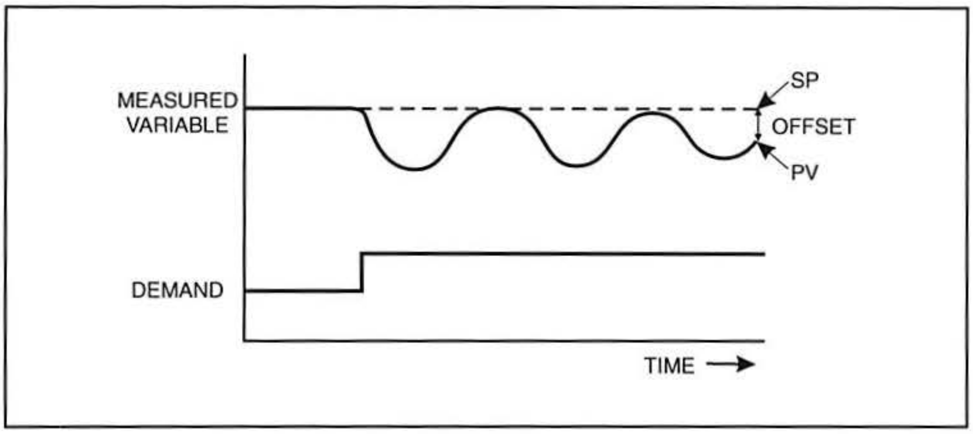

Figure 66. Process Response with Derivative Setting Too High

PD control is generally used in applications that have sudden load changes or systems that normally have a long time delay between when the controller applies corrective action and when the system responds to the action. Some temperature control systems use PD control because they are typically slow to react to changes, especially when raising the temperature of a process.

SKILL 3 USE A HONEYWELL CONTROLLER TO CONTROL A PROCESS USING PD CONTROL

Procedure Overview

In this procedure, you will control a temperature process using a Honeywell PID controller set for PD control. You will adjust the derivative (D) setting and observe the effect on the control loop.

❑ 1. Perform the following substeps to make sure the T5554 Analytical Process Control System is set up as shown in figure 67.

