PROCESS CONTROL SYSTEMS

8

LEARNING ACTIVITY PACKET

METHODS OF AUTOMATIC CONTROL

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AMATROL

INTEGRATED SYSTEMS TECHNOLOGY

B270-XD

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, PLC's, and software packages to provide accurate process control.

ITEMS NEEDED

Amatrol Supplied
- 1 T5552 Process Control Learning System

School Supplied
- 1 Water Supply (10 Gallons)
- 1 Compressed Air Supply

FIRST EDITION, LAP 8, REV. A

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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 state or transient state. A steady state is when the average of the process output over time remains constant. This typically occurs when the process output settles near or reaches its setpoint. A transient state is when the output continuously changes over time. A transient state occurs when the process output is changing from one setpoint to another.

Figure 1 shows an example of a process system's 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 in which 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.

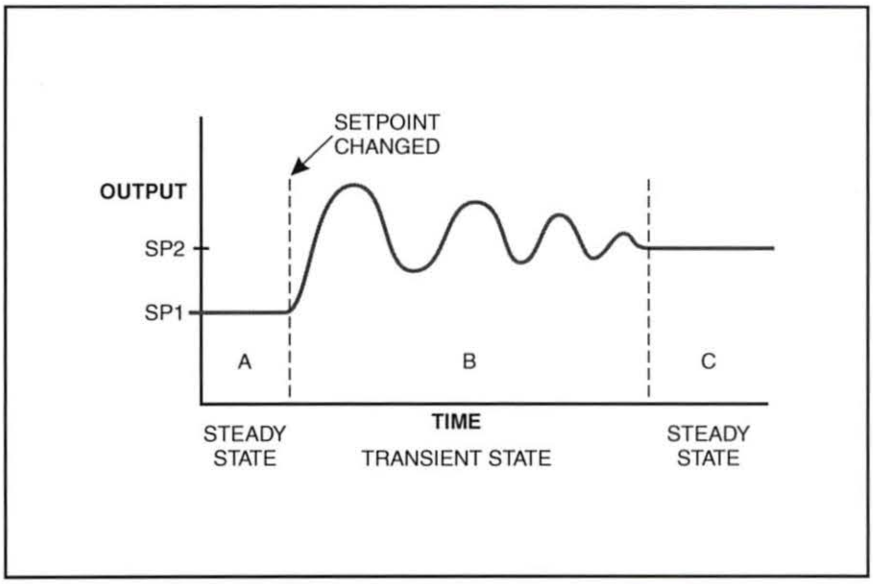

Figure 1. Process Response to a Change in Setpoint

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 after a disturbance occurs.

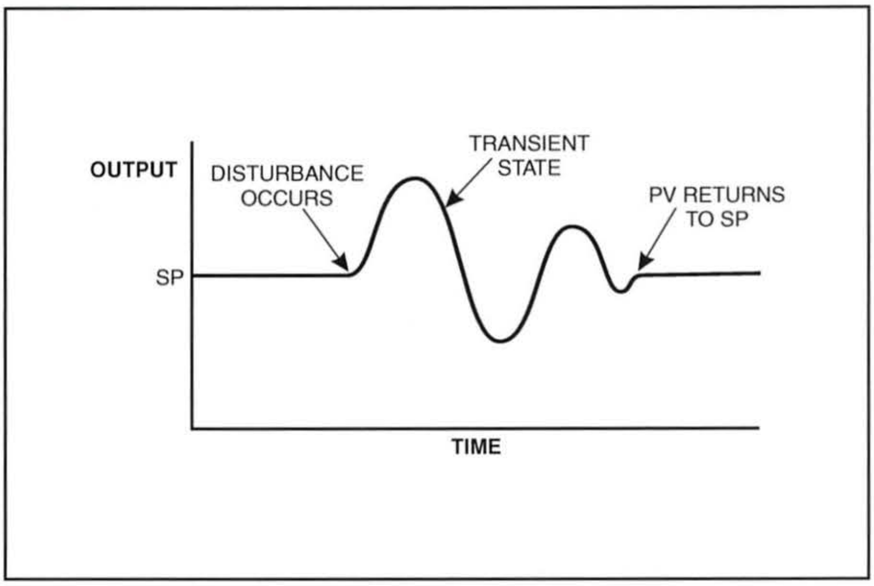

Figure 2. Process System Returns to Original SP after an Outside Disturbance

The performance of the control system during both steady state and transient state is important. In a steady state, the control system's 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.

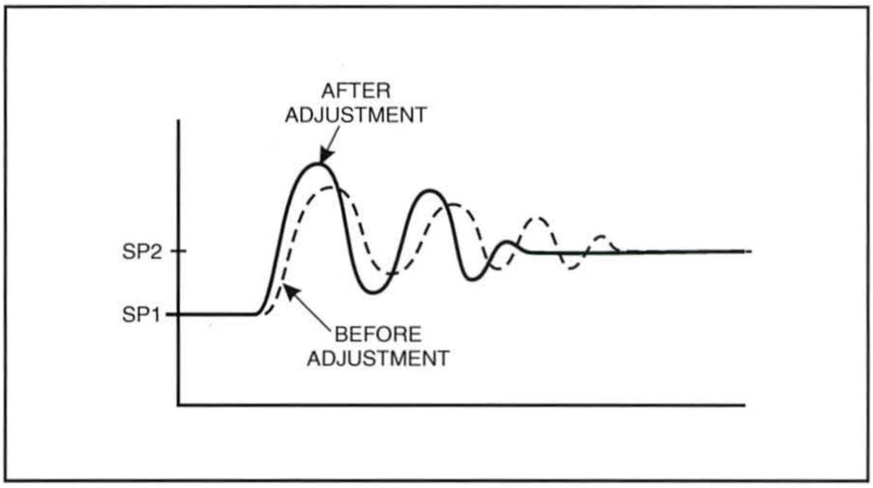

Figure 3. System Response Before and After a Controller Adjustment

OBJECTIVE 2 DEFINE GAIN AND EXPLAIN ITS IMPORTANCE

Read This

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 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.

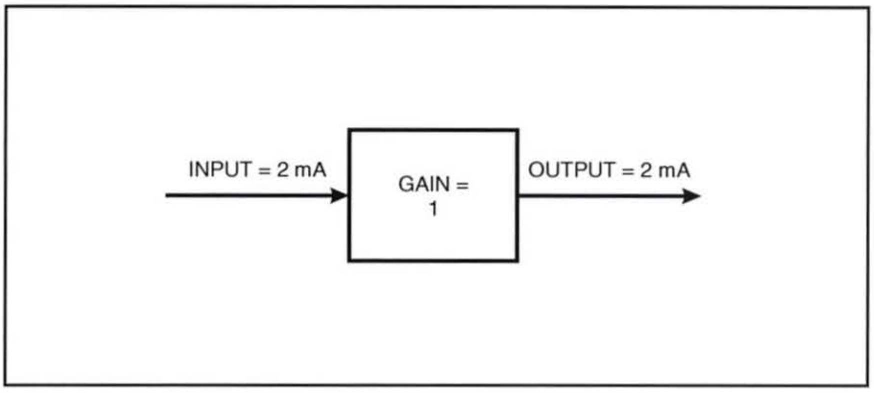

Figure 5. Device with Unity Gain

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.

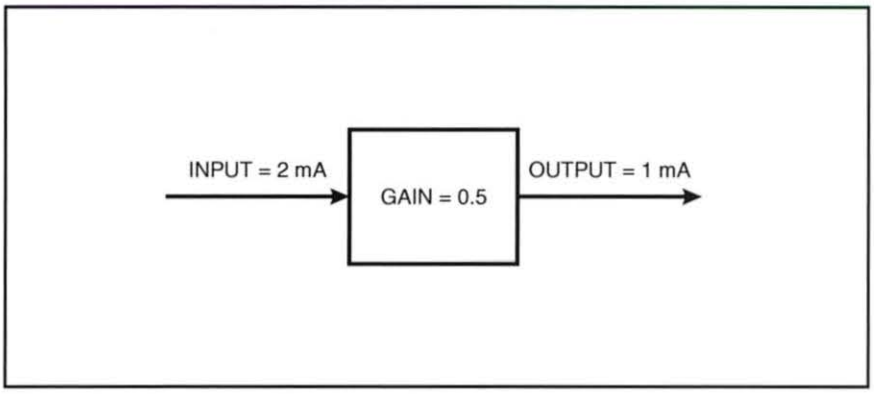

Figure 6. Device with Gain Less than 1

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.

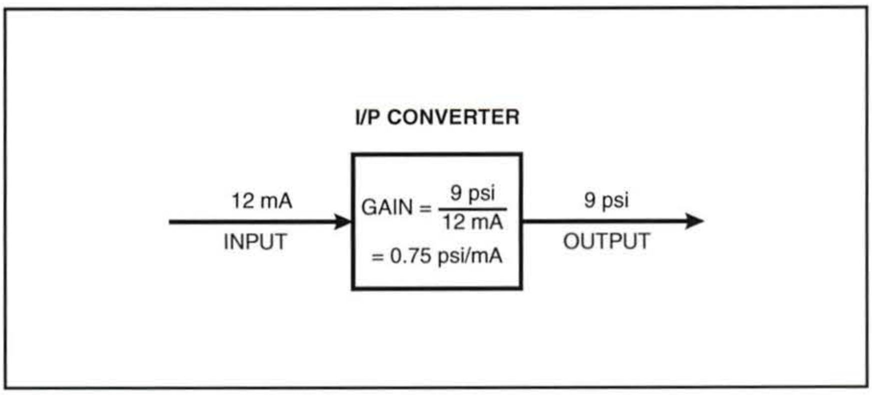

Figure 7. Gain Unit of I/P Converter

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.

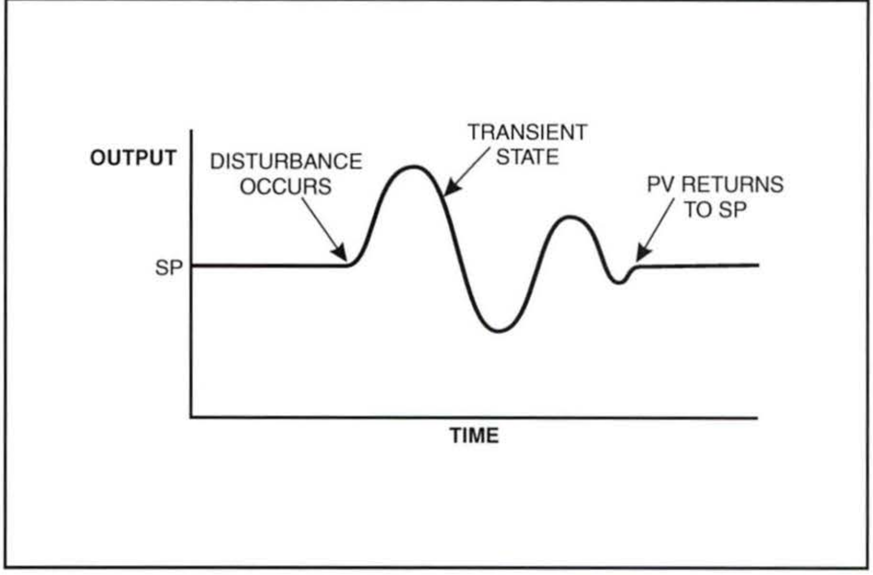

Figure 8. Stable Process System

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.

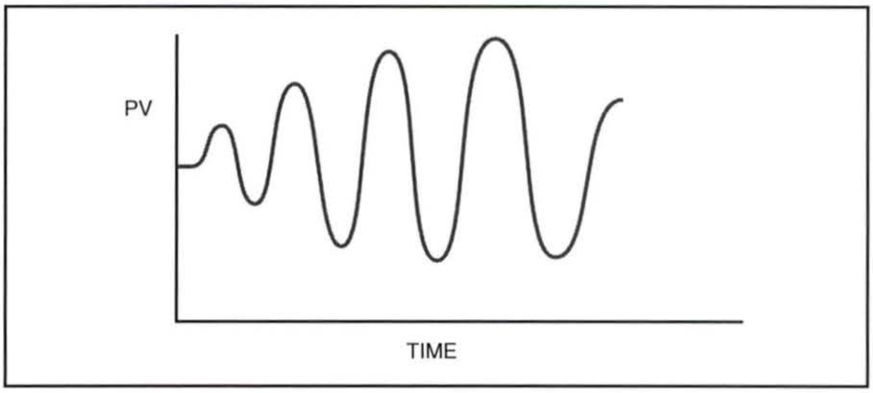

Figure 9. Output Curve for an Unstable Process

To be stable, process control systems must 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.

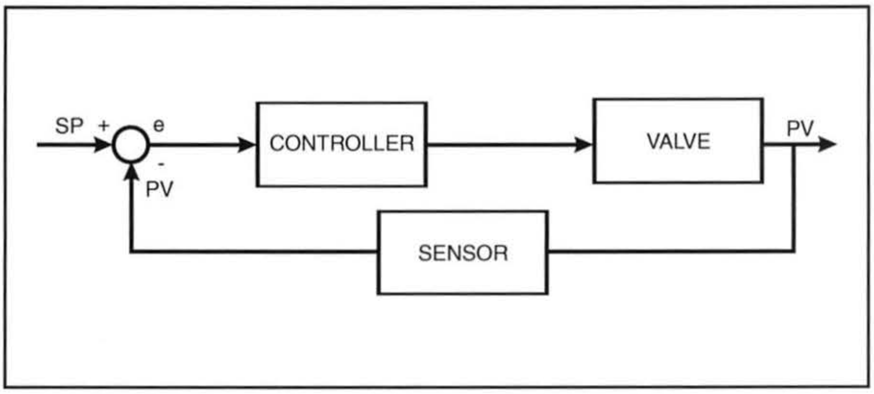

Figure 10. Negative Feedback System

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

Read This

The gain at which a process system becomes unstable is determined by the product of the gains of all components in the system rather than just one. This combination of gains is called the open loop gain. 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 open loop gain in figure 11 is 72 ($6 \times 4 \times 3 = 72$).

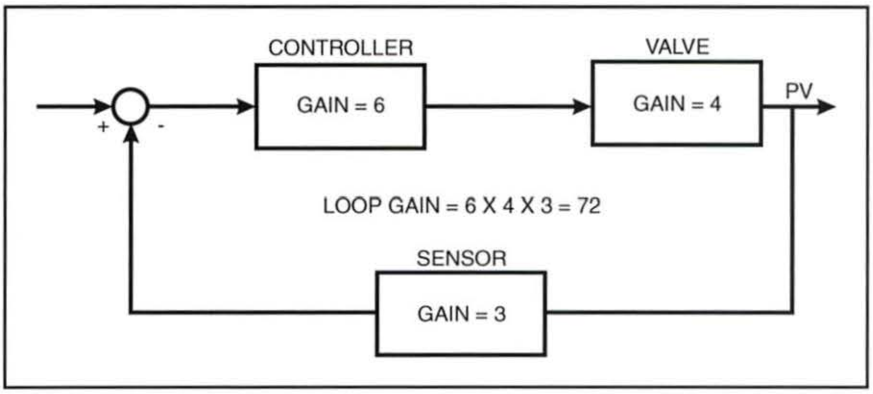

Figure 11. Process Control System Loop Gain

The open loop 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 loop 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 means that the average of the process output over time remains constant.

3. A process must be able to respond as quickly as possible to 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 if 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

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 (K_p) is 1, the output of the controller is 3 (the ratio of the output to the error is 1:1). 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 (the ratio of the output to the error is 2:1).

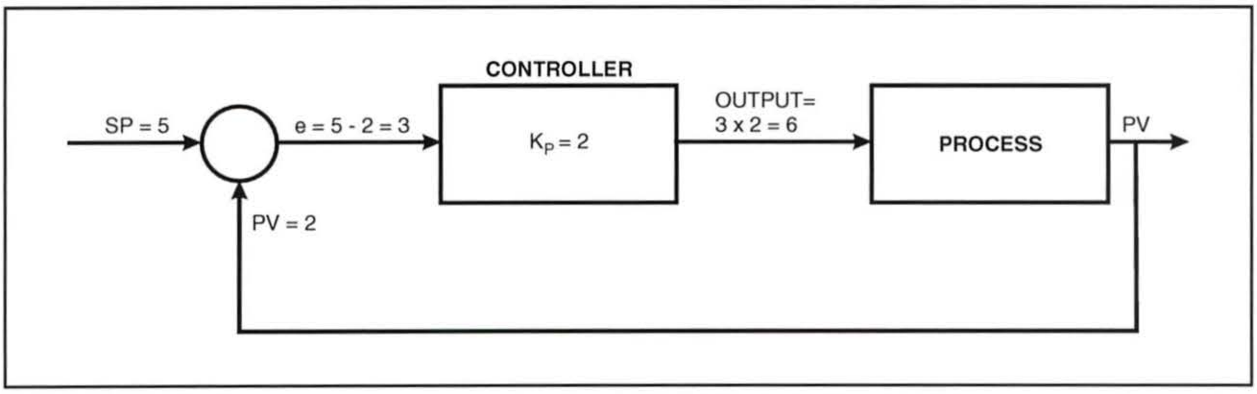

Figure 12. Block Diagram of a Controller Using Proportional Control with a Multiplying Factor of 2

To understand the operational characteristics of a proportional control system, examine the system in figure 13. Figure 13 shows the initial startup condition of a system using proportional control to maintain a constant level (controlled variable) in a tank. At startup, there is no flow into the tank, so there is no liquid in the tank.

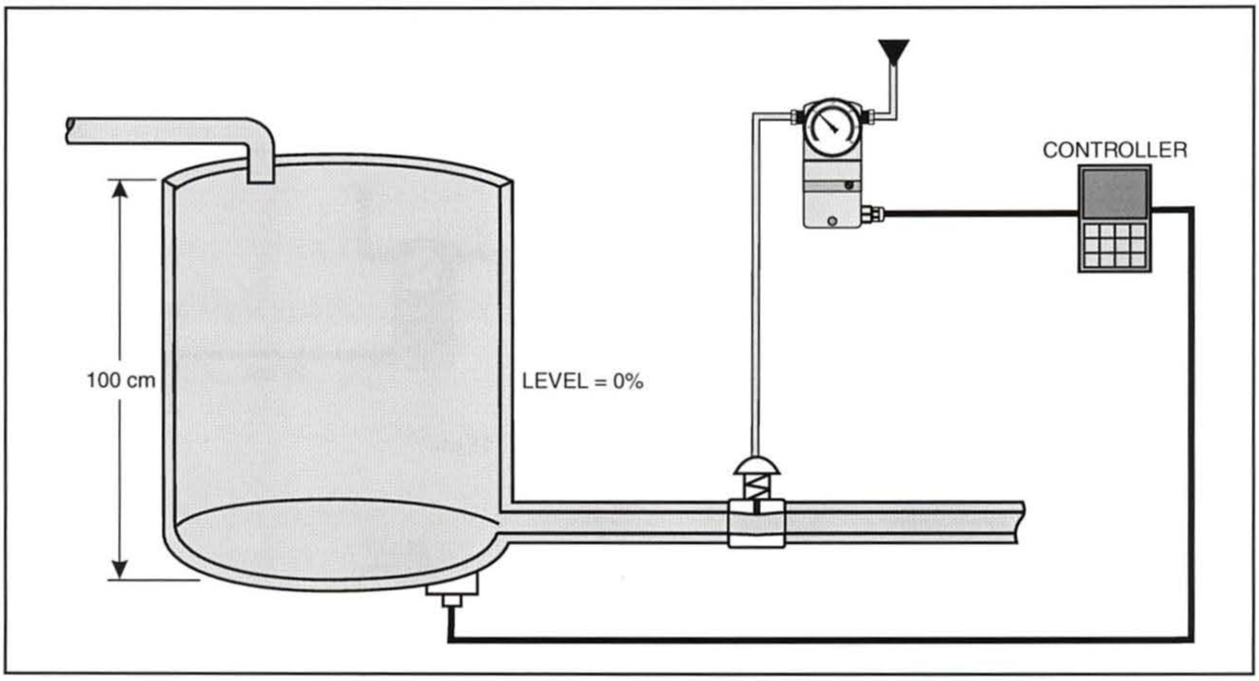

Figure 13. Level Control System Using Proportional Control

Figure 14 shows the condition after the operator has set the controller SP to 60% with a gain (K_p) of 2. With an error of 60% and a gain of 2, the output of the controller should be 120% (60 × 2 = 120). However, internal software of the controller limits the maximum output of the controller to 100%, or 20mA. The 100% output from the controller causes the IP converter to fully close the control valve, as figure 14 shows.

When liquid begins flowing into the tank, the level in the tank begins to rise toward the SP at the maximum rate.

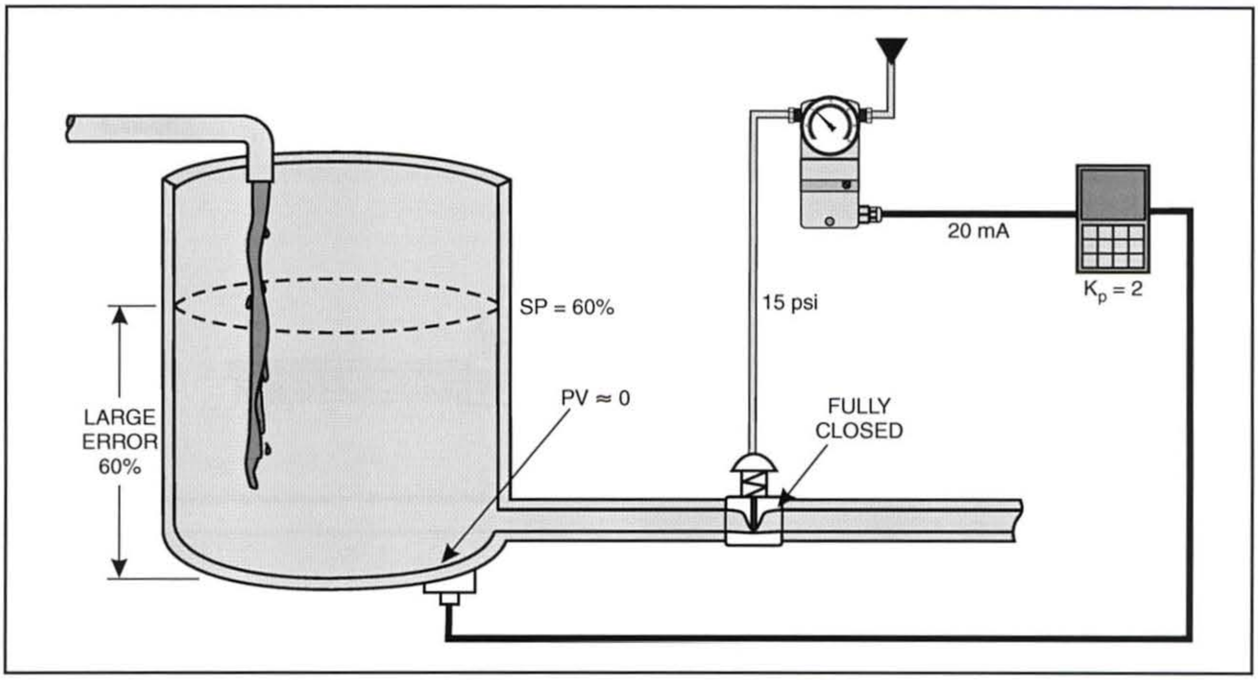

Figure 14. Proportional Response to SP Change

Figure 15 shows that the level (PV) has risen to 10%. At this point, the error is still large (50%) and the controller's output is still at 100%, keeping the valve fully closed. This allows the level to continue to increase at the maximum rate. At this point, the system acts more like an on/off system. This is a typical characteristic of proportional systems.