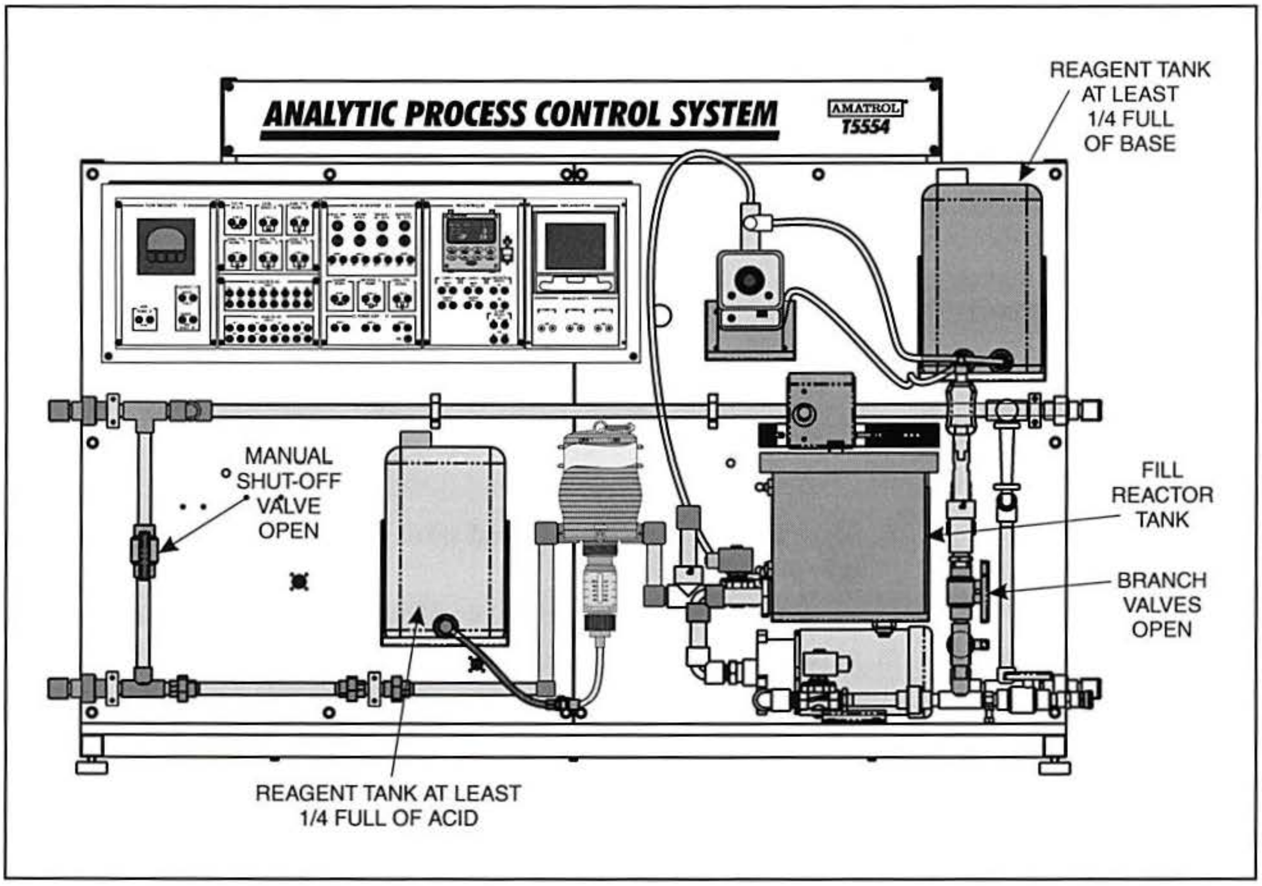

Figure 67. T5554 Setup

A. Make sure the water level in the reactor tank is between the level switches.

Be sure to keep the water level below the high level switch, as shown in figure 68. If the water actuates the high level switch, the inlet solenoid valve is closed to stop flow into the tank. If the water level is too high, drain some of the water from the tank.

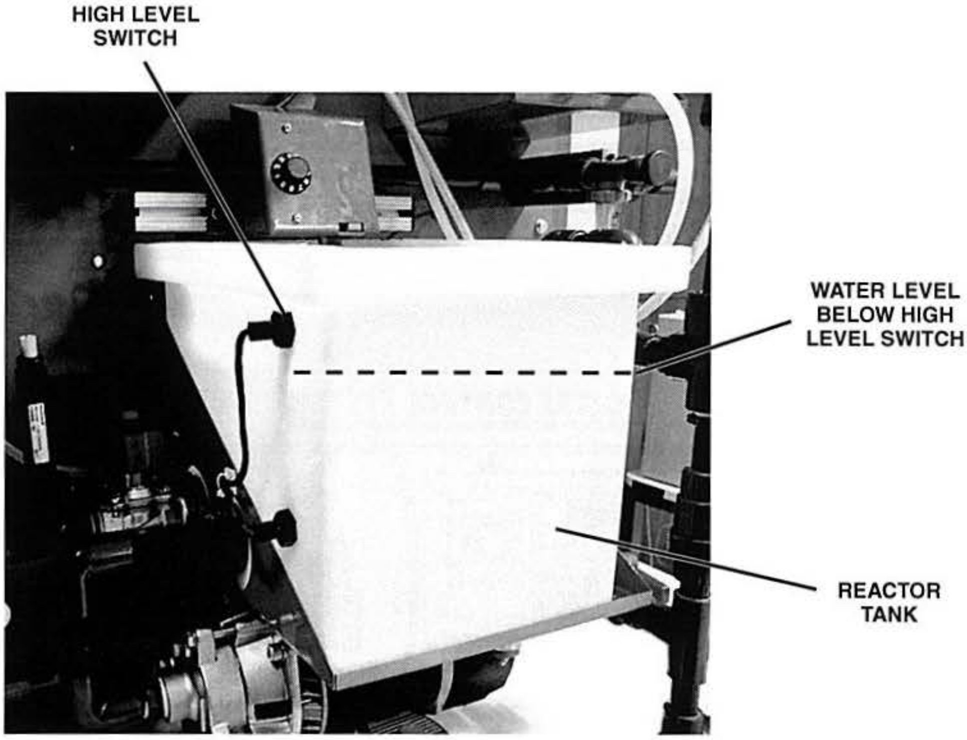

Figure 68. Water Below the High Level Switch

B. Make sure the drain shutoff hand valve is closed (shut) and the drain cap is in place.

C. Make sure the main shutoff valve and the two branch valves are open.

D. Make sure the reagent tanks are filled at least 1/4 full.

E. Make sure the bypass hand valve is closed.

- [ ] 2. Make sure the circuit shown in figure 69 is still connected. If not, connect it now.

   This allows the controller to continuously monitor and control the pH of the process fluid. Make sure a 250-Ohm resistor module is connected to the Loop 1 input on the controller.

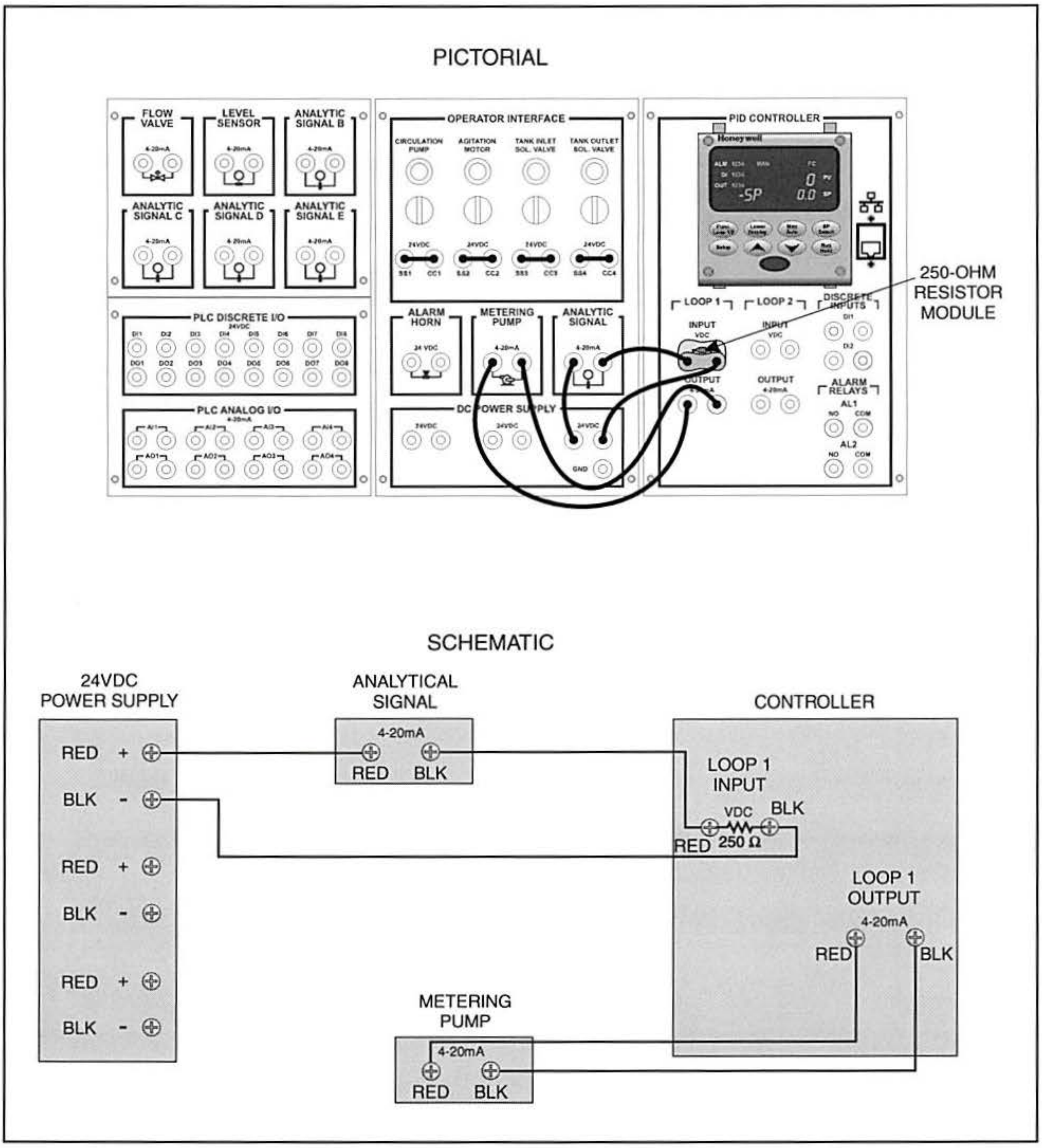

Figure 69. Continuous pH Control Circuit

❑ 3. Perform the following substeps to start up and set the controller for proportional-derivative (PD) control.

A. Use the **Setup** key on the controller to scroll through the groups until ALGORITHM appears on the display.

B. Use the **Func Loop 1/2** key to scroll to the parameter CONT ALG.

C. Use the ▲ and ▼ keys to set the parameter to **PD + MR**.

This allows you to program the proportional and derivative setting. It also allows you to use the manual reset setting to correct for offset if desired.

D. Set the PBorGAIN parameter in the CONTROL group to **GAIN**.

E. Set the ACTION parameter in the CONTROL group to **REVERSE**, if necessary.

F. Set the following parameters in the TUNING group.

PARAMETER	SETTING
GAIN	40
RATE MIN	0.05
MAN RSET	0

☐ 4. Program the remaining parameters shown in figure 70.

NOTE

The T5554 only has one reagent pump for the reactor tank. Therefore, you will only need one control loop.

PARAMETER GROUP	PARAMETER	VALUE OR SELECTION
OUTPUT ALG	OUT ALG C1 RANGE	CURRENT 4-20
INPUT 1	IN1 TYPE XMITTER1 IN1 HIGH IN1 LOW	1-5 VLINEAR 14.0 0.0
INPUT 2	IN2 TYPE	DISABLE
CONTROL	PV SOURC SP HiLIM SP LoLIM ACTION I Hi LIM I Lo LIM	INPUT 1 14.0 0.0 REVERSE 100.0 0.0
OPTIONS	DIG IN 1 DIG IN 2	NONE NONE
COM	ComSTATE	DISABL
ALARMS	A1S1TYPE A1S2TYPE A2S1TYPE A2S2TYPE	NONE NONE NONE NONE
DISPLAY	DECIMAL TEMPUNIT PWR FREQ	TWO NONE 60 HZ

Figure 70. Controller Settings for Continuous pH Control

☐ 5. Exit the setup mode by pressing the **Lower Display** key.

☐ 6. Toggle to the setpoint (SP) display and set it to **7.0**.

☐ 7. Make sure the bypass valve on the eductor pump is fully closed (knob turned fully clockwise).

☐ 8. Set the ratio control or the eductor pump to a ratio of **1:100 (1%)**.

This allows the eductor pump to inject the acid reagent into the process flow to create a disturbance in the system.