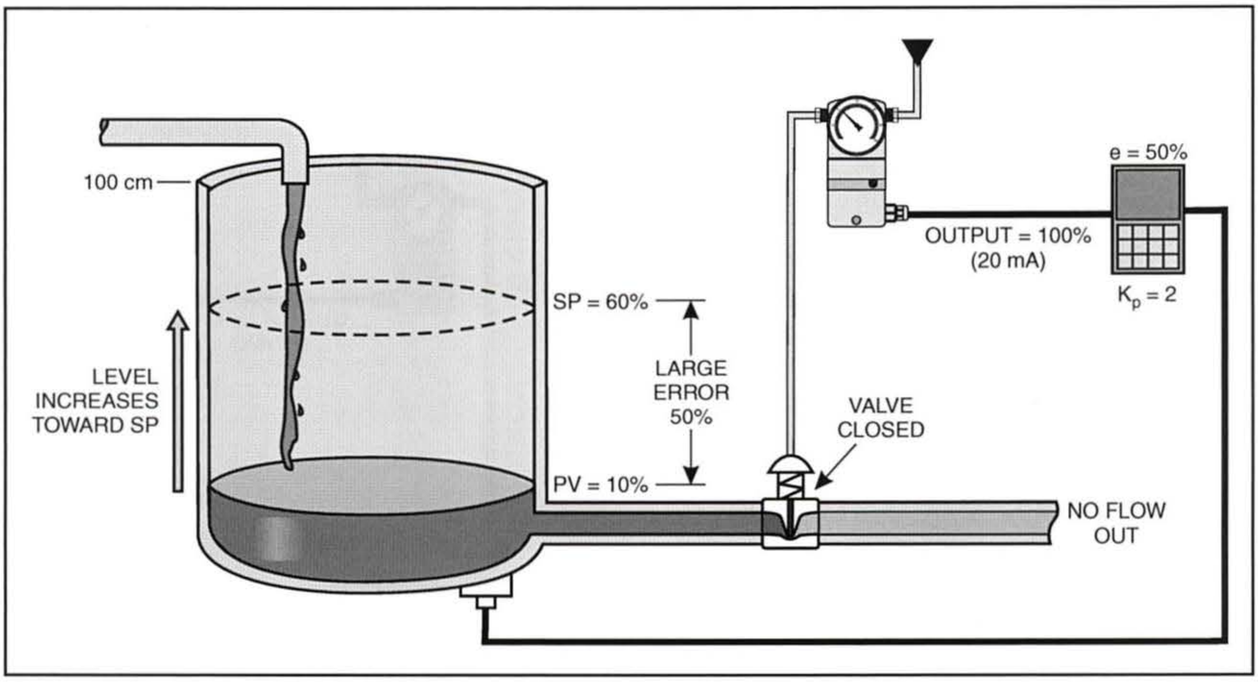

Figure 15. Proportional Control Response to Setpoint Increase

Eventually, the PV reaches a point that is close enough to the SP (i.e. the error is small enough) for the controller to begin proportionally decrease its output to open the valve. This causes the rate at which the level rises to begin to slow. The amount the valve opens is proportional to the error that remains in the system. Figure 16 shows the valve partially open when the PV reaches 35%. At this point, the output from the controller is only 50% (e = 25%, K_p = 2), so the tank is now only filling at 50% of the rate it was when the tank level was lower.

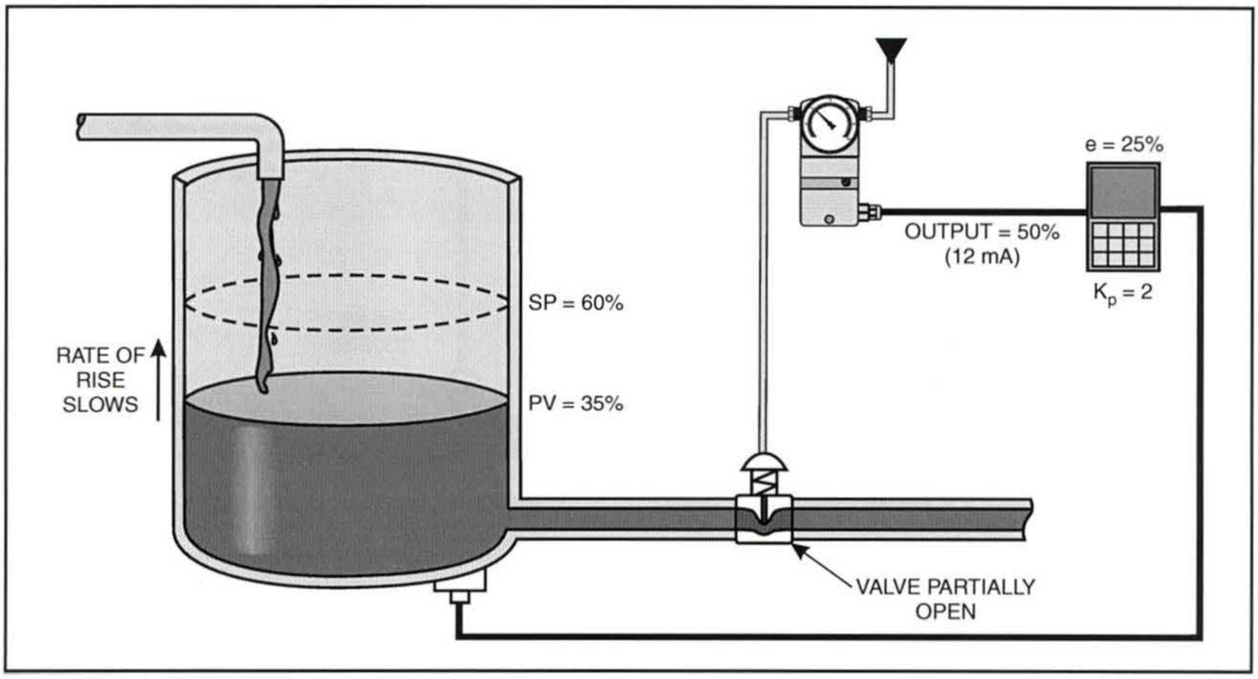

Figure 16. Proportional Control Response as PV Approaches SP

The point at which the controller begins to control the level proportionally depends on the gain setting. A low gain results in proportional control over a wide range of the valve's travel. A high gain results in proportional control only in a small range of the valve's travel.

As the PV continues to approach the SP, the rate at which the level rises continues to slow. Slowing the rate as the level rises keeps the system from overshooting the SP, as long as the gain is not too high.

The controller continues to open the valve in a proportional manner, which slows the rate of fill and gradually allows the output flow to equal the input flow. When the input and output flows are equal, as shown in figure 17, the difference that remains between the PV and the SP holds the controller output at a constant value and the PV settles (the system reaches a steady state).

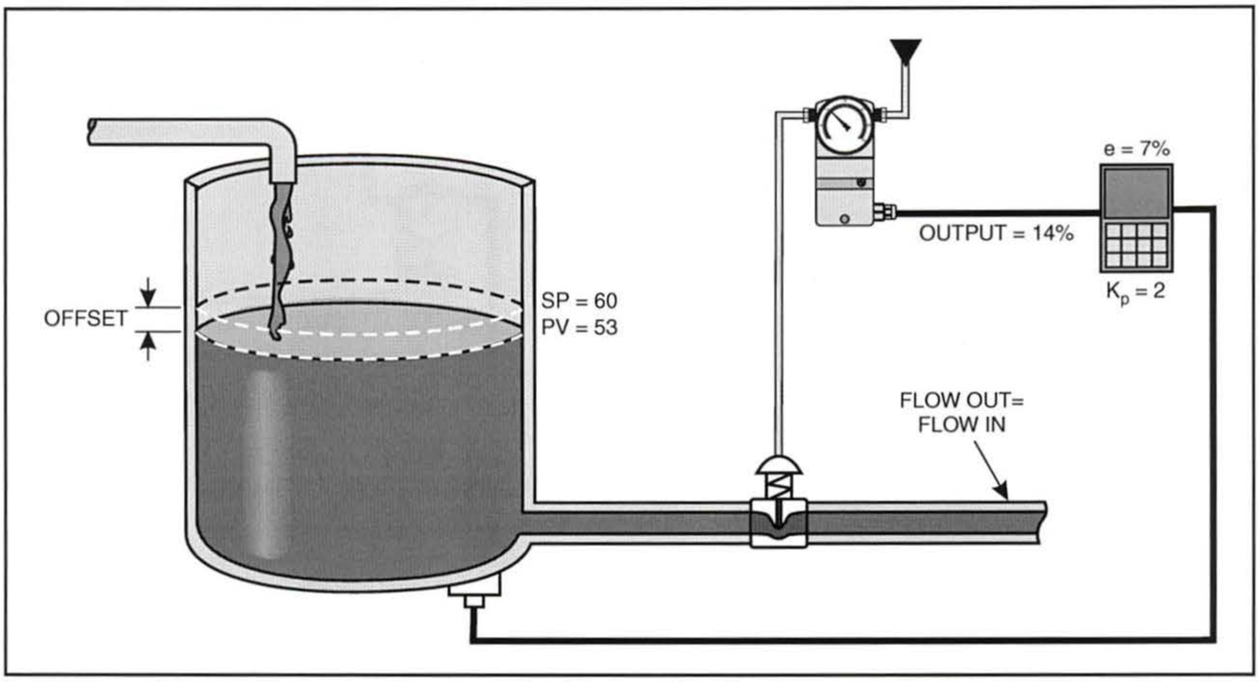

Figure 17. Proportional Control Response at Steady State

The steady state error that remains is a characteristic of proportional control called proportional offset, or simply offset. This error must exist so the controller can generate an output that holds the control valve open at the point where the flow into the tank equals the flow out of the tank. If the error were zero, the control valve would be fully open and the flow out would be greater than the flow in (the level would begin to drop).

Reducing the SP causes the proportional level control system to react in the opposite manner. Since the controller needs to drive the level down in the tank, the output initially goes to its minimum, which is 0% or 4 mA, as figure 18 shows. This causes the I/P converter to fully open the valve so the flow out of the tank is greater than the flow in. As the PV approaches the lower SP, the controller increases its output proportionally so that the valve closes. This continues until the system settles (flow out equals flow in).

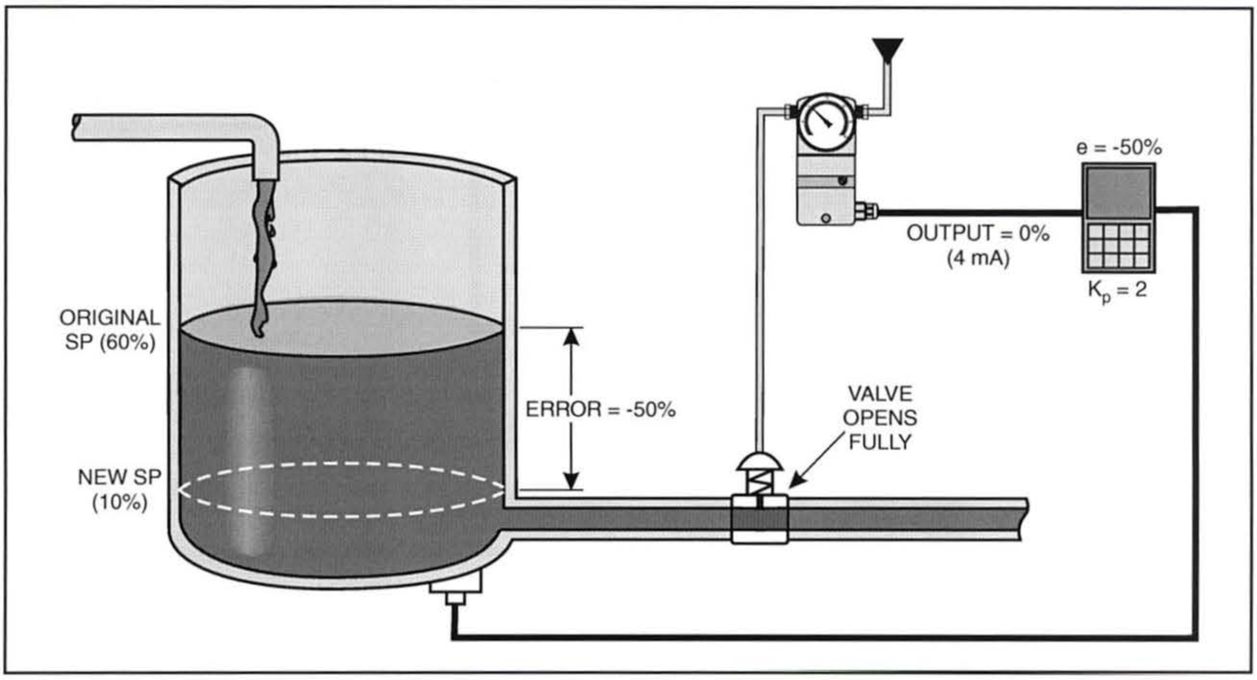

Figure 18. Effects of Decreasing SP

The goal of a proportional system is to provide an immediate response and achieve a steady state with minimum offset. The amount of offset in a system depends on the proportional gain that is set in the controller. If the gain setting is low, the system reacts slowly and a large offset occurs, as shown in figure 19.

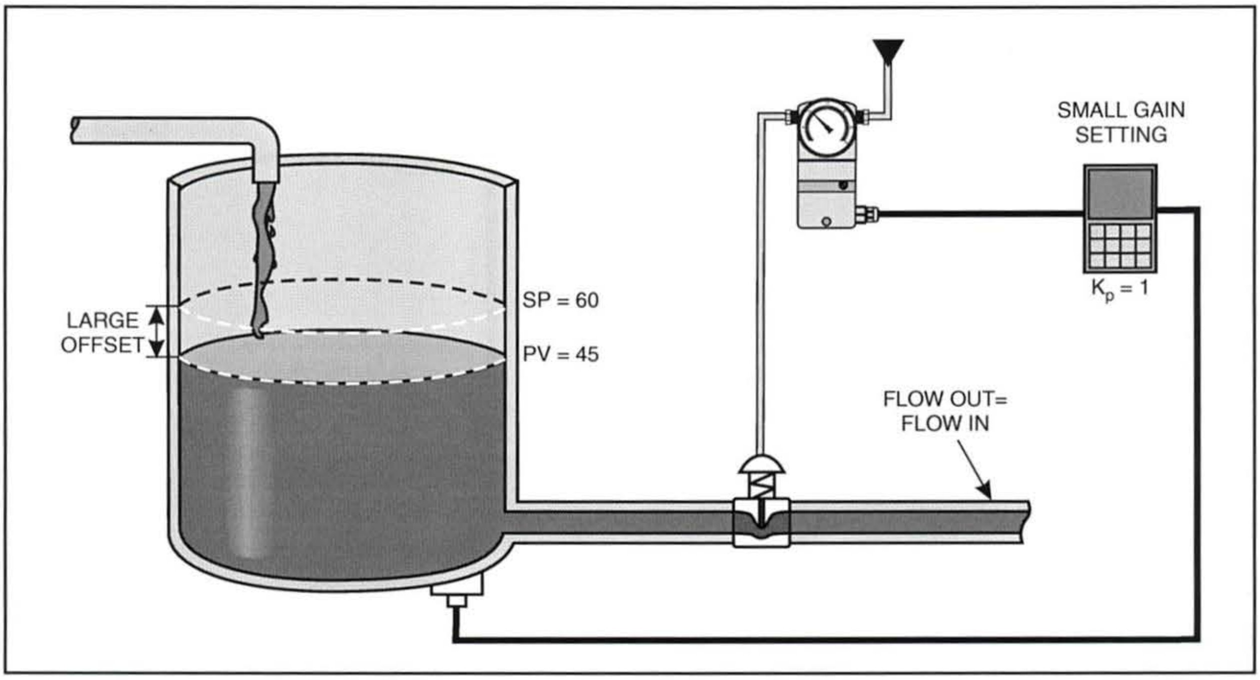

Figure 19. Process Response with a Low Gain Setting

If the gain setting is high, the offset is made smaller, as shown in figure 20, and the system reacts fast. However, a larger gain setting also results in more oscillations in the system because the controller tends to overcorrect for the error.

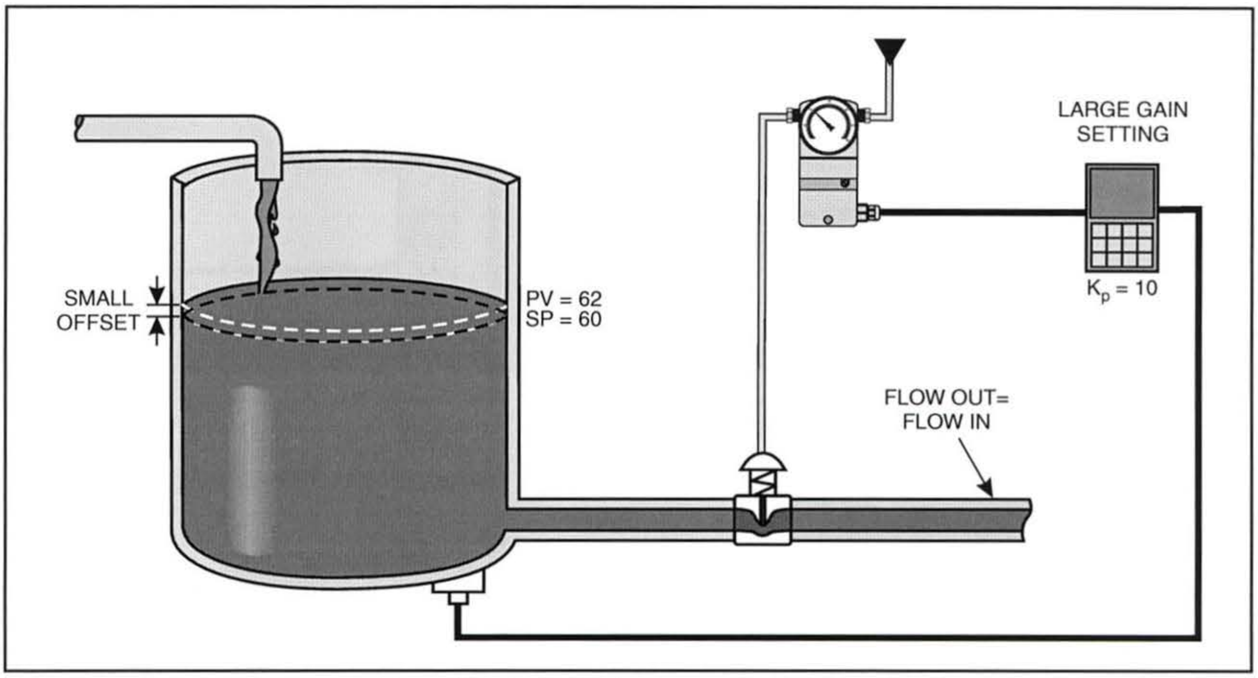

Figure 20. Process Response with a High Gain Setting

The tendency of the controller to overcorrect for the error as the gain increases is also the reason the gain is not simply set as high as possible in an attempt to eliminate the offset. If the gain continually increases, 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.

Proportional control is common in industry for controlling the level of fuel in containers, the level of water in wastewater treatment facilities, and the level of solid materials such as coal. Any process that can tolerate the offset that results from proportional control can benefit from this control method because of its simplicity and cost effectiveness.

OBJECTIVE 6 DEFINE PROPORTIONAL BAND AND EXPLAIN ITS IMPORTANCE

Proportional band (PB) is another way in which the proportional gain of a component 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 21. 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 21. Proportional Band vs. Proportional Gain

The proportional band (PB) better quantifies what happens with the process by describing the range in which the PV is proportionally controlled. For example, figure 22 shows a level control system using a controller that has a setpoint of 10 ft and a PB of 20%. The operating range is from 0 to 20 ft. Twenty percent of 20 ft is 4 ft. Therefore, the level is proportionally controlled within a band of 4 ft around the setpoint (i.e. between 8 and 12 ft.)

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

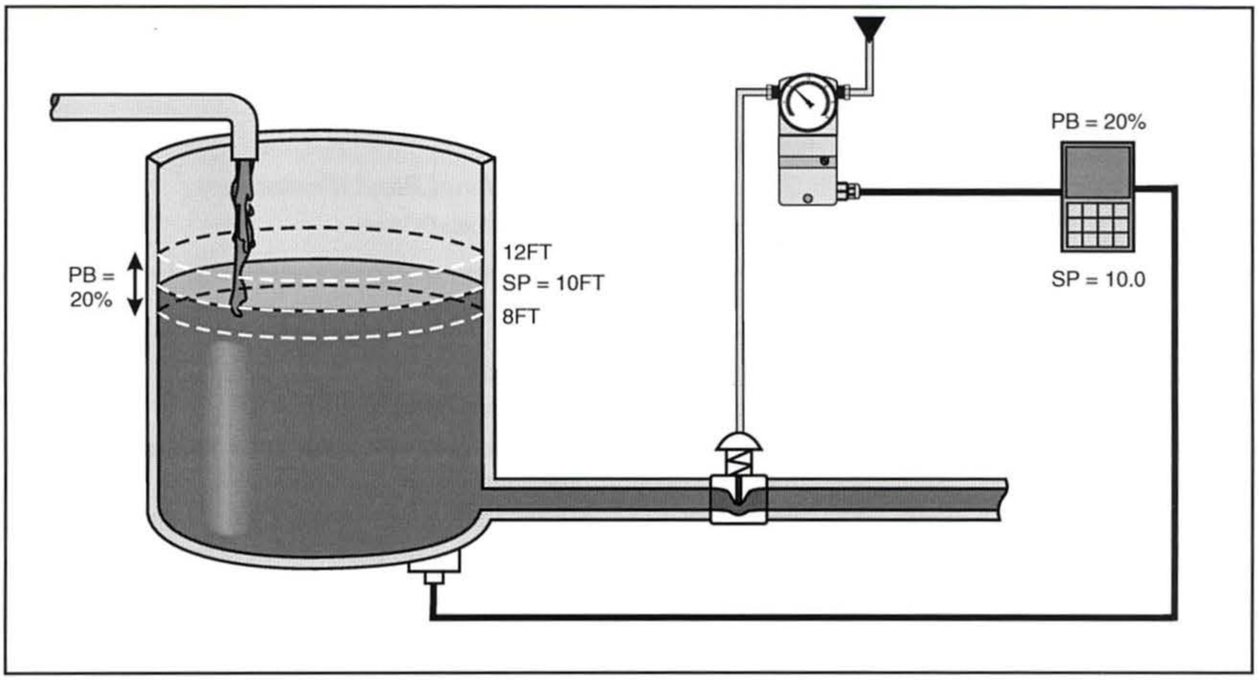

Figure 22. Level Control System with a PB of 20%

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 an upset, as figure 23 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.

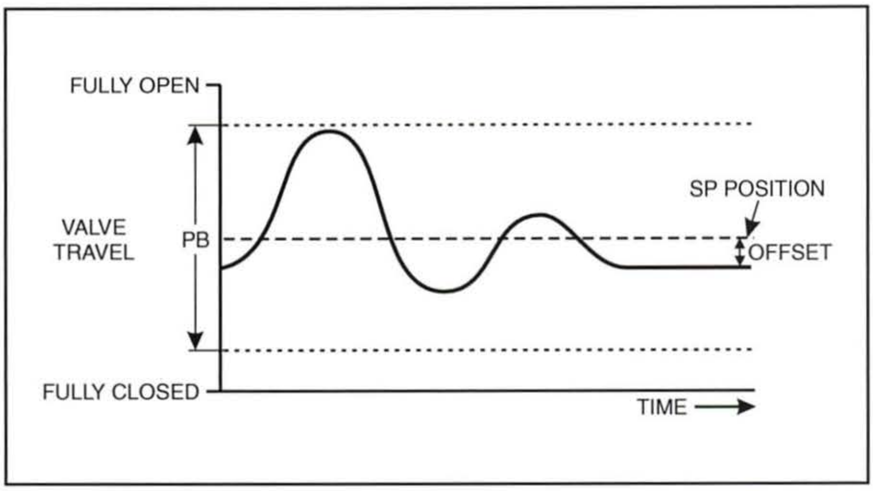

Figure 23. Valve Travel for a Large PB

A small (narrow) PB means that the valve moves proportionally through a small range of its full travel, as figure 24 shows. This results in a fast system response and a small offset. However, when an upset 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 will continually oscillate between fully open and fully closed (the system becomes unstable).