☐ 9. Place the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches in the **ON** position.

☐ 10. Set the **Agitator Speed** control to **6**.

Allow the eductor pump to inject the acid reagent into the process flow until the pH reading on the controller display is 6.50.

❑ 11. Once the measured pH reaches 6.50, perform the following substeps to set the metering pump controls.

A. Set the **Mode** selector switch to the **Automatic** position (turn CW).

B. Unlock the locking lever on the Percentage Stroke Length dial.

C. Set the Percentage Stroke Length dial to **50%**.

The setting of the Stroke Rate Percentage dial does not matter. The stroke rate will be controlled by the output of the controller.

❑ 12. Perform the following substeps to operate a continuous pH control system.

A. Place the controller in the automatic mode using the **Man/Auto** key.

B. Make sure the flow rate is set to **1.2 gpm**. If not, use the adjustment valve on the rotameter to adjust the flow rate.

C. Observe the operation of the system.

The controller should cause the metering pump to inject the base reagent into the water to neutralize the pH, measured at the outlet of the reactor tank. It will take several minutes for the system to reach steady state.

D. Determine the pH at which the process reaches steady state.

Steady State pH ________________________________

You should find that the process reaches steady state at a value other than the setpoint value of 7.0. In fact, the steady state pH may be above the setpoint value. This is due to the derivative gain.

Also, the derivative gain does not prevent offset.

E. Turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

F. Place the **Mode** selector switch on the metering pump in the Standby position.

G. Set the **Agitator Speed** control fully CCW.

H. Place the controller in the manual mode.

❑ 13. Enter the setup menu on the controller and change the RATE MIN parameter setting to **0.10**.

This will increase the derivative gain.

❑ 14. Turn on the **CIRCULATION PUMP** and **AGITATOR MOTOR**.

❑ 15. Set the **Agitator Speed** control to **6**.

❑ 16. Once the pH reaches 6.50, perform the following substeps to operate the continuous pH control system.

A. Place the controller in the automatic mode.

B. Set the **Mode** selector switch on the metering pump to the **Automatic** position.

C. Observe the operation of the system and determine the pH at which the process reaches steady state.

Steady State pH ______________________________

You should find that the pH reading does not reach steady state at the setpoint pH of 7. In fact, since the derivative gain is higher, the system may not reach steady state but instead oscillate.

D. Turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR**.

E. Place the metering pump in the standby mode.

F. Set the **Agitator Speed** control fully CCW.

G. Place the controller in the manual mode.

❑ 17. Turn off the main circuit breaker for the T5554.

❑ 18. Leave the circuit connected.

You will use it again in the next skill.

OBJECTIVE 15 DESCRIBE THE OPERATION OF PID CONTROL AND GIVE AN APPLICATION

Read This

Proportional-Integral-Derivative (PID) control combines all three control methods so that the response anticipates the error, is proportional and immediate, and continues to change until the error is zero. Figure 71 shows a block diagram of a system using PID control. The controller combines the three control methods to produce the output signal. The valve receives the output signal and controls the flow accordingly.

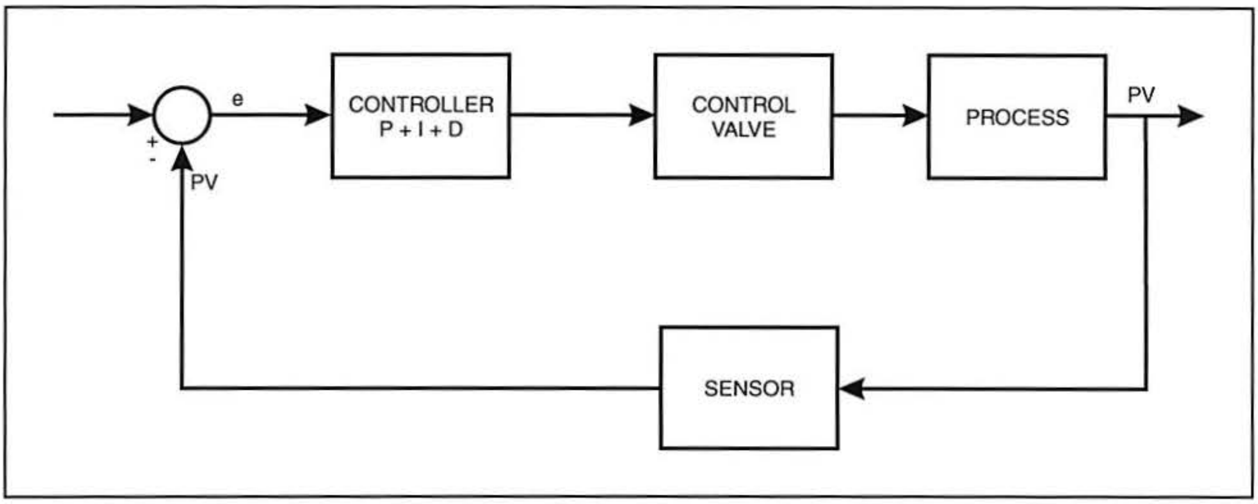

Figure 71. Block Diagram of a System Using PID Control

When programmed properly, PID control maintains the set point in a steady state. Any oscillations that occur have a small amplitude and duration. Figure 72 shows a response curve for a system that uses PID control.

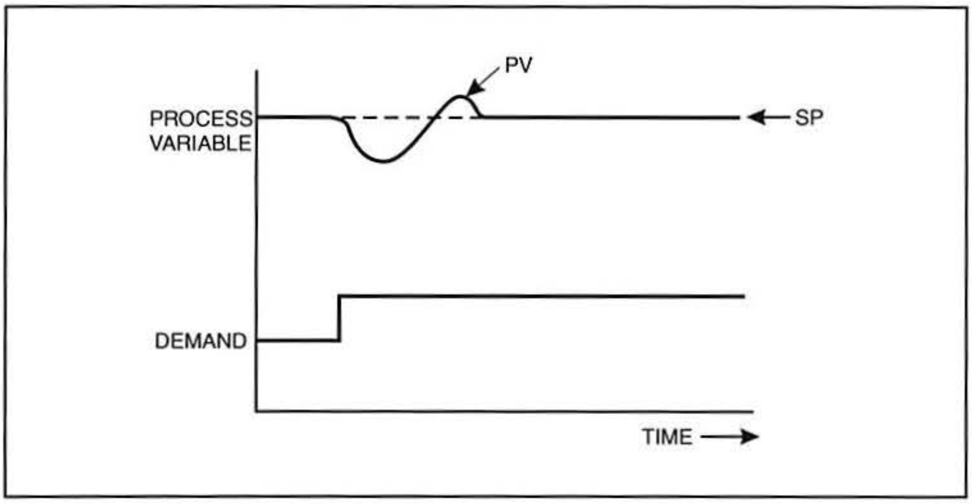

Figure 72. Process Response to PID Control

The advantages of PID control include an immediate reaction to error, a proportional response, and no offset. However, it is much more difficult to program the controller so that all three control methods work together and perform at the best level. One reason for this is that although each method operates at the same time, there are times when a particular method is contributing more to the corrective action than the other methods.

Figure 73 shows a response curve for a system using PID control. First, the derivative action applies an immediate corrective action. Next, the proportional action contributes more to create a proportional response. Finally, the integral action eliminates offset. Making the three control actions work well together (i.e. so that the response is smooth and stable) usually requires adjusting the controller several times.

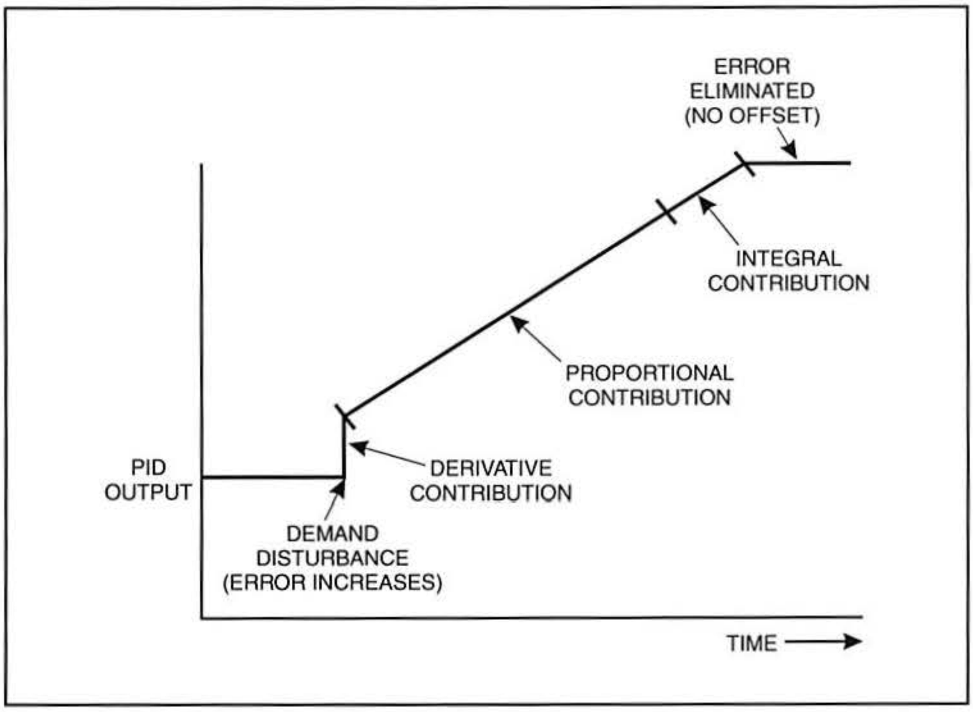

Figure 73. Process Response to PID Control

In many cases, meeting the challenge of properly programming a controller to use PID control is not worth the effort. Often, the P, PI, or PD method is enough to control the process within acceptable limits. However, some temperature applications that require the process to maintain the set point at all times use PID control.

SKILL 4 USE A HONEYWELL PID CONTROLLER TO CONTROL A PROCESS USING PID CONTROL

Procedure Overview

In this procedure, you will control a temperature process using PID control. You will change the process setpoint and observe the system response. This will help you better understand how the three control modes work together to provide stable control of a process.