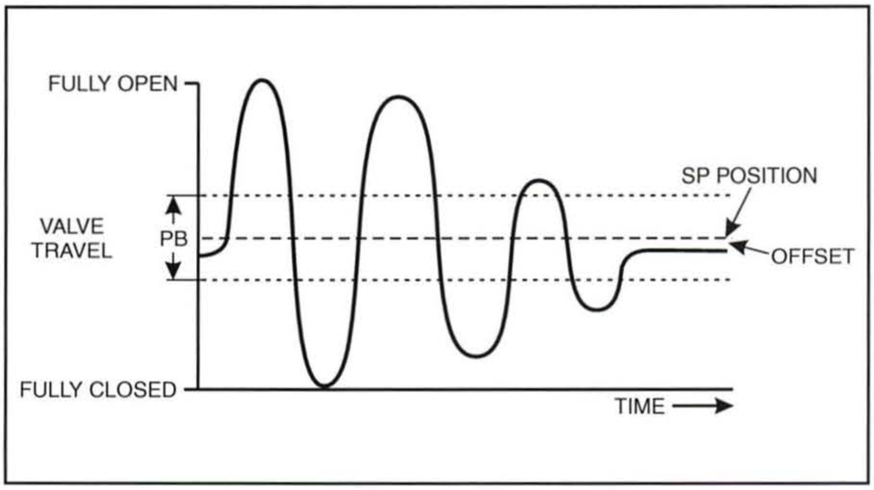

Figure 24. Valve Travel for a Small PB

Figure 25 summarizes the ideal response of a control valve in a proportional level control system. At point A, the system is in 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. At point B, the flow rate reaches a maximum value, which indicates that the control valve is fully open.

The valve remains fully open until the level reaches point C, at which point the level is close enough to the setpoint for 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 new setpoint and point D.

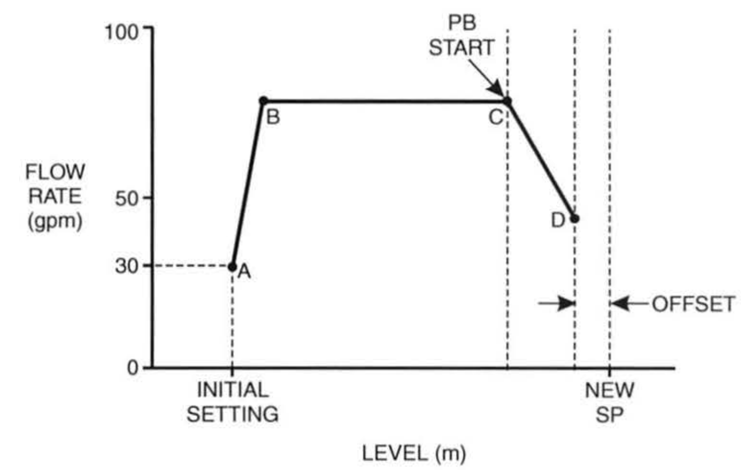

Figure 25. Response of a Proportional Level Control System

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

Read This

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 setting that can be used in the controller 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 the offset.

For example, the level control system in figure 26 has a 5% offset using a proportional controller without manual reset. This offset is what enables the controller to provide the output that is needed to make the inflow match the outflow at steady state. 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 tank level (PV) to move away from the SP.

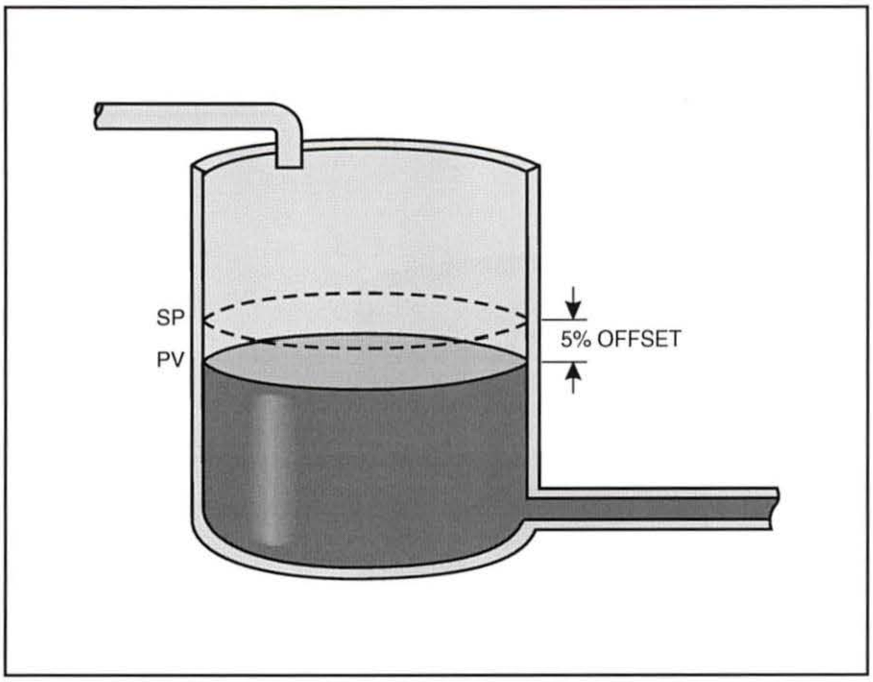

Figure 26. Offset in a Proportional System

The reset constant adds to the controller output, as figure 27 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.

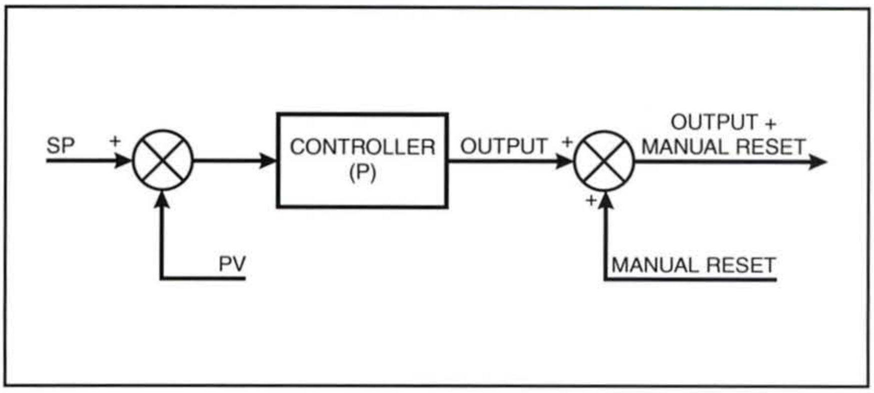

Figure 27. Manual Reset Added to Controller Output

If the manual reset is adjusted to 5% in the system in figure 26, the offset is eliminated, as shown in figure 28.

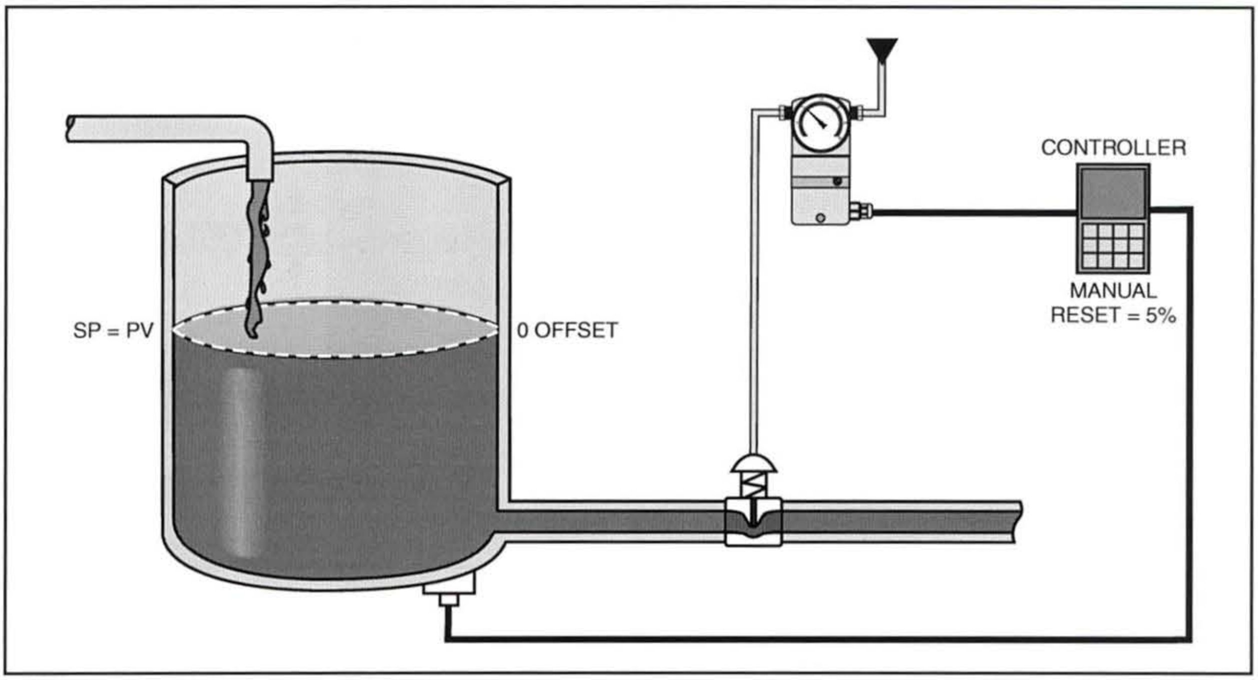

Figure 28. Proportional System with Manual Reset

Unfortunately, the manual reset value is only good as long as conditions do not change. If the SP is increased, as shown in figure 29, a new offset results. To eliminate the new offset, a new manual reset value is required, as figure 29 also shows.

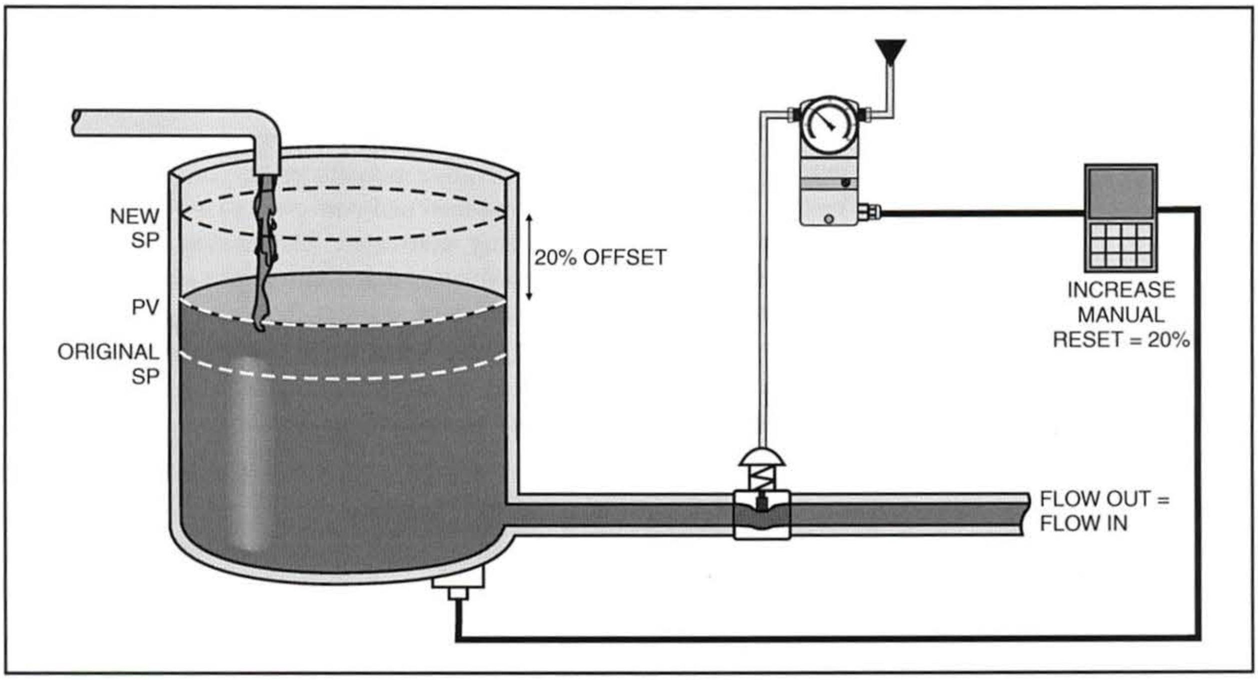

Figure 29. Change in the SP Requires a New Manual Reset

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 30. 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 an I/P converter that changes the electrical analog output into a pressure output, which adjusts the valve position in the proportional valve. Changing the valve position changes the value of the process variable.

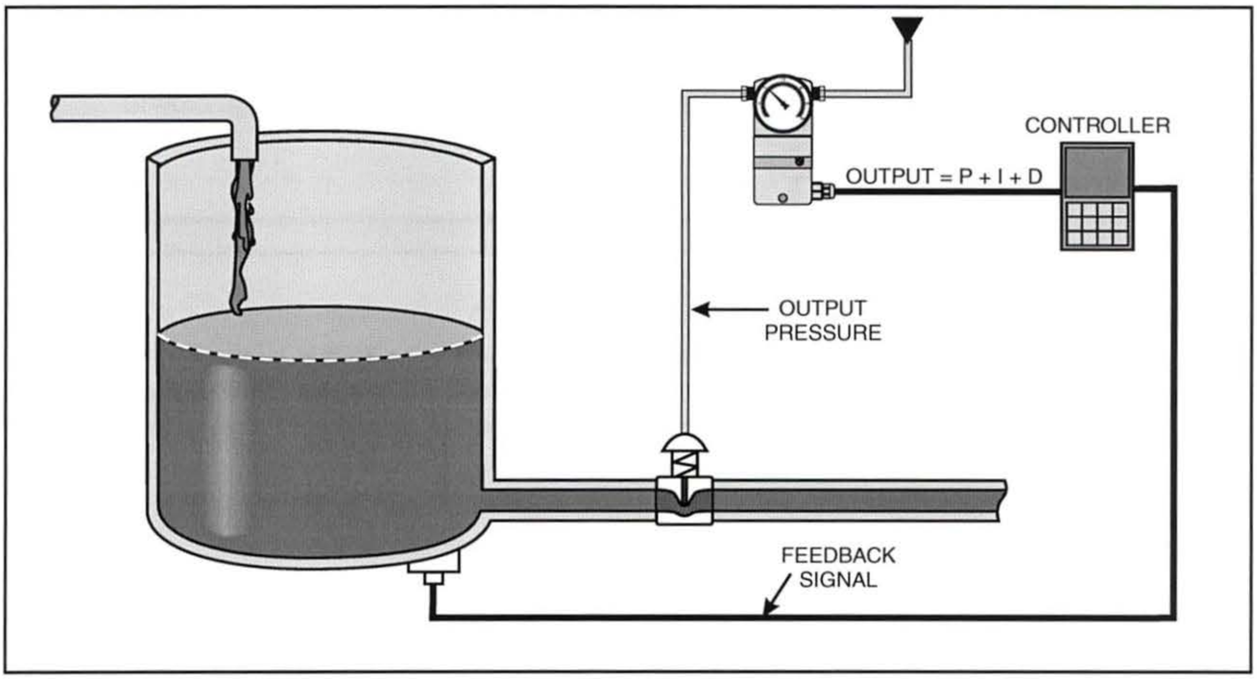

Figure 30. Electronic Controller Based Closed Loop Level System

In an electronic controller based closed loop system, the operator determines what control method the process requires and enters the parameters into the controller. These parameters include the settings for proportional, integral, and derivative gains, 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:

  IN1 TYPE

  XMITTER 1

  IN1 HIGH

  IN1 LOW

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

  Scroll to the "CONT ALG" parameter, as shown in figure 31, which stands for Control Algorithm.

Figure 31. Control Algorithm Parameter in a Honeywell Controller

Three 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" programming 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 32.

Figure 32. 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 33. These parameters determine the integral action.

Figure 33. MIN or RPM Selection on a Honeywell Controller

- **Locate the "TUNING" programming group and enter the required parameters.**

  Depending on the chosen algorithm, each of the three control methods (proportion, integral, and derivative) may be active in the controller. Therefore, each must be set 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 "CONTROL" 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 or 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 level 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 proportional GAIN setting.

- ❑ 1. Perform a lockout/tagout.
- ❑ 2. Perform the following substeps to set up the T5552, as shown in figure 34.

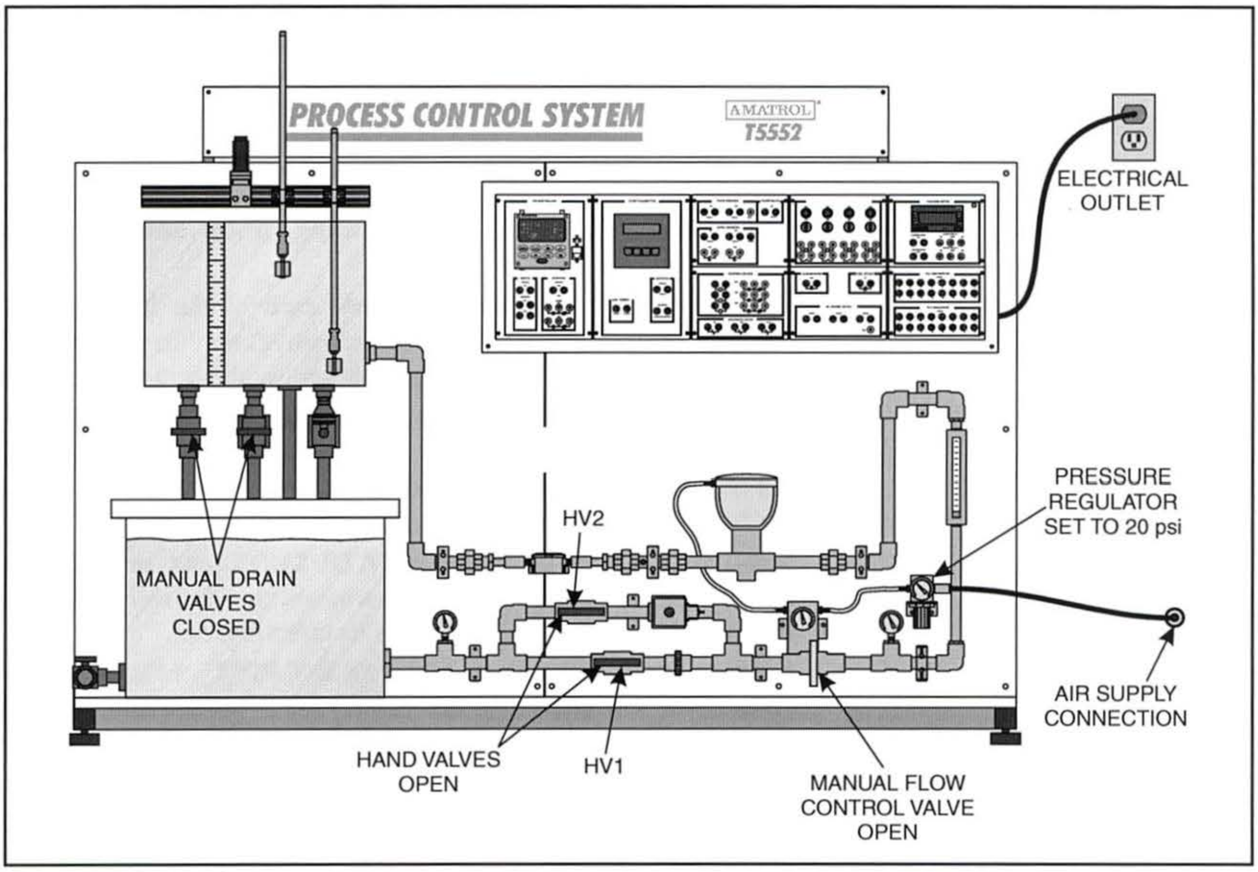

Figure 34. T5552 Setup

A. Connect the air supply line to the T5552.

B. Set the pressure regulator to 20 psi.

C. Fill the reservoir tank with water.

D. Close (fully clockwise) the two manual process tank drain valves.

E. Connect the circuit shown in figure 35.

This circuit allows you to operate a closed loop level control system.

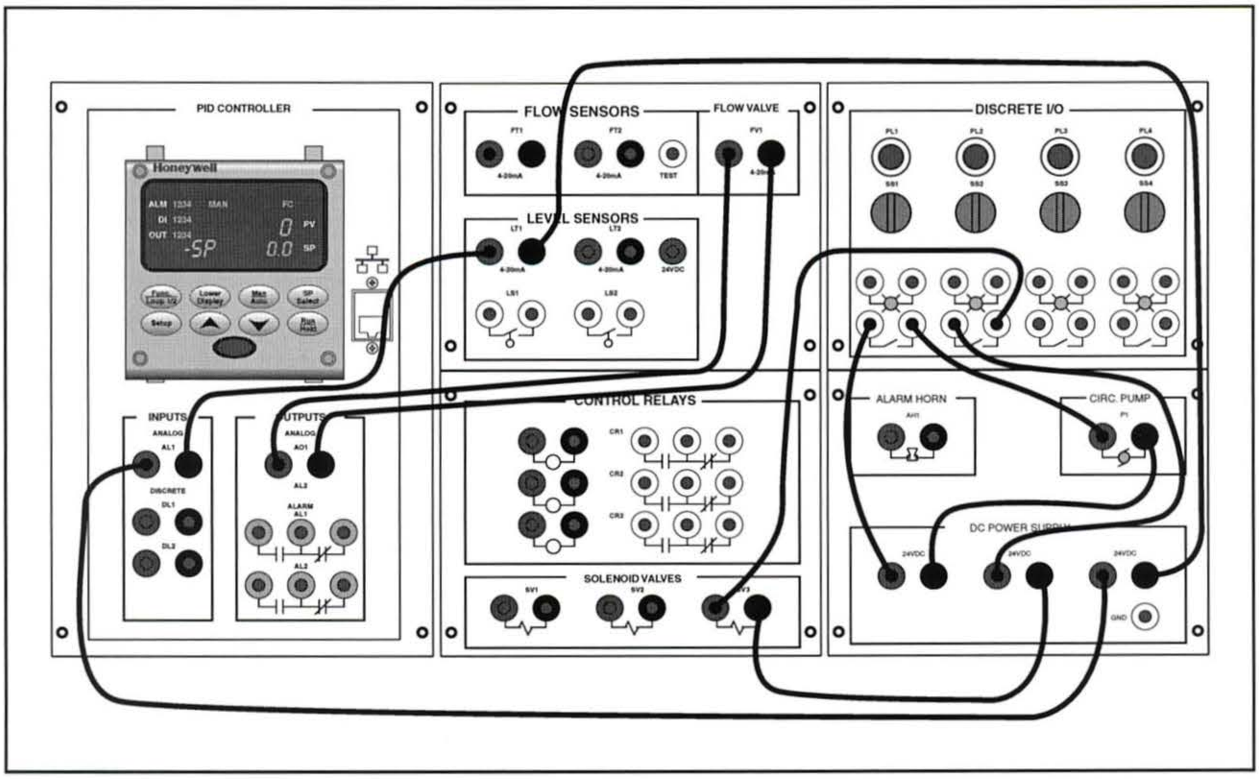

Figure 35. Connections for Closed Loop Level Control

Figure 36 shows the P&ID for the T5552. The active components and wiring are highlighted.