❑ 1. Perform the following substeps to make sure the T5554 Analytical Process Control System is set up as shown in figure 74.

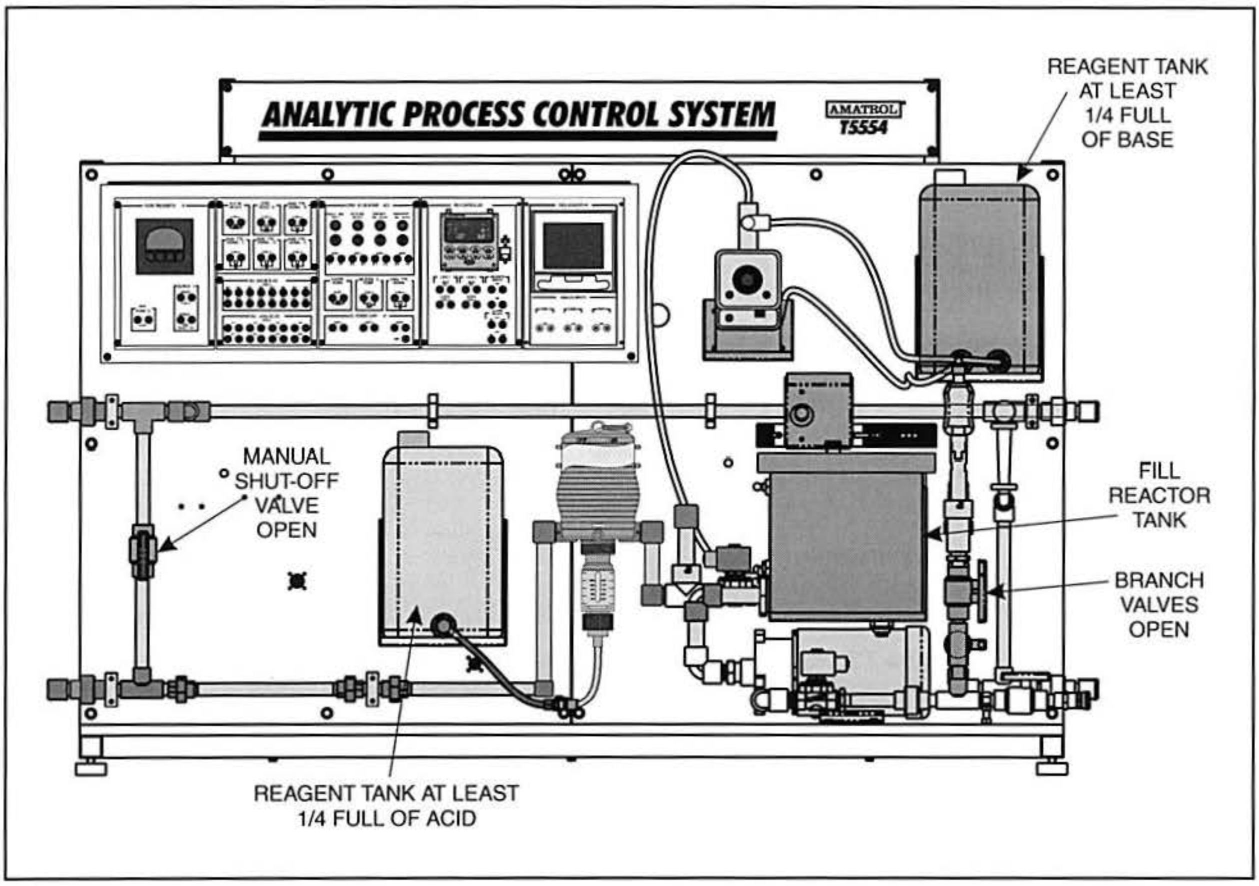

Figure 74. T5554 Setup

A. Make sure the water level in the reactor tank is between the level switches.

Be sure to keep the water level below the high level switch, as shown in figure 75. If the water actuates the high level switch, the inlet solenoid valve is closed to stop flow into the tank. If the water level is too high, drain some of the water from the tank.