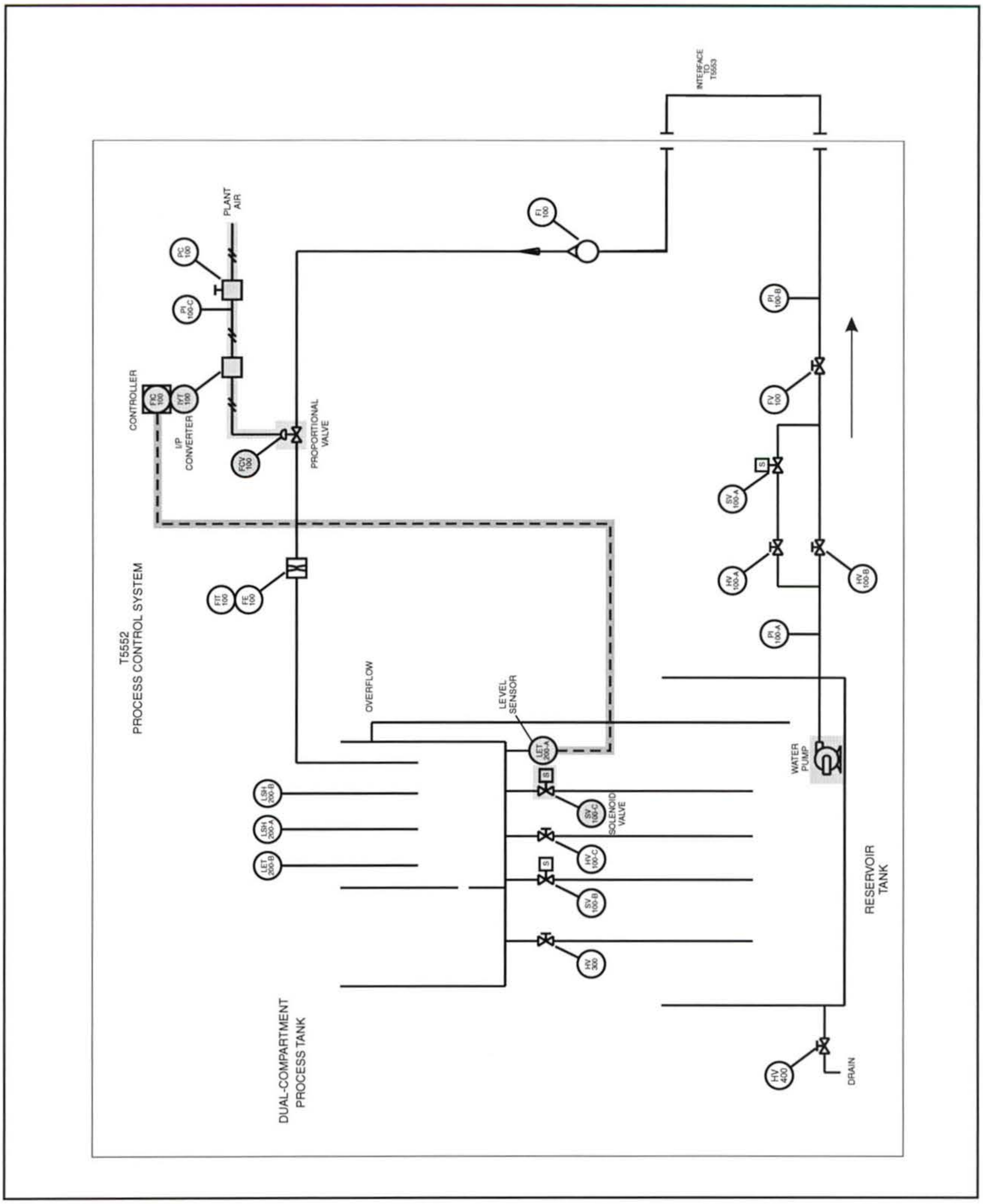

Figure 36. T5552 P&ID

❑ 3. Remove the lockout/tagout.

❑ 4. 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 controller uses. The setting PD+MR prevents the controller from using any integral control and allows you to adjust the manual reset 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 **DIRECT**.

Since the diaphragm-activated valve is an air-to-close valve, the action of the controller should be direct.

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

G. Set the following parameters in the TUNING group:

PARAMETER	SETTING
GAIN	20.0
RATE MIN	0.0
MAN RES	0.0

The GAIN parameter sets the controller's 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 RES 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. Set the following parameters in the INPUT 1 group:

PARAMETER	SETTING
IN1 TYPE	1-5 V
XMITTER1	LINEAR
IN1 HIGH	27.70
IN1 LOW	0.0
BIAS IN1	-1.6

The IN1 TYPE parameter indicates the type of input signal the controller is receiving. The XMITTER1 parameter describes the type of transmitter sending the signal. The IN1 HIGH and IN1 LOW parameters describe the high and low display values for the input, respectively. The BIAS IN1 allows the displayed value to account for offset or drift in the sensor.

I. Press the **Lower Display** key to exit the setup menu.

J. Use the **Lower Display** key to display the setpoint (SP) on the display.

K. Use the up ▲ and down ▼ keys to set the SP to **4.0**.

Notice This

NOTE

If you are unable to set the SP to 4.0, check the SP HiLIM parameter in the Control group and set it to a value higher than 4.

L. Press the **Man/Auto** key to place the controller in automatic mode.

❑ 5. Perform the following substeps to operate the system.

A. Make sure the manual flow control valve is fully open (CCW).

B. Turn on selector switch **SS1** to start the pump.

C. As the tank begins to fill, turn on selector switch **SS2** to energize (open) solenoid drain valve **SV3**.

D. Use the **Lower Display** key to view the output (OUT) on the display.

E. Record the value of the process variable (PV) when the controller makes the first adjustment to the output.

PV ________________________________(inches)

F. Record the value of the PV and the output when the system reaches a steady state. Consider the process steady if the PV does not change by more than ± .01 inch for 2 min.

PV ____(inches)

Output ____(%)

You should find that the PV steadies at a level between 4.2 and 4.5 inches and the controller output is between 28-30%.

G. Use the **Lower Display** key to view the bias BIA value on the display.

This parameter represents the manual reset for the controller. It has a range of 0-100% and is the same parameter as the MAN RES in the TUNING group of the setup menu; it simply has a different name in the control display mode. However, changing the value in either menu changes the value in the other menu. Adjusting this value is the same as manually adjusting the valve position. The purpose of the manual reset or bias is to eliminate offset.

NOTE

Do not confuse the MAN RES/BIA parameter with the BIAS IN1. The BIAS IN1 parameter adjusts the displayed value to account for offset or drift in the output of the feedback sensor. The BIA parameter refers to the manual reset and adjusts the controller output.

H. Use the **up** ▲ and **down** ▼ keys to adjust the bias value until the PV equals the SP (4.0).

Adjust the bias by increments of 5 and wait for the PV to settle.

This will take several adjustments of the bias value to accomplish.

I. Record the value of the bias when the PV equals the SP.

Bias ____(%)

You should find that a bias of between 25 and 30% stabilizes the PV at the SP.

❑ 6. Perform the following substeps to determine the effects of changing the setpoint.

A. Press the **Man/Auto** key to place the controller in manual mode.

B. Change the setpoint to **6.0**.

NOTE

The setpoint can be changed without switching to manual mode. However, switching provides more of a step change.

C. Use the **Man/Auto** key to place the controller in automatic mode.

D. Press the **Lower Display** key to view the controller output (OUT) on the display.

E. When the controller makes the first adjustment to the output, record the value of the process variable (PV) every five seconds until the system becomes steady. Record your readings in a table similar to the one shown in figure 37.

This will take several minutes.

PROPORTIONAL CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 37. PV Table

F. Record the value of the PV and the output when the process steadies and determine if offset exists.

PV ______________________________(inches)

Output ______________________________(%)

Offset Exists ______________________________(Yes/No)

You should notice that although the manual reset was adjusted so that the PV matched the SP at 4.0 inches, offset occurs if the setpoint is changed. The offset occurs because when the SP changes, the controller again provides a proportional response to the new error and the valve again reaches a steady state at a position that is not equal to the SP. In this case, there is a large bias on the system and only a small jump from the first SP to the second SP, therefore the offset should be small (0.02-0.05 inches).

❑ 7. Perform the following substeps to reset the system using a higher gain setting to determine the effect it has on system response.

A. Place the controller in manual mode.

B. Turn off selector switch **SS1** to stop the pump.

C. Turn off selector switch **SS2** to close solenoid drain valve SV3.

D. Open the process tank manual drain valves to drain the tank. When the tank is empty, close the valves.

E. Change the bias setting to **0** and change the setpoint to **4.0**.

F. Enter the setup menu and change the **GAIN** setting in the TUNING group to **40**.

This is 2 times more gain than in the first system and should show a noticeable change in system response.

G. Place the controller in automatic mode.

❑ 8. Perform the following substeps to operate the system.

A. Turn on selector switch **SS1** to start the pump.

B. As the tank begins to fill, turn on selector switch **SS2** to energize (open) solenoid drain valve **SV3**.

C. Use the **Lower Display** key to view the output (OUT) on the display.

D. Record the value of the process variable (PV) when the controller makes the first adjustment to the output.

PV ______________________________(inches)

E. Record the value of the PV and the output when the system becomes steady. Consider the process steady if the PV does not change by more than ± .01 inch for 2 minutes.

PV ____(inches)

Output ____(%)

The PV should become steady between 4.15 and 4.25 inches. The controller output should be between 28 and 30%. Although the output is approximately the same as when the lower gain value was used, the controller is responding faster to steady the process. Also, there is less offset.

F. Use the **Lower Display** key to view the bias value (BIA) on the display.

G. Use the **up** ▲ and **down** ▼ keys to adjust the bias value until the PV equals the SP (4.0).

Adjust the bias by increments of 5 again and wait for the PV to settle. When the PV nears the SP, use lower increments of the bias.

H. Record the value of the bias when the PV equals the SP.

Bias ____(%)

You should find that a bias of between 20 and 25% steadies the PV at the SP. The bias is smaller because there was a smaller offset.

❑ 9. Perform the following substeps to determine the effects of changing the setpoint.

A. Press the **Man/Auto** key to place the controller in manual mode.

B. Change the setpoint to **6.0** to determine if the system can stabilize without offset.

C. Press the **Man/Auto** key to place the controller in automatic mode.

D. Use the **Lower Display** key to view the controller output (OUT) on the display.

E. When the controller makes the first adjustment to the output, record the value of the process variable (PV) every five seconds until the system becomes steady. Record your readings in a table similar to the one shown in figure 38.

This will take several minutes.

PROPORTIONAL CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 38. PV Table

F. Record the value of the PV and the output when the process steadies and determine if offset exists.

PV ______________________________(inches)

Output ______________________________(%)

Offset Exists ______________________________(Yes/No)

You should notice that offset still occurs if the setpoint is changed. However, the offset should be smaller (approximately 0.01 inches).

❑ 10. Perform the following substeps to shut down the T5552.

A. Turn off selector switch **SS1** to stop the pump.

B. Turn off selector switch **SS2** to close solenoid drain valve SV3.

C. Open the process tank manual drain valves to drain the tank. When the tank is empty, close the valves.

D. Turn off the main circuit breaker.

E. Disconnect the circuit if this is your last activity. If it is not your last activity, leave the circuit connected to use in the next skill.

❑11. Perform the following substeps to plot the response of the system for each of the GAIN settings.

A. Create a graph of PV vs. time, similar to figure 39 on a piece of graph paper.

You will use this to plot the response of the system with a gain of 20.

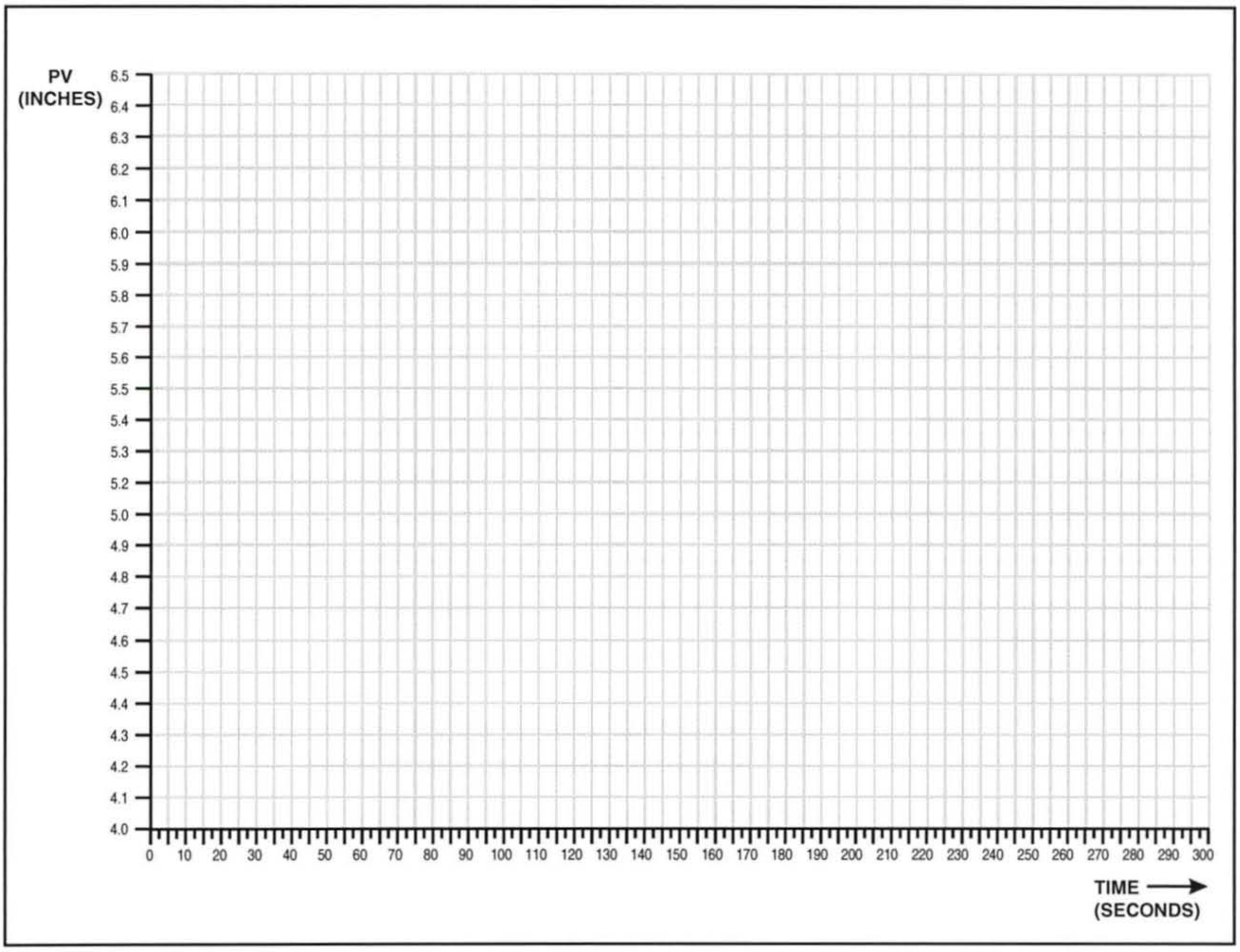

Figure 39. Graph of PV vs. Time

B. Plot the response of the system using the data you collected in step 6E.

Your response curve should be similar to the one in figure 40, with the PV falling just short of the SP (small offset).

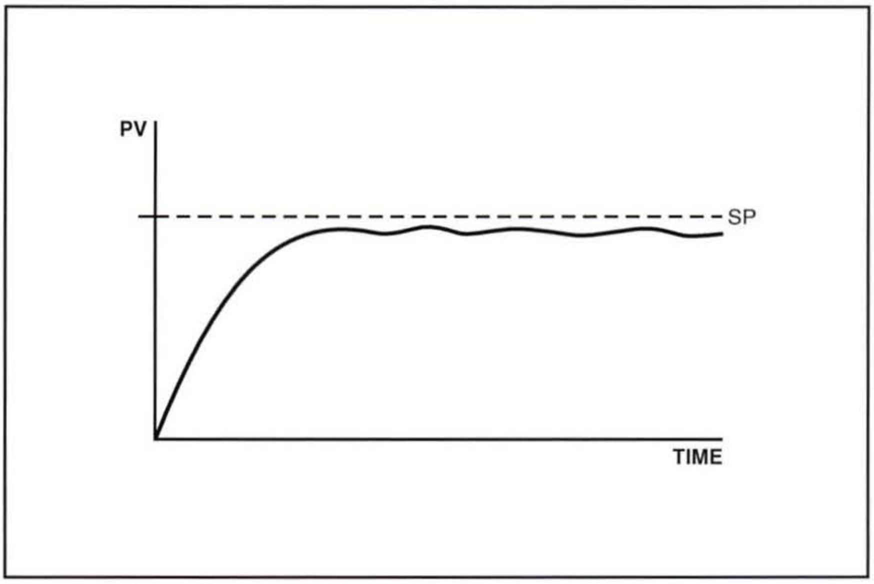

Figure 40. Graph of PV vs. Time

C. Create another graph of PV vs. time on a different piece of graph paper.

D. Plot the response of the system with a gain of 40 using the data you collected in step 9E.

Your response curve should be similar to the one in figure 41. You should notice that the system responds faster and settles just above the setpoint.

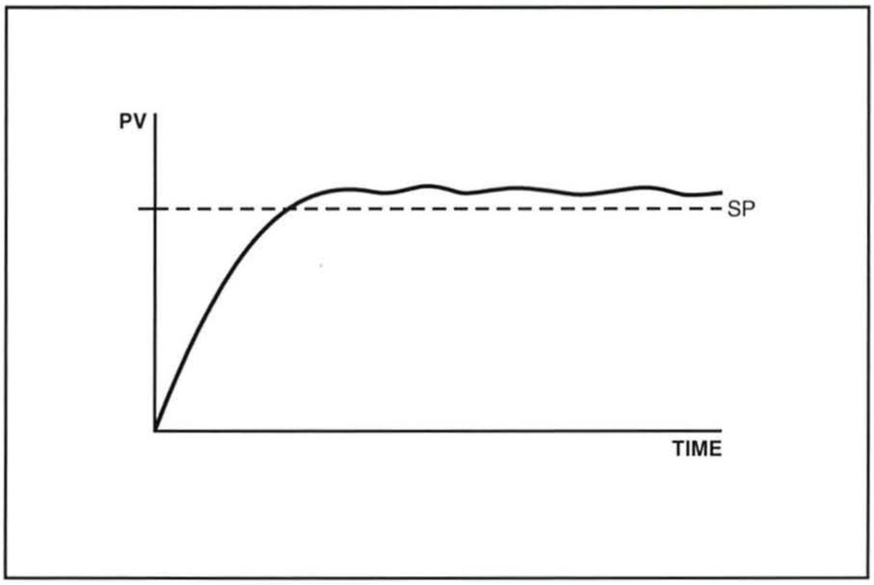

Figure 41. Graph of PV vs. Time

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 ______________ that uses computer algorithms 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 band (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, offset reappears.

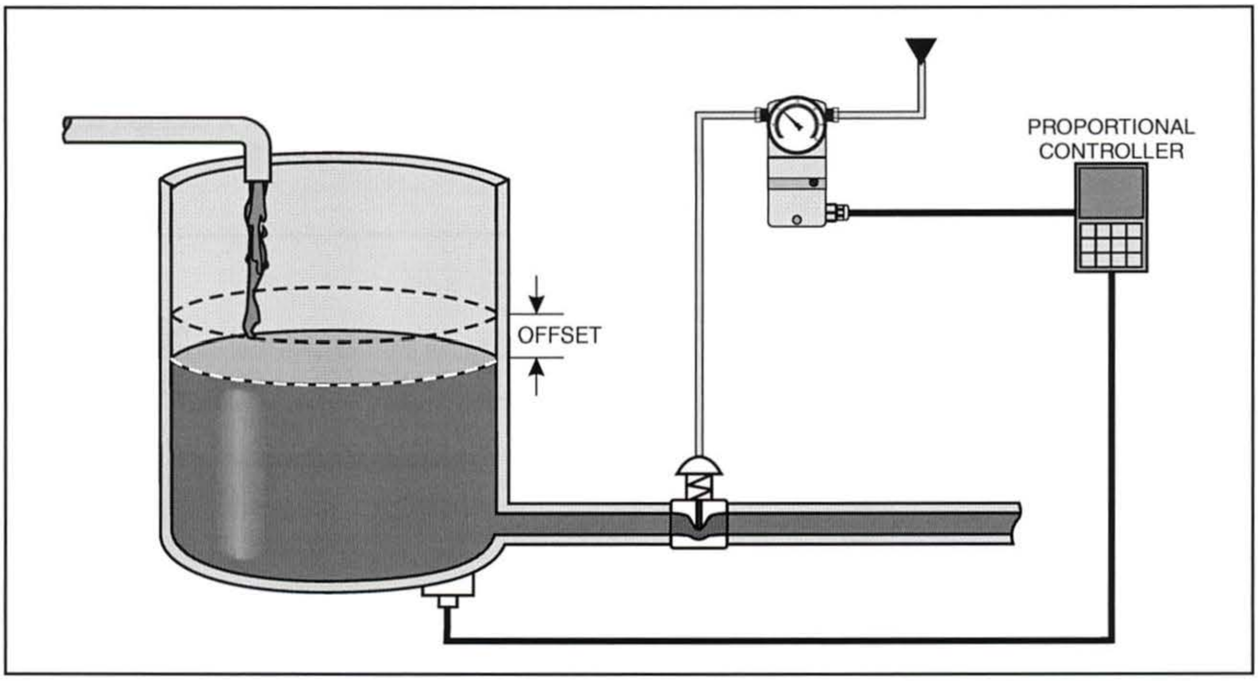

Figure 42. Proportional Control Offset

Offset can be eliminated for all control demand levels by adding integral control to the proportional control. Integral control is added by setting the integral gain in the PID controller. Integral control 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.

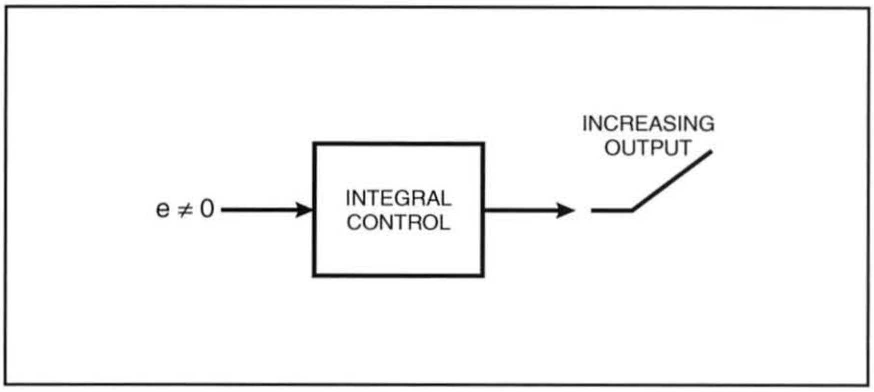

Figure 43. Linear Output Resulting from a Non-Zero Error Signal

When the error is equal to zero, as shown in figure 44, then the output remains at a non-zero constant value that holds the error 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.

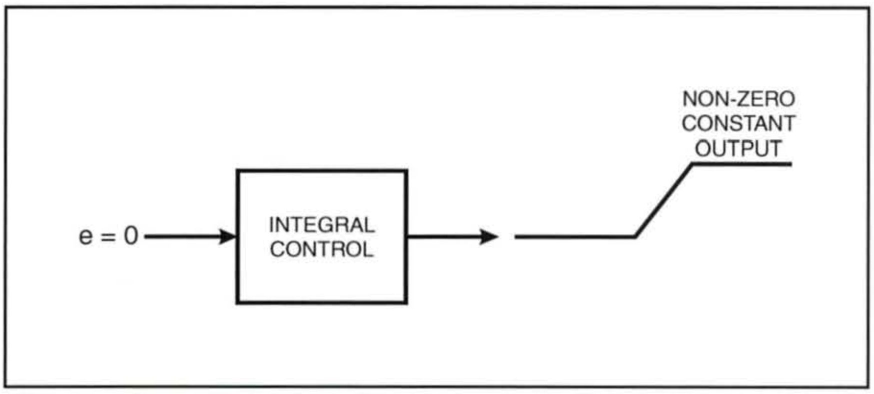

Figure 44. Constant Output Resulting from a Zero Error Signal

Figure 45 shows an example of a controller's 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 control increases the controller output signal at a constant rate as long as the error is present. When the error returns to zero, the controller output becomes constant, holding the system at the new setpoint.

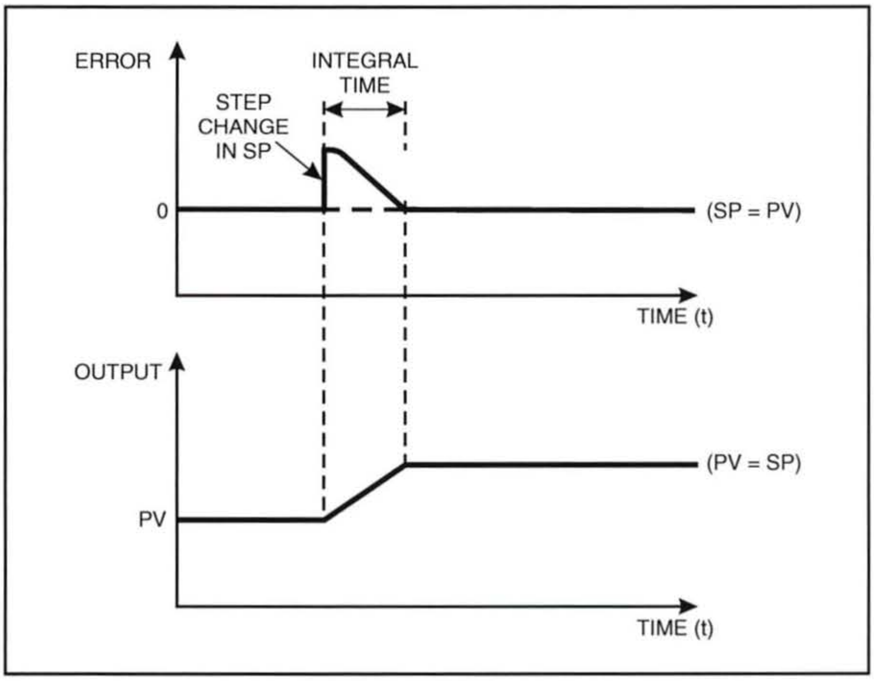

Figure 45. Controller Response to Error Due to Integral Control

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 46 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.

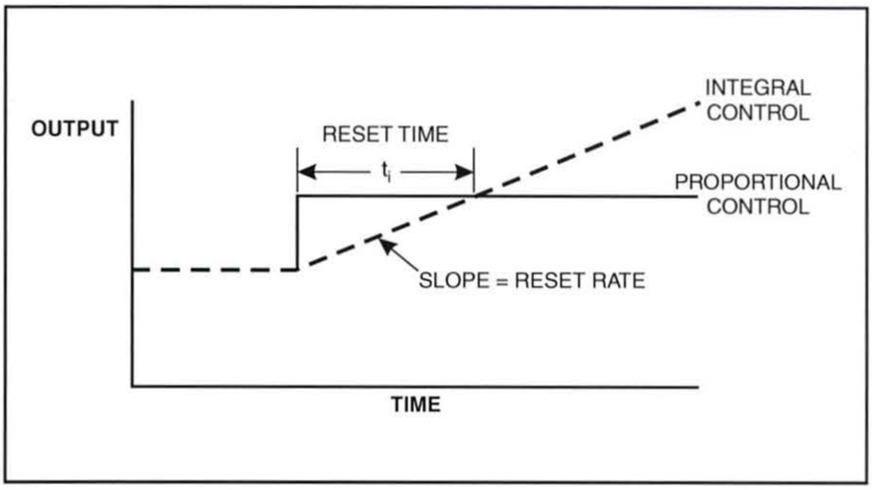

Figure 46. Reset Time and Reset Rate

The objective of any control method is quick process response 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 47.

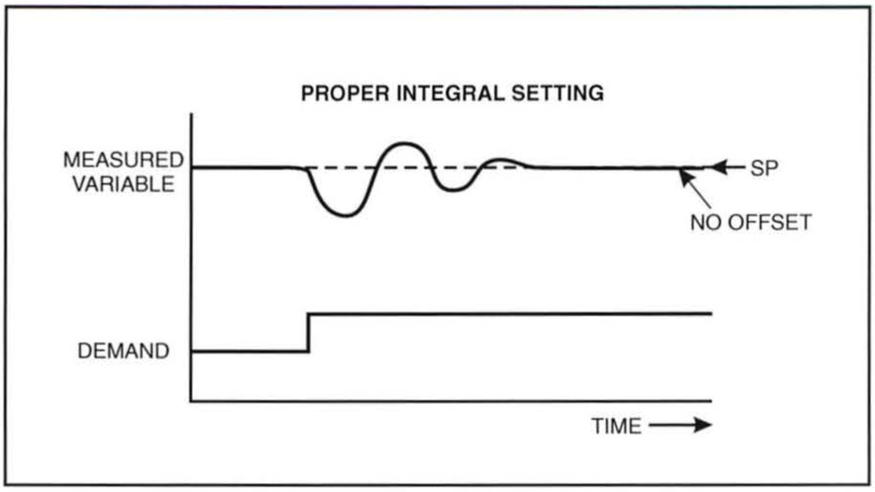

Figure 47. Proper Integral Setting

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 48 shows the effect of a high integral time (low integral rate) setting.

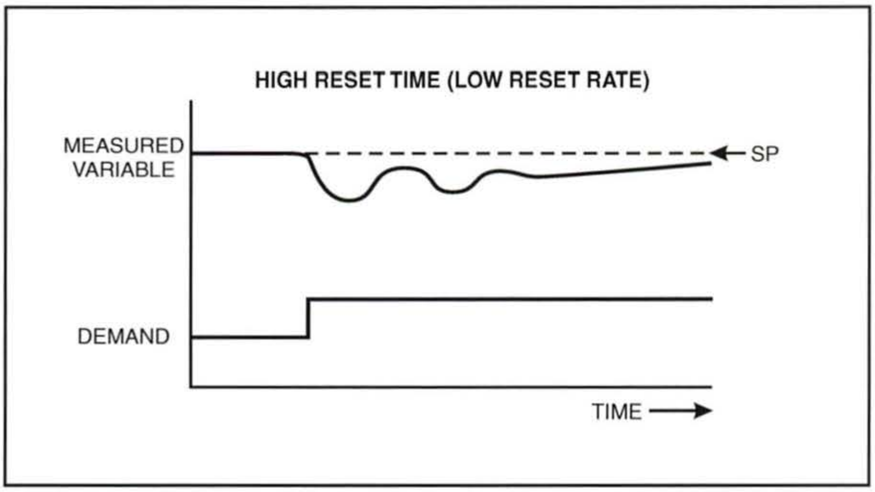

Figure 48. Effect of a High Reset Time or Low Reset Rate Setting

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 49 shows how a low reset time or high reset rate setting results in an unstable system.

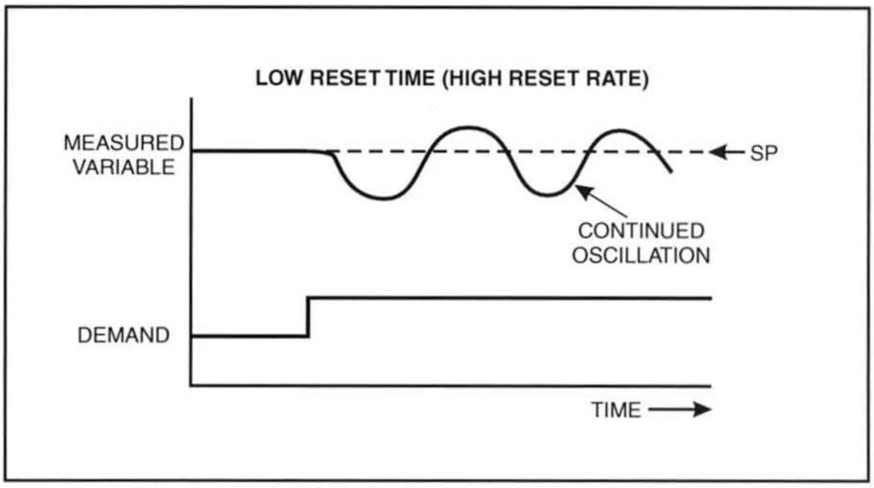

Figure 49. A Low Reset Time (High Reset Rate) Results in an Unstable System

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 50.

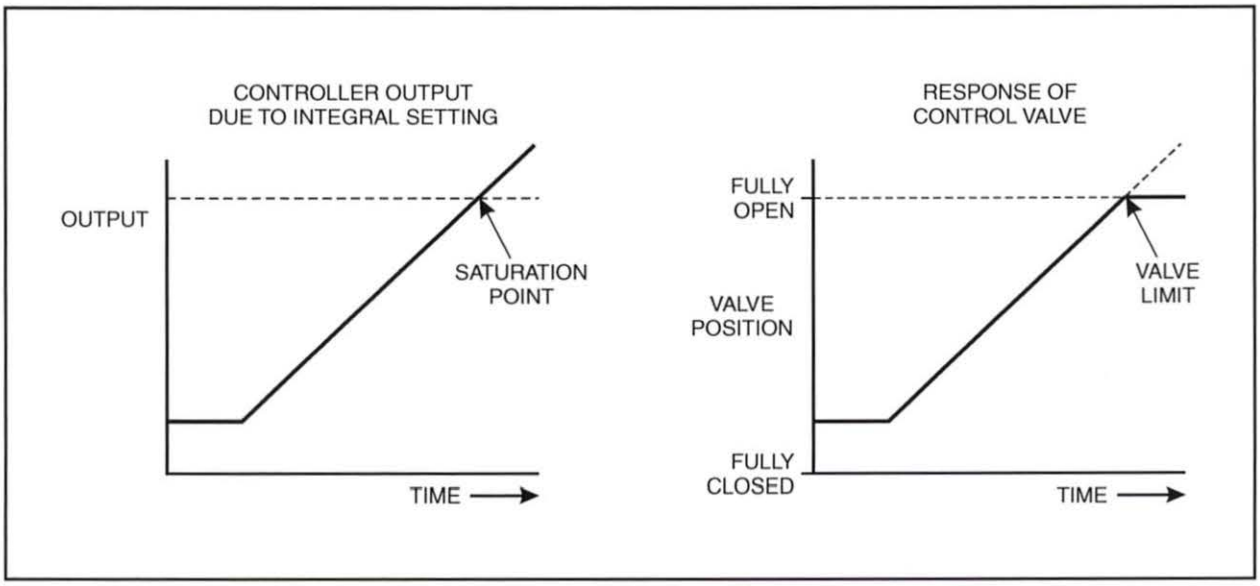

Figure 50. Integral Control Saturated

Temperature control processes often experience problems with reset windup. For example, figure 51 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).

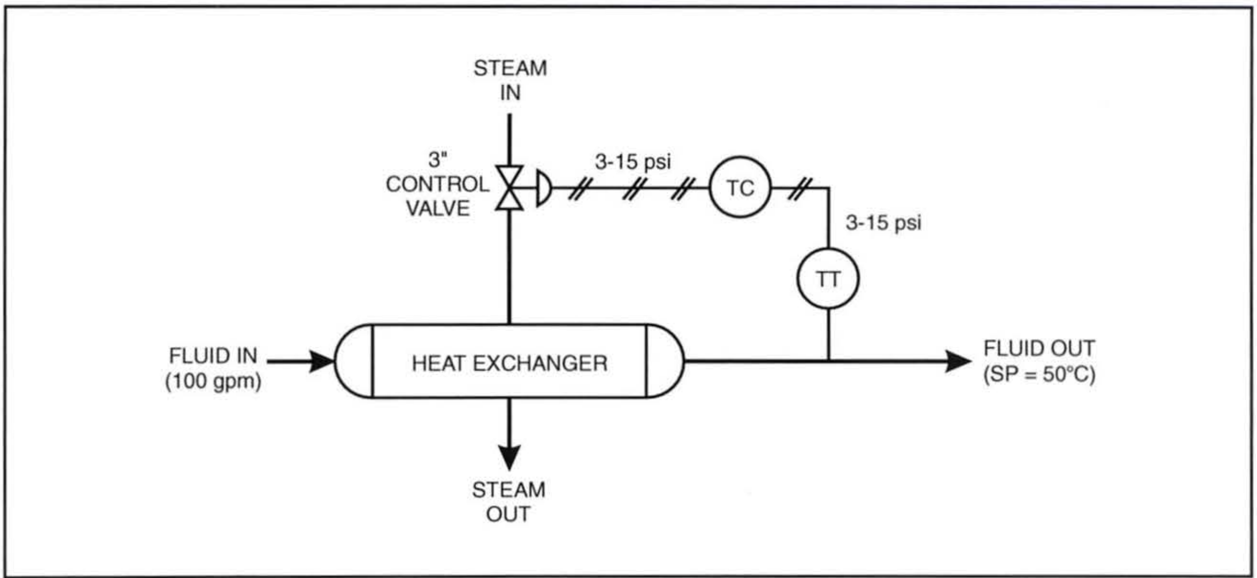

Figure 51. Temperature Control Process

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 52 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.

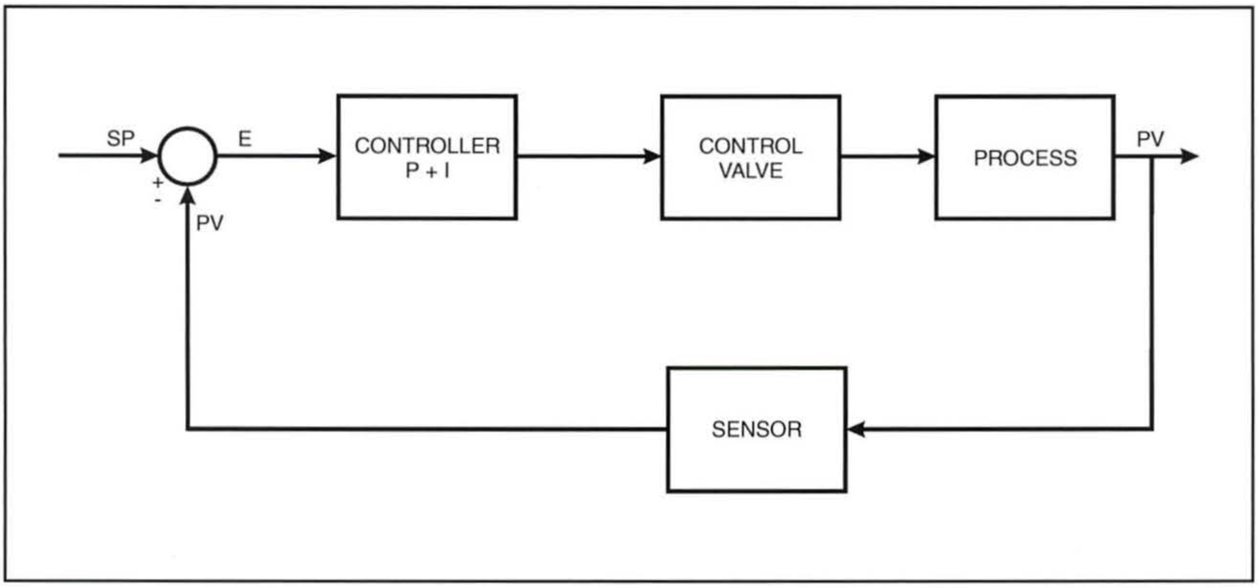

Figure 52. Block Diagram of a Process System Using PI Control

Figure 53 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.

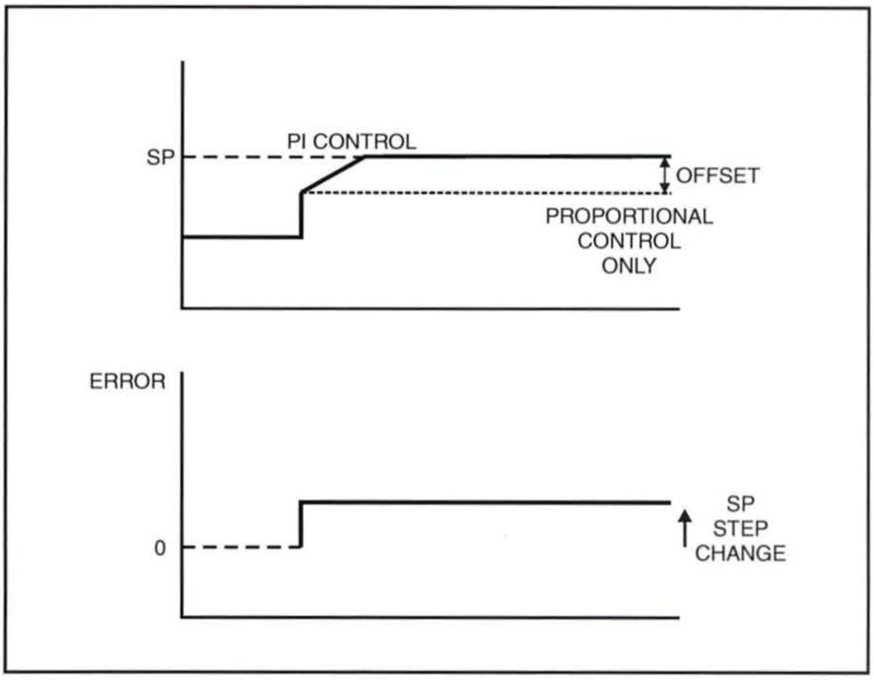

Figure 53. Controller Response Using Proportional Control vs. PI Control

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 often used in flow and level control systems. It is effective in flow control systems because they are generally subject to noise and frequent oscillations. Level control systems often have large offsets after disturbances. The added integral control eliminates this offset.

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

Procedure Overview

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

Do This

❑ 1. Perform a lockout/tagout.

❑ 2. Perform the following substeps to set up the T5552, as shown in figure 54.

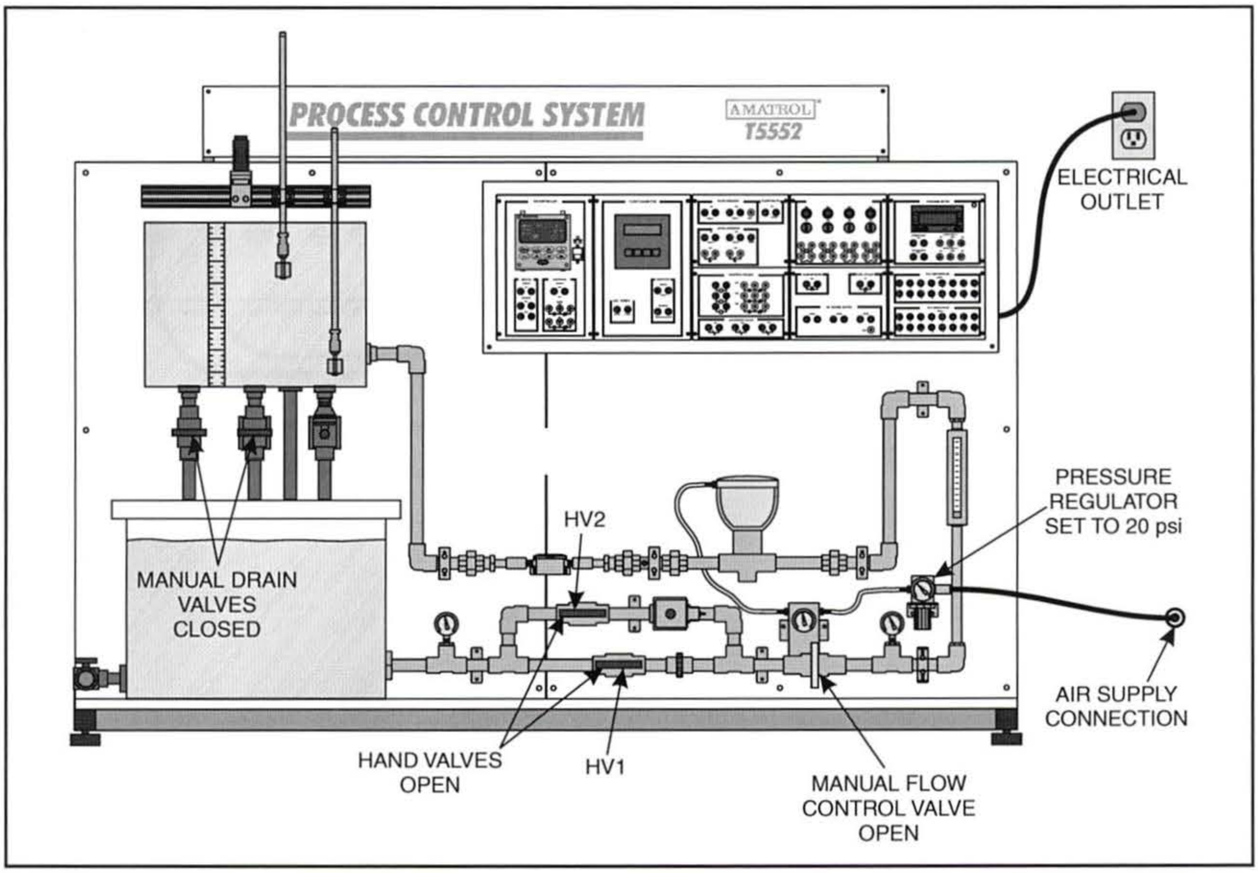

Figure 54. T5552 Setup

A. Connect the air supply line to the T5552.

B. Set the pressure regulator to 20 psi.

C. Fill the reservoir tank with water.

D. Close (fully clockwise) the two manual process tank drain valves.

E. Make sure the circuit is still connected as shown in figure 55. If it is not, reconnect it.

This circuit allows you to operate a closed loop level control system.