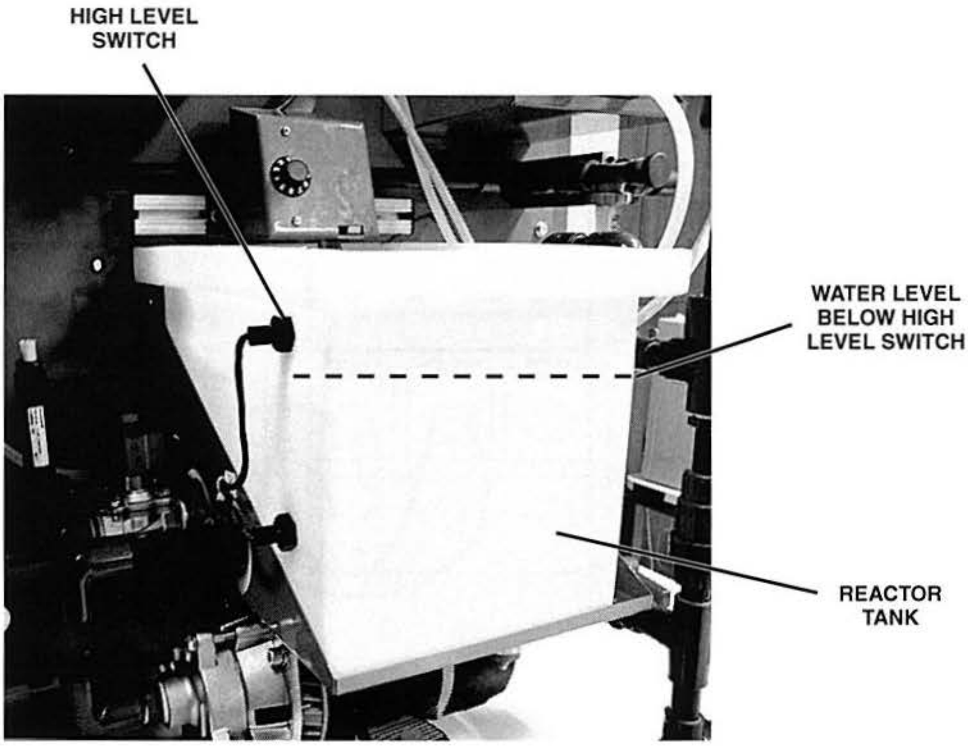

Figure 75. Water Below the High Level Switch

B. Make sure the drain shutoff hand valve is closed (shut) and the drain cap is in place.

C. Make sure the main shutoff valve and the two branch valves are open.

D. Make sure the reagent tanks are filled at least 1/4 full.

E. Make sure the bypass hand valve is closed.

❑ 2. Make sure the circuit shown in figure 76 is still connected. If not, connect it now.

This allows the controller to continuously monitor and control the pH of the process fluid. Make sure a 250-Ohm resistor module is connected to the Loop 1 input on the controller.

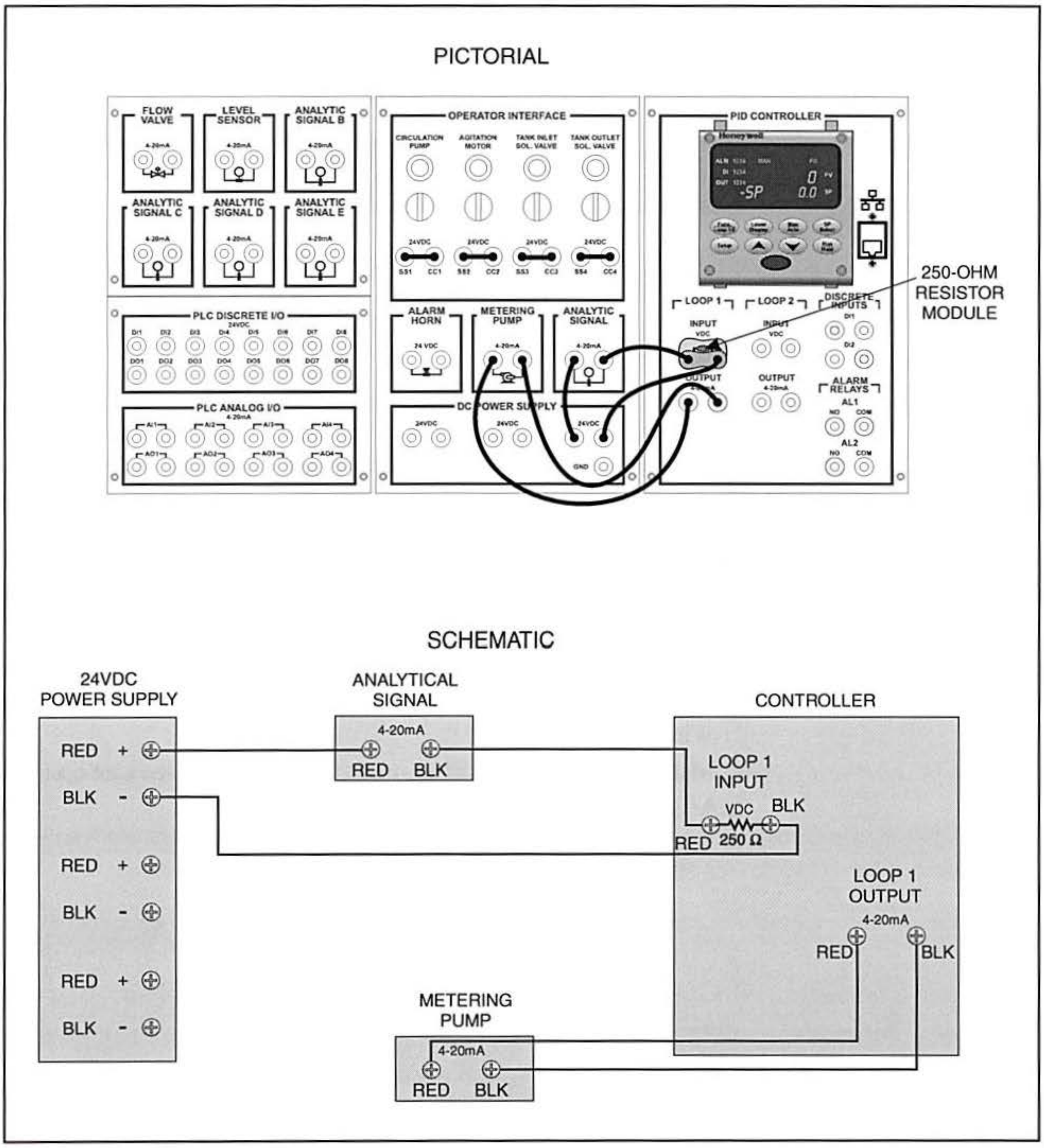

Figure 76. Continuous pH Control Circuit

❑ 3. Turn on the main circuit breaker.

❑ 4. Place the controller in the manual mode and program it for PID control according to the parameters listed in the table of figure 77.

NOTE

The T5554 only has one reagent pump for the reactor tank. Therefore, you will only need one control loop.

PARAMETER GROUP	PARAMETER	VALUE OR SELECTION
OUTPUT ALG	OUT ALG C1 RANGE	CURRENT 4-20
INPUT 1	IN1 TYPE XMITTER1 IN1 HIGH IN1 LOW	1-5 VLINEAR 14.0 0.0
INPUT 2	IN2 TYPE	DISABLE
CONTROL	PV SOURC SP HiLIM SP LoLIM ACTION I Hi LIM I Lo LIM	INPUT 1 14.0 0.0 REVERSE 100.0 0.0
OPTIONS	DIG IN 1 DIG IN 2	NONE NONE
COM	ComSTATE	DISABL
ALARMS	A1S1TYPE A1S2TYPE A2S1TYPE A2S2TYPE	NONE NONE NONE NONE
DISPLAY	DECIMAL TEMPUNIT PWR FREQ	TWO NONE 60 HZ

*In order to set this parameter, the Control Algorithm (CONT ALG) parameter must be set to PIDA

Figure 77. Controller Settings for Continuous pH Control

❑ 5. Exit the setup mode by pressing the **Lower Display** key.

❑ 6. Toggle to the setpoint (SP) display and set it to **7.0**.

❑ 7. Make sure the bypass valve on the eductor pump is fully closed (knob turned fully clockwise).

❑ 8. Set the ratio control or the eductor pump to a ratio of **1:100 (1%)**.

This allows the eductor pump to inject the acid reagent into the process flow to create a disturbance in the system.

❑ 9. Turn on the CIRCULATION PUMP and AGITATOR MOTOR.

❑ 10. Set the **Agitator Speed** control to **6**.

Allow the eductor pump to inject the acid reagent into the process flow until the pH reading on the controller display is 6.50.

❑ 11. Once the measured pH reaches 6.50, perform the following substeps to set the metering pump controls.

A. Set the **Mode** selector switch to the **Automatic** position (turn CW).

B. Unlock the locking lever on the Percentage Stroke Length dial.

C. Set the Percentage Stroke Length dial to **50%**.

The setting of the Stroke Rate Percentage dial does not matter. The stroke rate will be controlled by the output of the controller.

❑ 12. Perform the following substeps to operate a continuous pH control system.

A. Place the controller in the automatic mode using the **Man/Auto** key.

B. Make sure the flow rate is set to **1.2 gpm**. If not, use the adjustment valve on the rotameter to adjust the flow.

C. Observe the operation of the system.

The controller should cause the metering pump to inject the base reagent into the water to neutralize the pH, measured at the outlet of the reactor tank. It will take several minutes for the system to reach steady state.

D. Determine the pH at which the process reaches steady state.

Steady State pH ______________________________

You should find that the process reaches steady state around the setpoint (7.0). The integral gain helps to eliminate the offset.

There may be some slight oscillation around the setpoint. If so, you can lower the gain slightly.

E. When the pH of the water is neutralized, turn off the **CIRCULATION PUMP** and **AGITATOR MOTOR** selector switches.

F. Place the **Mode** selector switch on the metering pump in the **Standby** position.

G. Set the **Agitator Speed** control fully CCW.

H. Place the controller in the manual mode.

❑ 13. Perform the following substeps to shut down the T5554.

A. Turn off the main power circuit breaker for the T5554.

B. Disconnect the circuit.

SEGMENT 4

SELF REVIEW

1. A type of control that responds to the rate at which the error signal is changing is ______________ control.

2. Derivative control is commonly used along with proportional control in _________________ control systems.

3. If the error's rate of change is ________, the derivative control will not respond to it.

4. Controllers with derivative control often include a(n) _______ that smooths out step changes in error.

5. Temperature control systems typically tend to be _____ to react to changes, especially if the operator is trying to raise the temperature of a process.

6. _____________ control combines the three control methods in a way that provides smooth, stable control of a process.

7. One drawback of PID control is that it is difficult to ____________.

8. The advantages of PID control include an immediate response to error, a proportional response, and no ________.

9. Any oscillations that occur in a PID controlled system have a small __________ and duration.