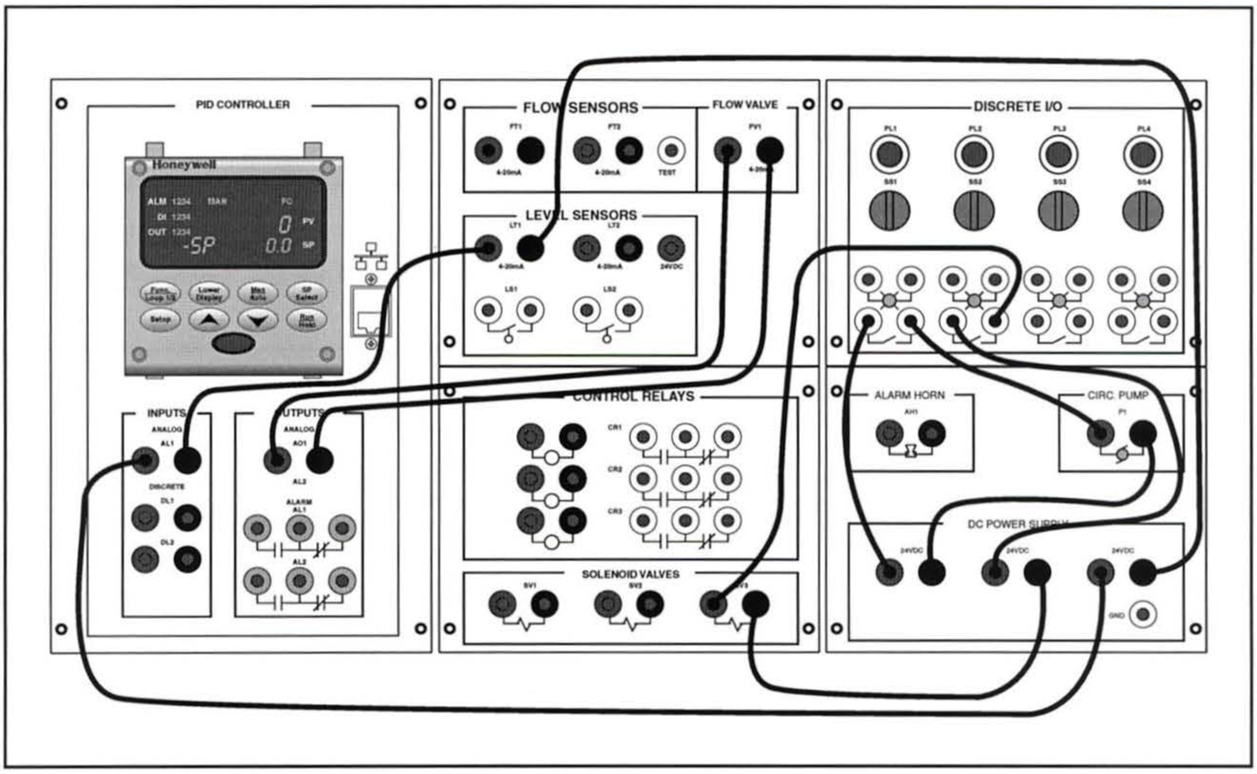

Figure 55. Connections for Closed Loop Level Control

Figure 56 shows the P&ID for the T5552. The active components and wiring are highlighted.

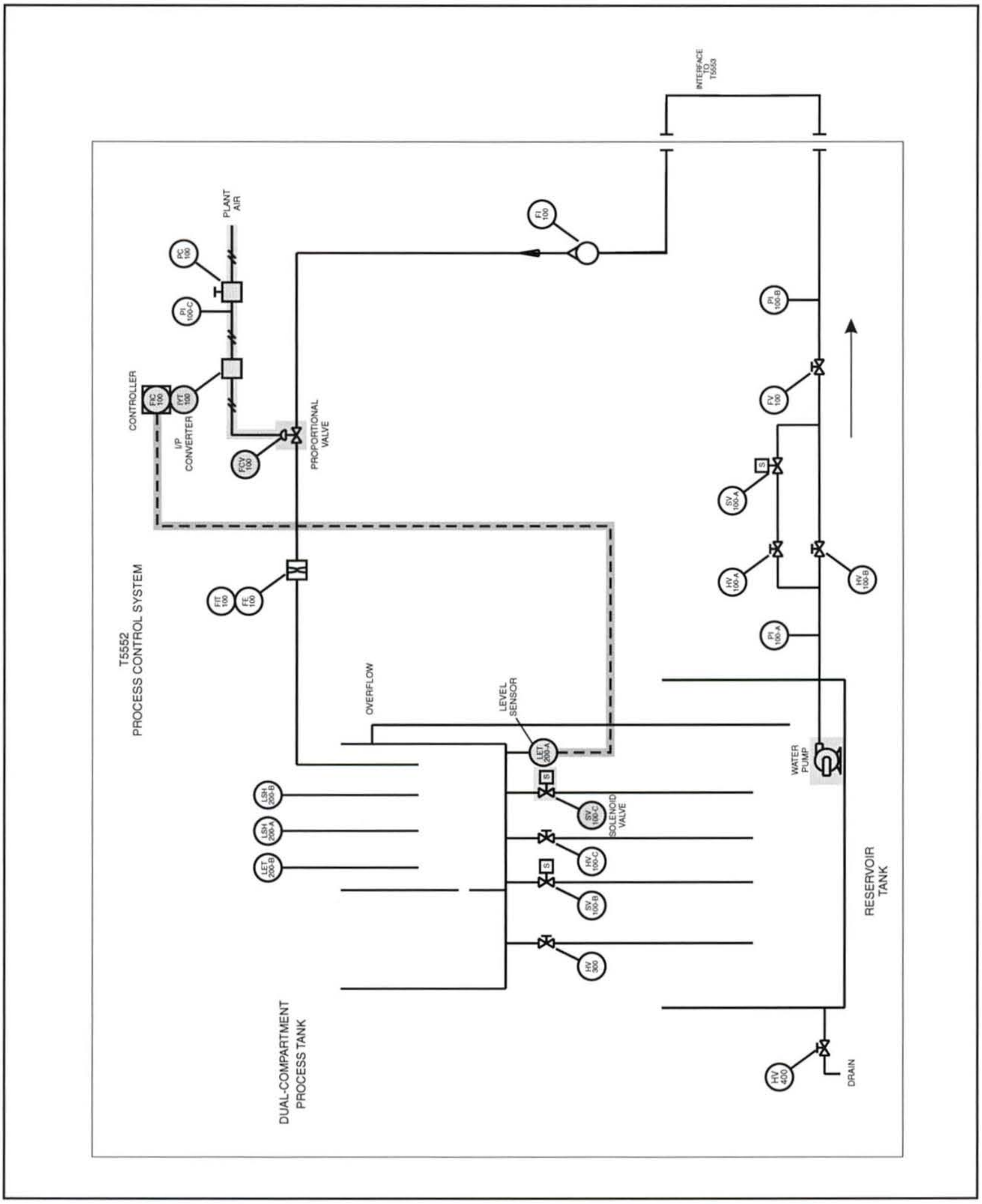

Figure 56. T5552 P&ID

❑ 3. Remove the lockout/tagout.

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

A. Turn on the main circuit breaker and allow the controller to complete its diagnostic test.

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 function 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.

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

E. Set the following parameters in the CONTROL group:

PARAMETER	SETTING
PBorGAIN	GAIN
MINorRPM	MIN
ACTION	DIRECT

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

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

G. Set the following parameters in the TUNING group:

PARAMETER	SETTING
GAIN	20.0
RATE MIN	0.0
RSET MIN	0.25

The GAIN parameter sets the controller's 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.

H. Set the following parameters in the INPUT 1 function group:

PARAMETER	SETTING
IN1 TYPE	1-5 V
XMITTER 1	LINEAR
IN1 HI	27.7
IN1 LO	0.0
BIAS IN1	-1.6
FILTER	0

I. Use the **Lower Display** key to exit the setup menu and display the setpoint (SP) parameter.

J. Use the up ▲ and down ▼ keys to set the SP to **3.0**.

K. Press the **Man/Auto** key to place the controller in automatic mode.

❑ 5. Perform the following substeps to control the process using proportional-integral (PI) control and observe the time it takes to bring the process under control after a disturbance.

During the process, you will record the displayed PV every five seconds until the process is stable. This will allow you to later plot the response of the system for different integral (reset) settings.

A. Start the circulation pump by placing **SS1** in the **ON** position.

B. Open the solenoid drain valve by placing **SS2** in the **ON** position.

C. Allow the process variable (PV) to reach a steady state at the SP.

D. After the process steadies at the SP, press the **Man/Auto** key to place the controller in manual mode.

E. Change the SP to **6.0**.

F. Press the **Man/Auto** key to return the controller to automatic mode.

G. Use the **Lower Display** key to view the output (OUT) on the display.

H. When the controller makes the first adjustment to the output, record the PV value every five seconds until the system steadies at the SP. Record your readings in a table similar to the one shown in figure 57.

This will take several minutes.

PROPORTIONAL-INTEGRAL CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 57. PV Table

I. After you have taken your readings and the system is steady, change the SP back to **3.0**.

J. When the PV steadies at 3.0, change the integral (reset) setting to **0.15**.

This equates to 9 seconds.

K. Place the controller in the manual mode, change the SP to **6.0,** and repeat substeps 5F-H for the new integral setting.

PROPORTIONAL-INTEGRAL CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 58. PV Table

L. After you have taken your readings and the system is steady, change the SP back to **3.0**.

M. When the PV steadies at 3.0, change the integral (reset) setting to **0.10**.

This equates to 6 seconds (1/10 of a minute).

N. Place the controller in the manual mode, change the SP to **6.0,** and repeat substep 5F-H for the new integral setting.

PROPORTIONAL-INTEGRAL CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 59. PV Table

❑ 6. Perform the following substeps to shut down the T5552.

A. Place the selector switch **SS1** in the **OFF** position (up) to stop the circulation pump.

B. Place the selector switch **SS2** in the **OFF** position (up) to close the solenoid drain valve.

C. Press the **Man/Auto** key on the controller to switch the controller to the manual mode.

D. Open both of the manual drain valves on the process tank to completely drain the tank. When the tank is empty, close both valves.

E. Turn off the main circuit breaker.

F. Disconnect the circuit if this is your last activity. If it is not your last activity, leave the circuit connected to use in the next skill.

❑ 7. Perform the following substeps to plot the response of the system for each of the integral settings.

A. Create a graph of PV vs. time, similar to figure 60, on a piece of graph paper.

You will use this to plot the response of the system with an integral setting of 1 minute.

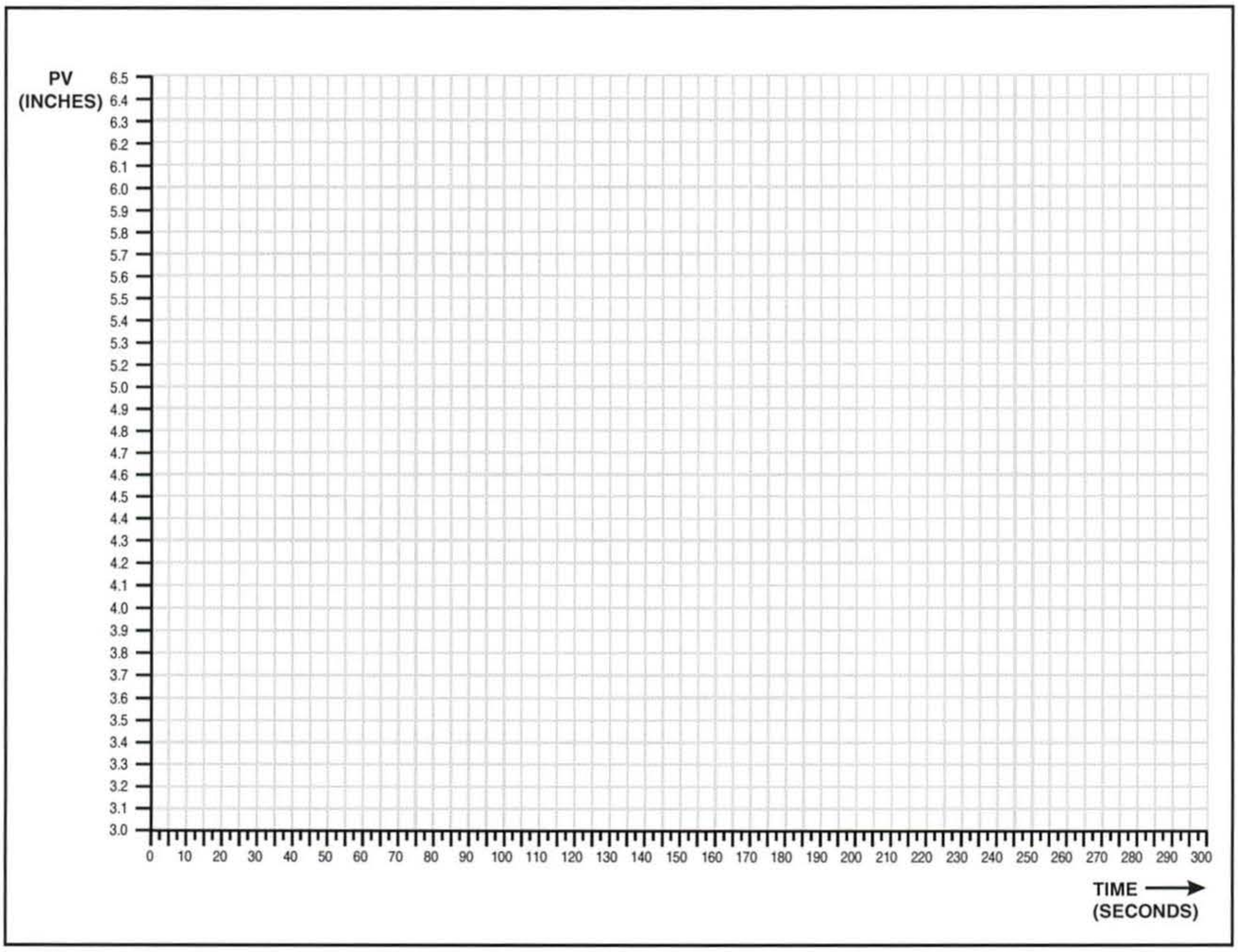

Figure 60. Graph of PV vs. Time

B. Plot the response of the system using the data you collected in substep 5H.

C. Create another graph of PV vs. time on a different piece of graph paper.

D. Plot the response of the system with an integral setting of 0.15 (substep 5K).

   You should notice that the system responds faster and has smaller oscillations.

E. Create a third graph of PV vs. time on another piece of graph paper.

F. Plot the response of the system with an integral setting of 0.10 (substep 5N).

   Figure 61 shows the ideal response curve for the system. Compare your results to this response curve.

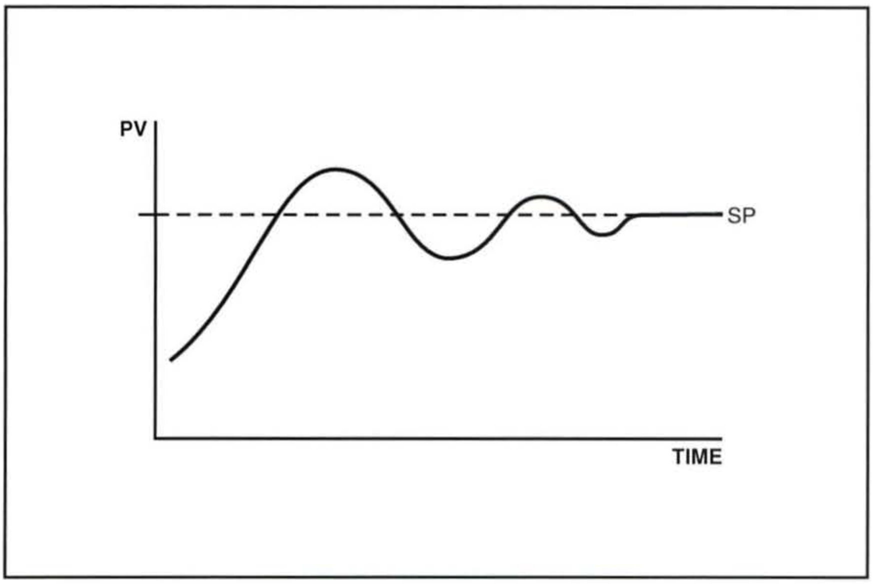

Figure 61. Ideal Response for PI Control

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

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 damp oscillations. It reduces overshoot by anticipating the error and applying the needed correction before the error becomes large. Figure 62 shows the response of a system using PI control and a system using PID control.

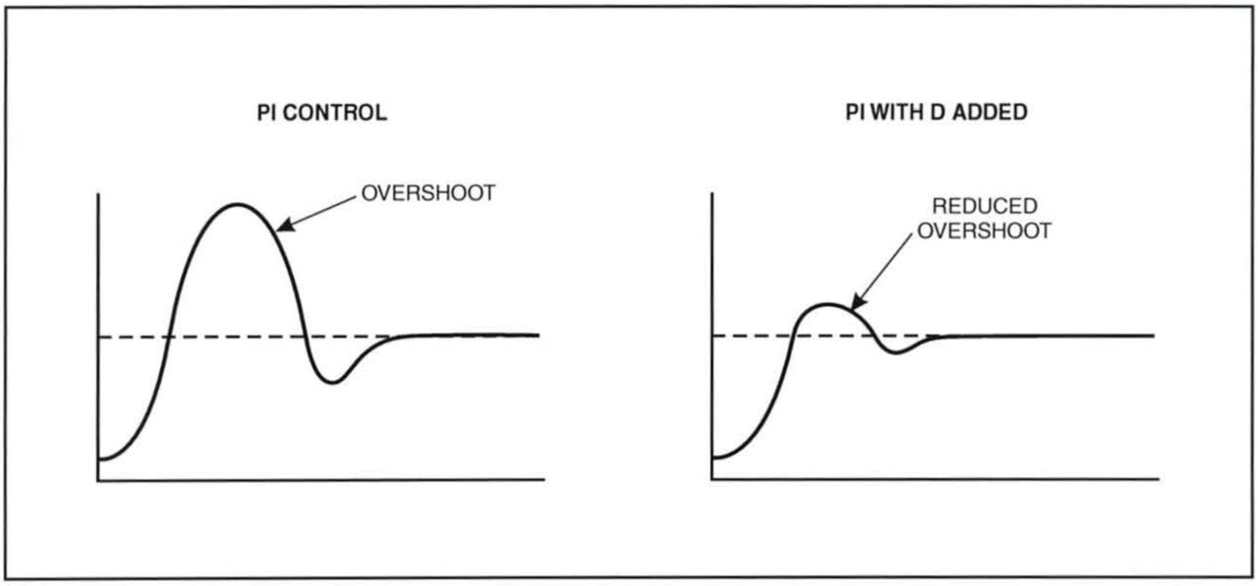

Figure 62. PI Control Vs. PID Control

Figure 63 shows a block diagram of a process system that uses 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 element (D) in the controller increases the controller output according to how fast the signal is changing.

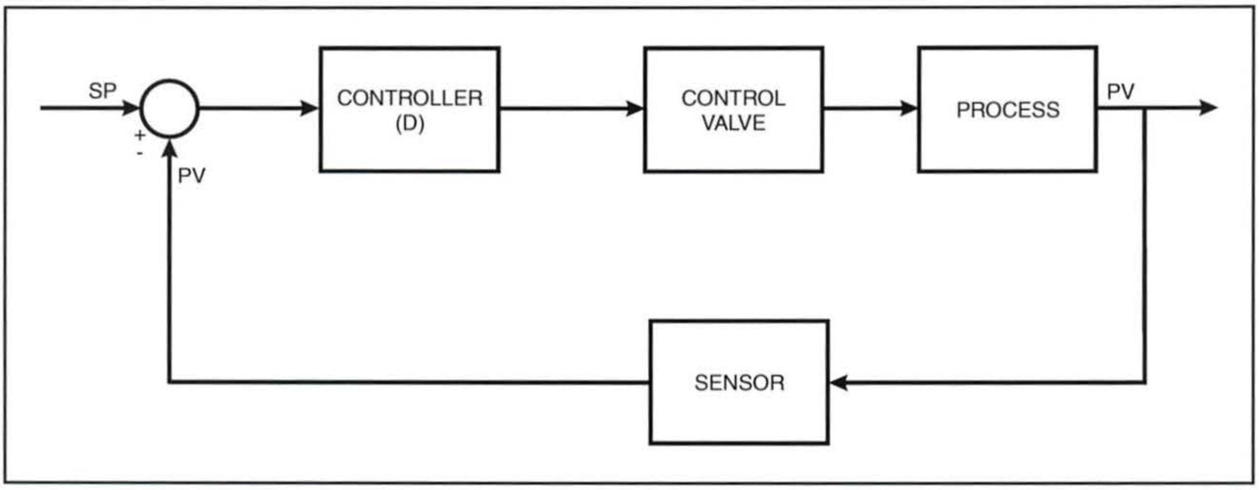

Figure 63. Block Diagram of a Process System Using Derivative Control

If the error signal is changing quickly, the derivative element increases the controller output by a large amount, as figure 64 shows.

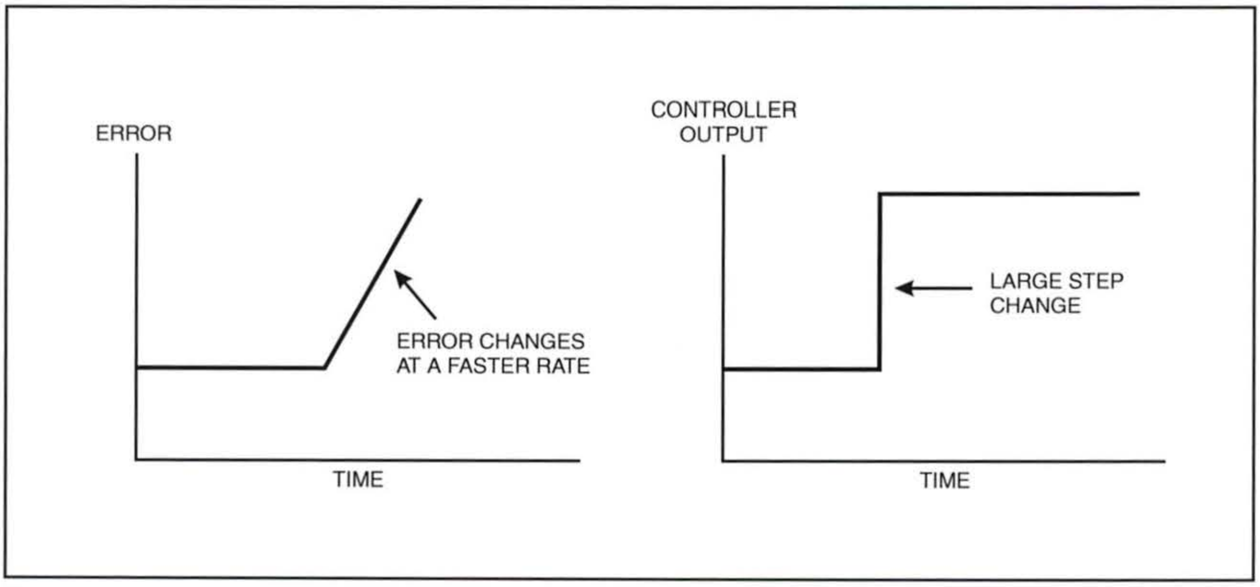

Figure 64. Derivative Response to an Error Signal Changing at a Fast Rate

If the signal changes slowly, the derivative element increases the controller output by a smaller amount, as figure 65 shows.

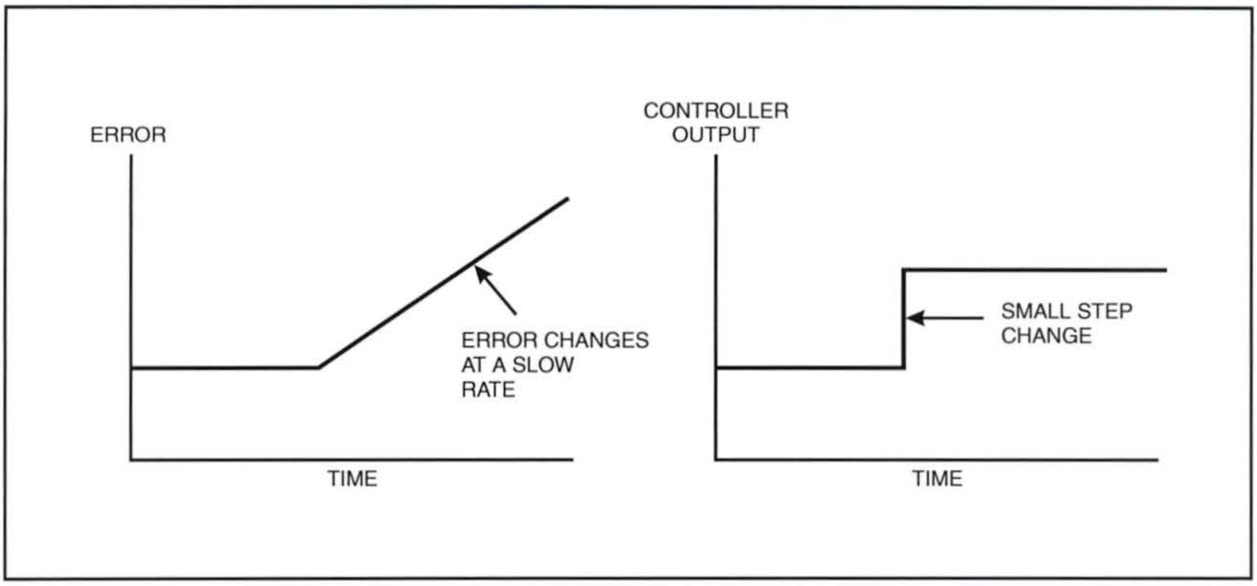

Figure 65. Derivative Response to an Error Signal Changing at a Slow Rate

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 66. The error must be changing for derivative control to have any effect.

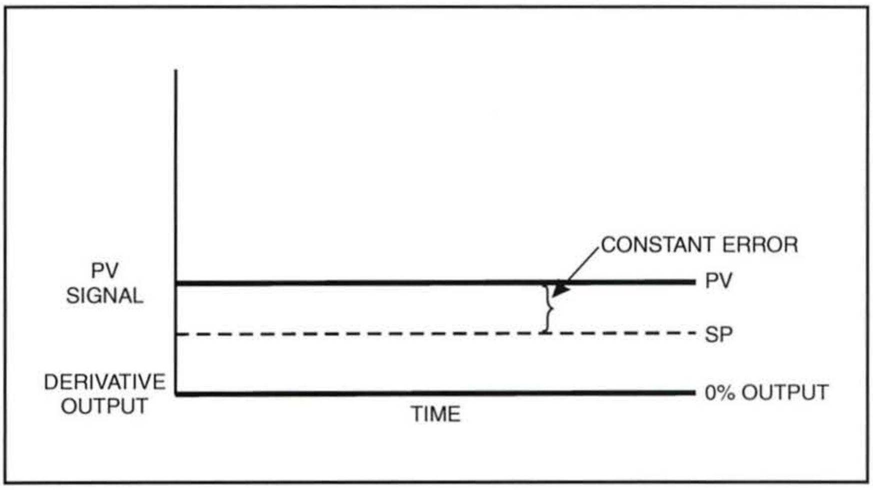

Figure 66. Derivative Response to Constant Error

Derivative Response with a Filter

Because the derivative response increases as the error signal's 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 67. 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.

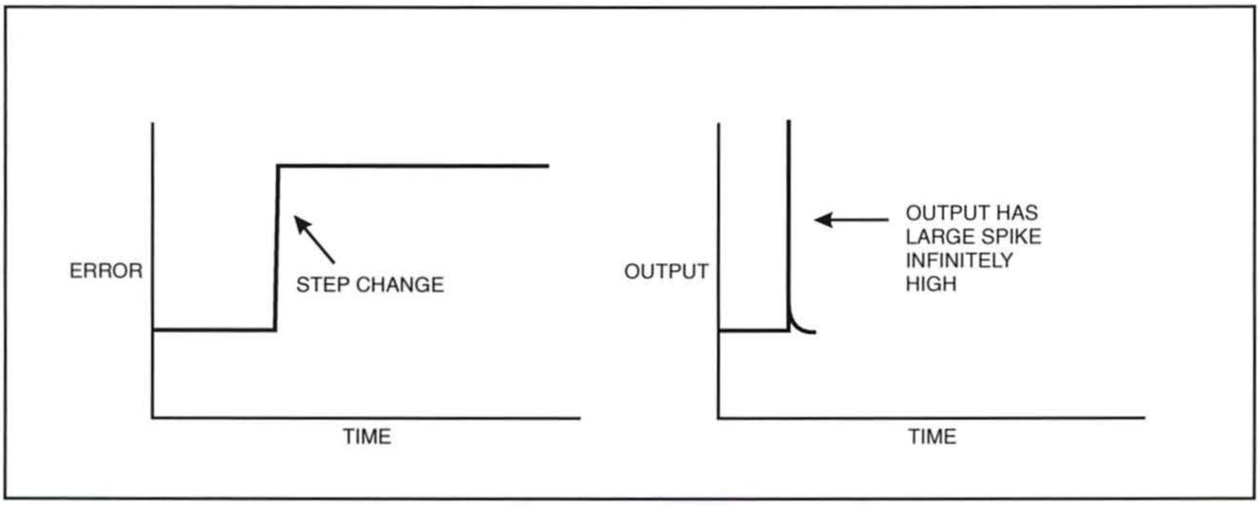

Figure 67. Derivative Response to a Step Change in Error

In figure 68, 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. You should 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.

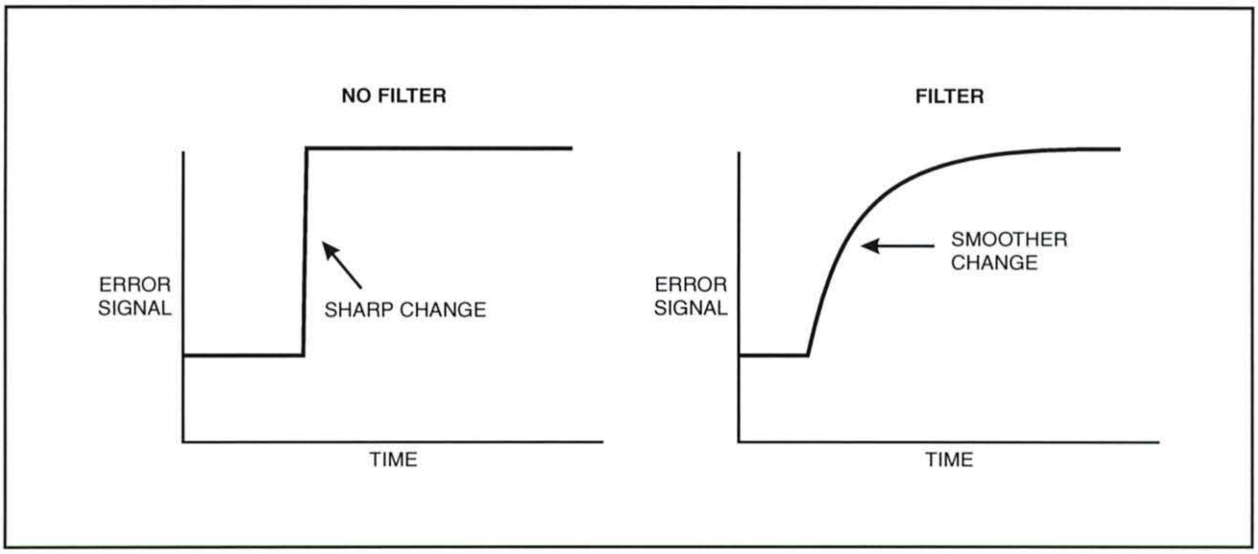

Figure 68. Step Change with and without a Filter

Figure 69 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 signal 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).

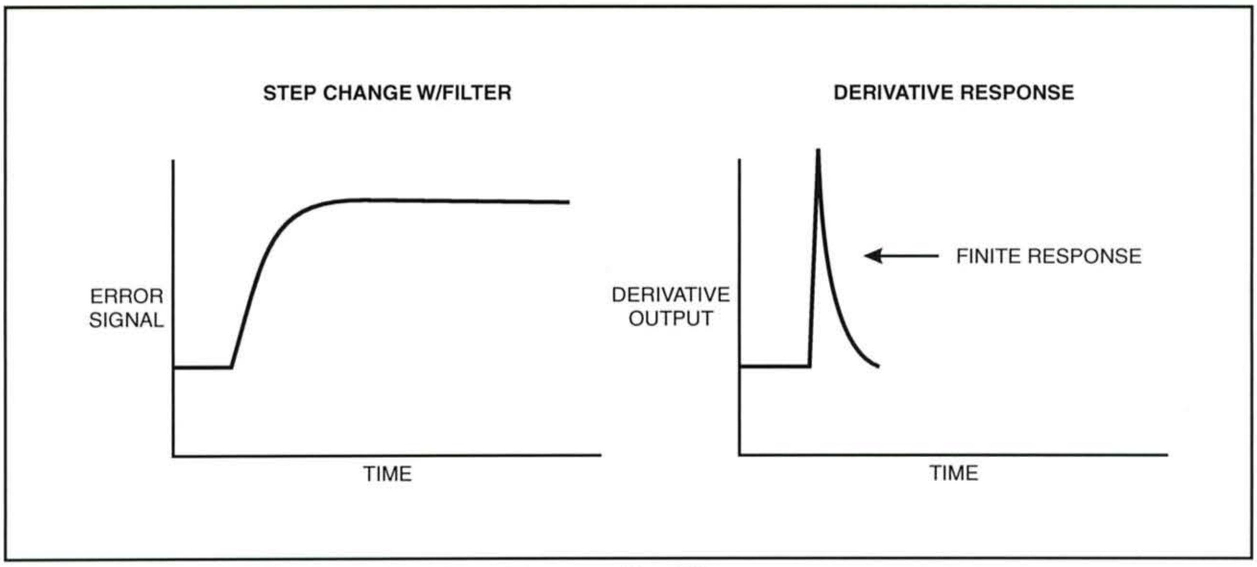

Figure 69. Derivative Response to a Step Change with a Filter

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 signal but also anticipates the error signal based on how quickly the error is changing. Figure 70 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.

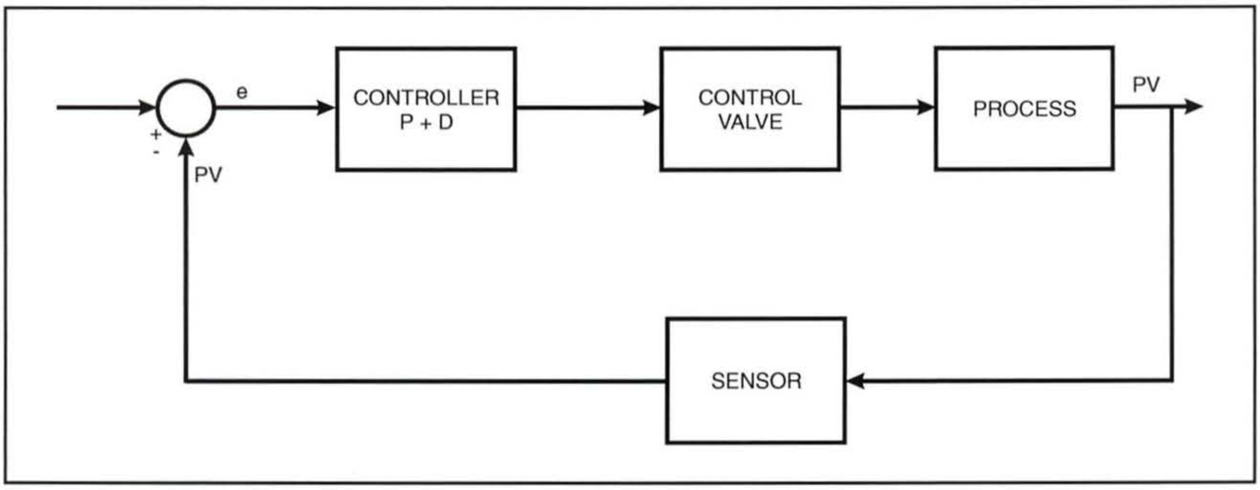

Figure 70. Block Diagram of a Process Control System Using PD Control

During operation the derivative control action leads the proportional control action by a certain amount of time called the derivative time (t_d). Derivative time is a value that is programmed into the controller. Its value determines how much derivative action occurs. As t_d increases, the derivative action increases. Figure 71 shows a graph of a proportional and derivative response to error.

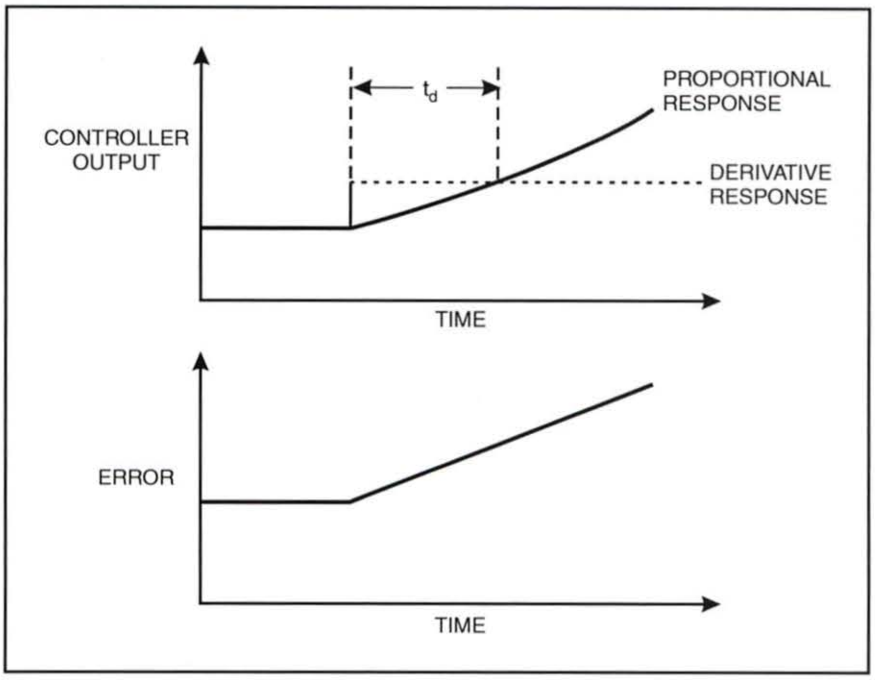

Figure 71. Graph of Proportional and Derivative Response to Error

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 72 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 20% using PD control. This allows the system to respond faster to the error. The figure also shows that the derivative time (t_d) equals one minute. Therefore, the proportional-only control system requires one extra minute to match the output of the PD system.

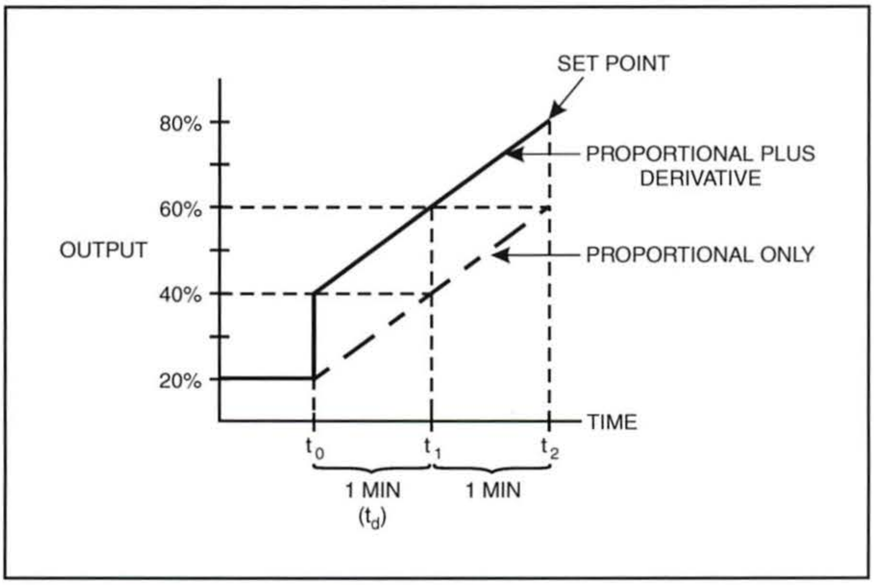

Figure 72. Proportional Response vs. PD Response

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 73. The figure also shows that derivative control does not eliminate offset.

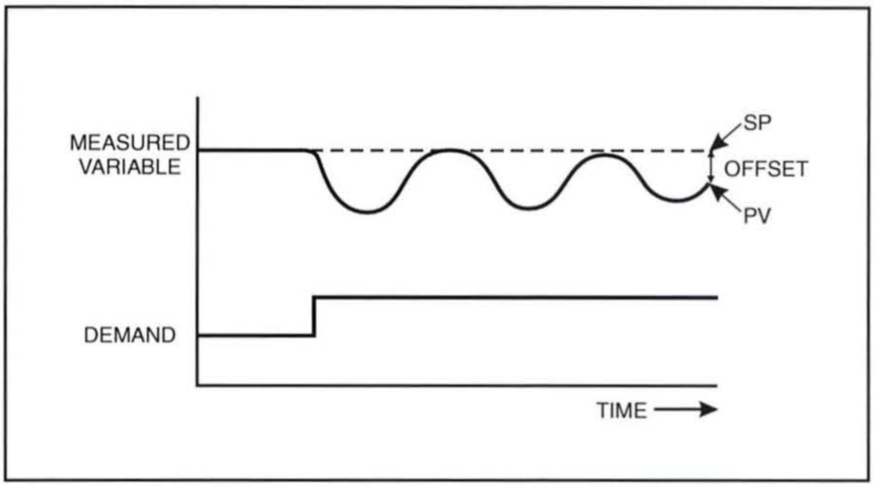

Figure 73. Process Response with Derivative Setting Too High

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. 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 level 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. While it is uncommon to control level processes using PD control, using it here will allow you to visually see the effects of this control type.

❑ 1. Perform a lockout/tagout.

❑ 2. Perform the following substeps to set up the T5552, as shown in figure 74.

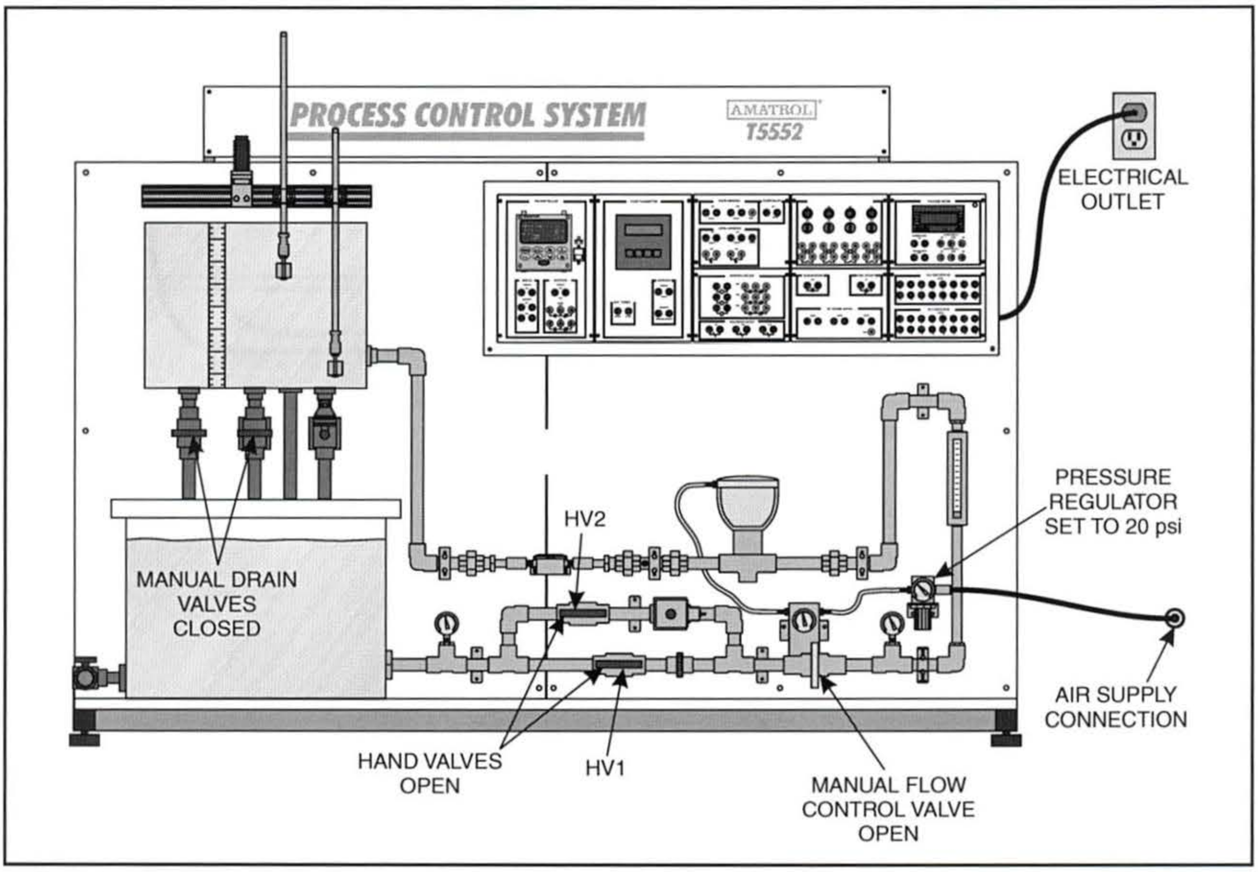

Figure 74. T5552 Setup

A. Connect the air supply line to the T5552.

B. Set the pressure regulator to 20 psi.

C. Fill the reservoir tank with water.

D. Close (fully clockwise) the two manual process tank drain valves.

E. Make sure the circuit is still connected as shown in figure 75. If it is not, reconnect it.

This circuit allows you to operate a closed loop level control system.

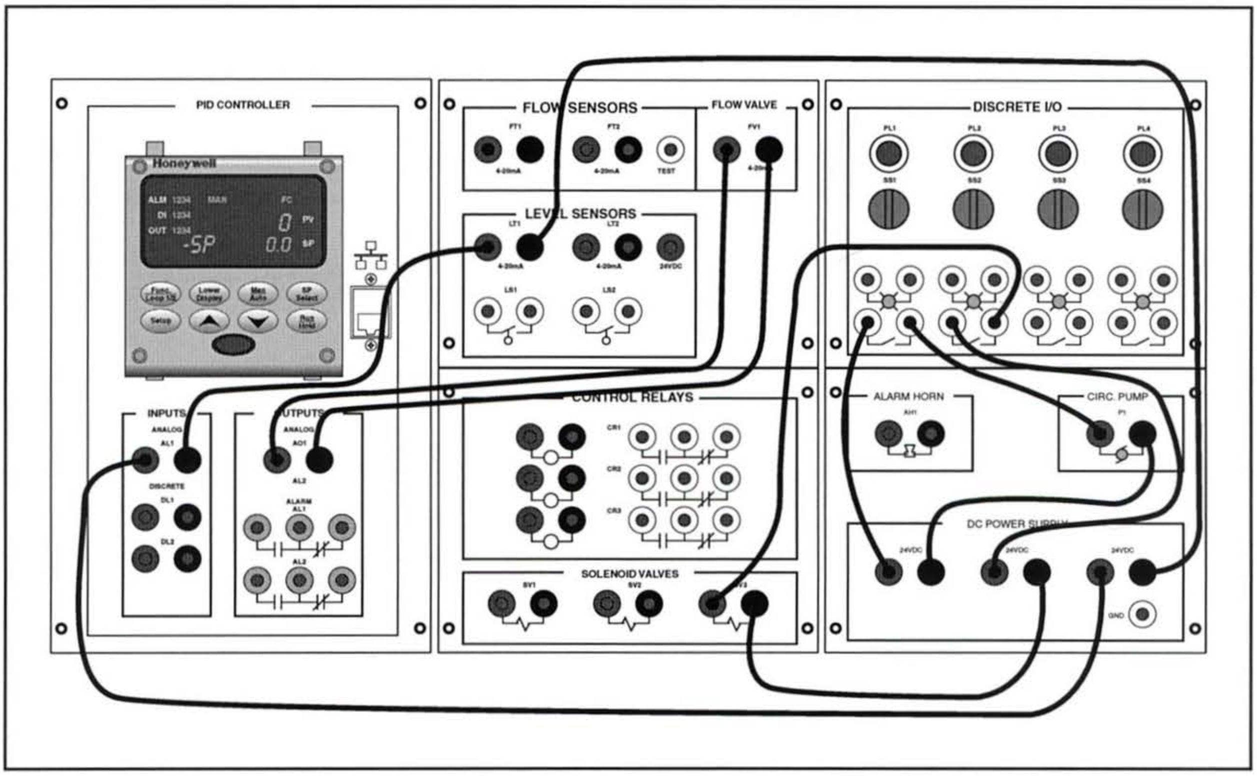

Figure 75. Connections for Closed Loop Level Control

Figure 76 shows the P&ID for the T5552. The active components and wiring are highlighted.

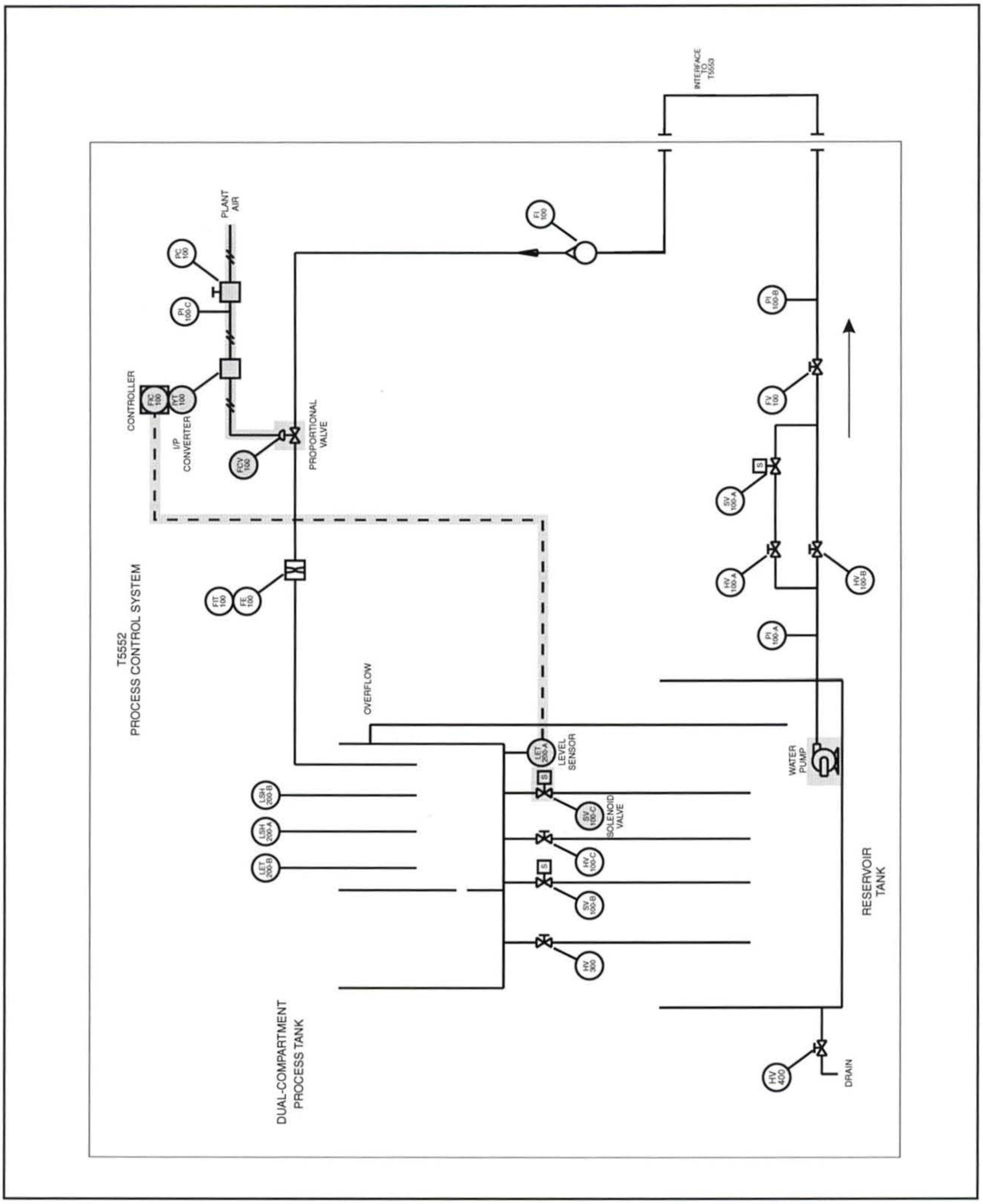

Figure 76. T5552 P&ID

❑ 3. Remove the lockout/tagout.

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

A. Turn on the main circuit breaker and allow the controller to complete its diagnostic test.

B. Use the **Lower Display** key to scroll through the values until the set point value is displayed.

C. Use the up ▲ and down ▼ keys to change the set point value to **5.00**.

D. Press the **Setup** key to enter the setup menu.

E. Set the following parameters in the INPUT 1 setup group:

PARAMETER	SETTING
IN1 TYPE	1-5 V
XMITTER 1	LINEAR
IN1 HIGH	27.70
IN1 LOW	0.0
BIAS IN1	-1.6
FILTER 1	1

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

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

H. Use the up ▲ and down ▼ 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.

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

J. Set the ACTION parameter in the control group to **DIRECT**.

K. Set the following parameters in the TUNING group.

PARAMETER	SETTING
GAIN	25
RATE MIN	1.00
MAN RSET	30

L. Press the **Lower Display** key to exit the setup menu.

M. Switch the controller to the automatic mode by pressing the **Man/Auto** key.

N. Start the circulation pump by placing **SS1** in the **ON** position.

O. Use the **Lower Display** key to view the controller output (OUT) on the display

❑ 5. Perform the following substeps to control the process using proportional-derivative (PD) control and observe how long it takes to bring the process under control after a disturbance.

During the process, you will record the displayed PV every five seconds until the process is steady. This will allow you to later plot the response of the system for different derivative (rate) settings.

A. Open the solenoid drain valve by placing **SS2** in the **ON** position.

B. When the controller makes the first adjustment to the output, observe the display of the controller and record the PV value every five seconds until the system becomes steady. Record your readings in a table similar to the one shown in figure 77.

This will take several minutes.

PROPORTIONAL-DERIVATIVE CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 77. PV Table

C. Once you have taken your readings, close the solenoid valve (SS2 off) and turn off the pump (SS1 off).

D. Open the process tank manual drain valves to drain the tank. When the tank is empty, close the valves.

E. Change the derivative (rate) setting to **0.5**.

This equates to 30 seconds (1/2 of a minute).

F. Turn on the pump (SS1 on), open the solenoid drain valve (SS2 on), and repeat substep 5B for the new derivative setting.

PROPORTIONAL-DERIVATIVE CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 78. PV Table

G. Once you have taken your readings, close the solenoid drain valve, and turn off the pump.

H. Open the process tank manual drain valves to drain the tank. When the tank is empty, close the valves.

I. Change the derivative (rate) setting to **0.25**.

This equates to 15 seconds (1/4 of a minute).

J. Turn on the pump, open the solenoid drain valve, and repeat substep 5B for the new derivative setting.

PROPORTIONAL-DERIVATIVE CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 79. PV Table

❑ 6. Perform the following substeps to shut down the T5552.

A. Place the selector switch **SS1** in the **OFF** position (up) to stop the circulation pump.

B. Place the selector switch **SS2** in the **OFF** position (up) to close the drain solenoid valve.

C. Press the **Man/Auto** key on the controller to switch the controller to the manual mode.

D. Open both of the manual drain valves on the process tank to completely drain the tank. When the tank is empty, close both valves.

E. Turn off the main circuit breaker.

F. Disconnect the circuit if this is your last activity. If it is not your last activity, leave the circuit connected to use in the next skill.

❑ 7. Perform the following substeps to plot the response of the system for each of the derivative settings.

A. Create a graph of PV vs. time, similar to figure 80, on a piece of graph paper.

You will use this to plot the response of the system with a derivative setting of 1 minute. You may need to use a different scale than in the previous skills, as shown in figure 80, to cover the entire range of values.

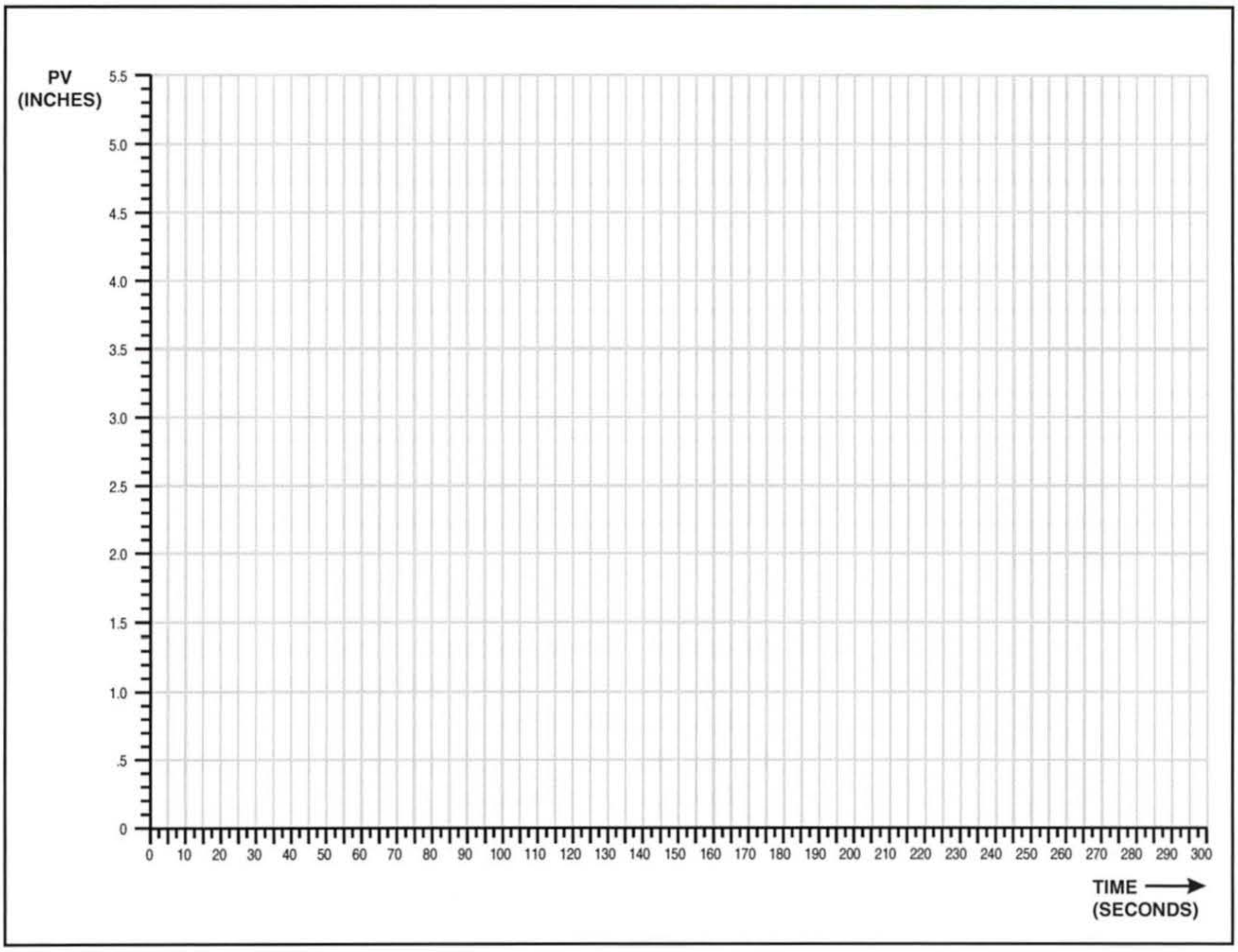

Figure 80. Graph of PV vs. Time

B. Plot the response of the system using the data you collected in step 5B.

C. Create another graph of PV vs. time on a different piece of paper.

D. Plot the response of the system with a derivative setting of 0.5 using the data you collected in step 5F.

You should notice that the system responds faster but offset still occurs.

E. Create a third graph of PV vs. time on another piece of graph paper.

F. Plot the response of the system with a derivative setting of 0.25 using the data you collected in step 5J.

The ideal response of the system using PD control should resemble the output shown in figure 81. Compare your results to this response curve.

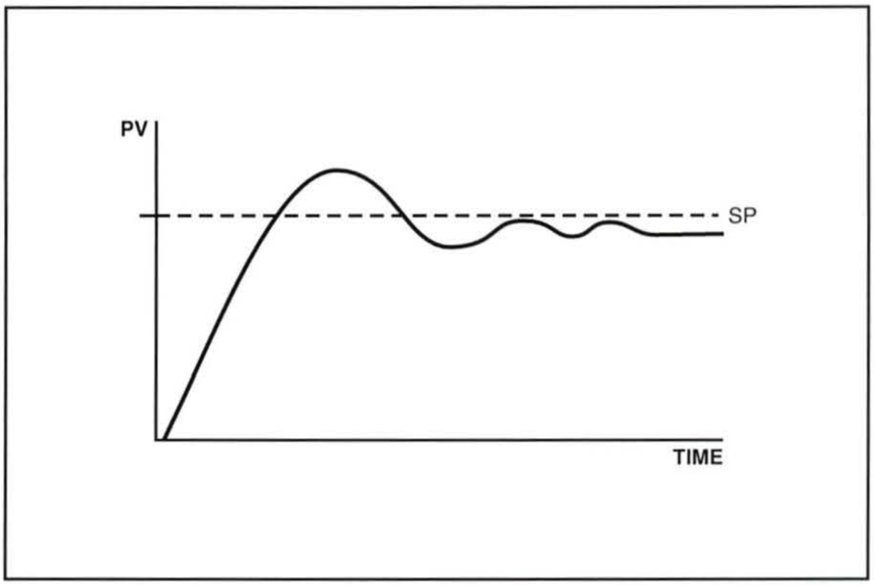

Figure 81. Ideal Response for PD Control

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

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 82 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.

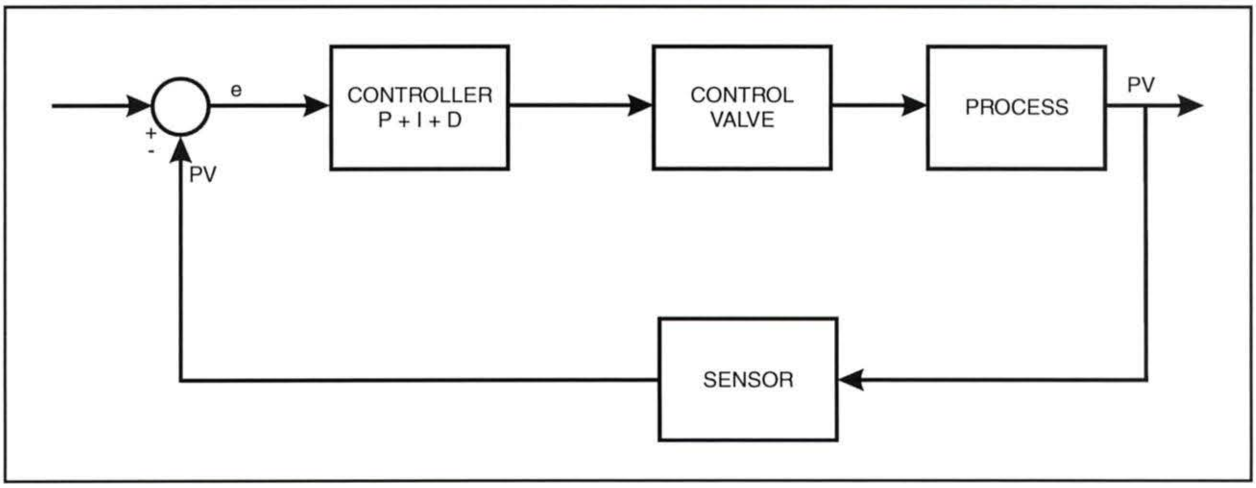

Figure 82. Block Diagram of a System Using PID Control

When programmed properly, PID control maintains the set point in a steady state. Any oscillations that occur have a small amplitude and duration. Figure 83 shows a response curve for a system that uses PID control.

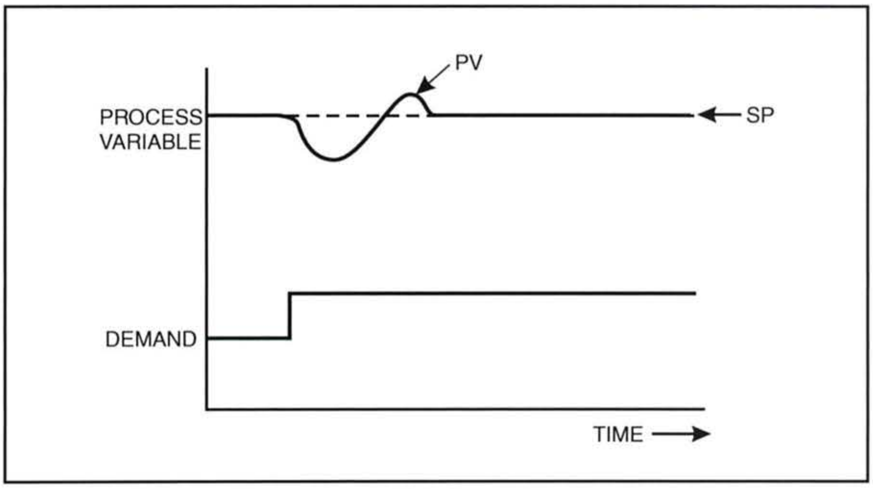

Figure 83. Process Response to PID Control

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 84 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.

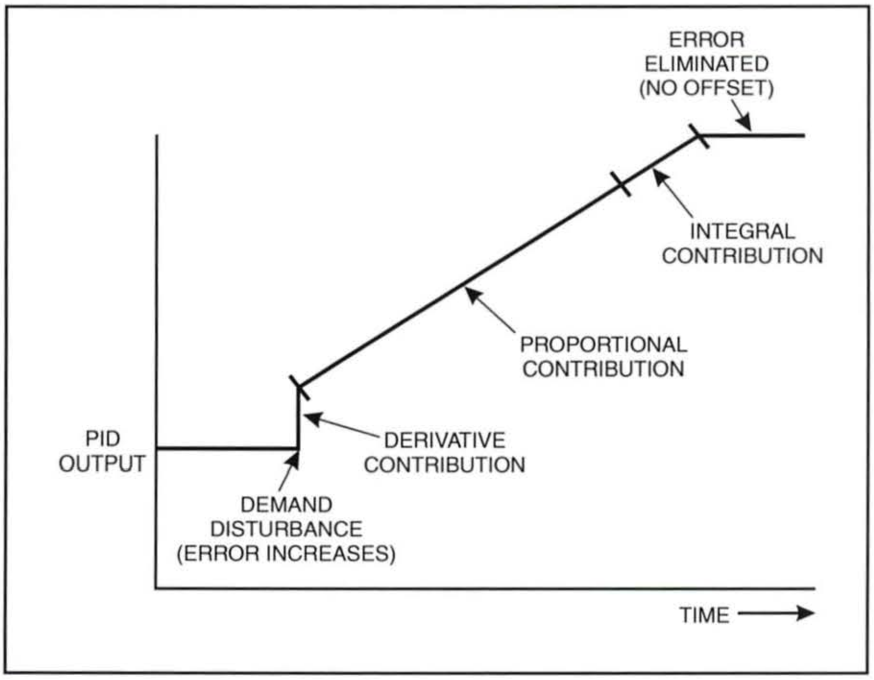

Figure 84. Contributions of P, I, and D throughout an Error

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 the level in the tank using PID control. You will change the parameters of each control type separately and note the changes. This will help you to better understand how the three control modes work together to provide stable control of a process.

- ❑ 1. Perform a lockout/tagout.
- ❑ 2. Perform the following substeps to set up the T5552, as shown in figure 85.

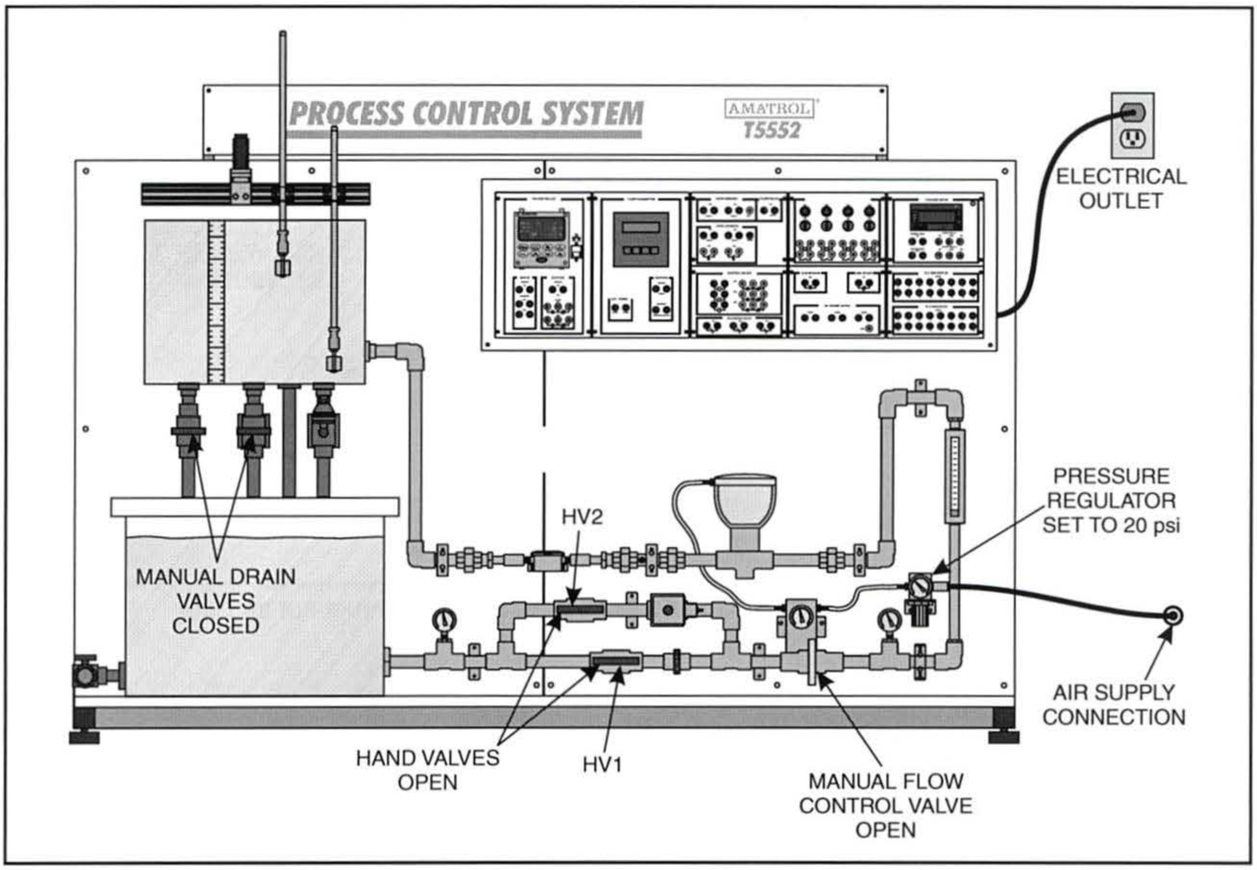

Figure 85. T5552 Setup

A. Connect the air supply line to the T5552.

B. Set the pressure regulator 20 psi.

C. Fill the reservoir tank with water.

D. Close (fully clockwise) the two manual process tank drain valves.

E. Make sure the circuit is still connected as shown in figure 86. If it is not, reconnect it.

This circuit allows you to operate a closed loop level control system.

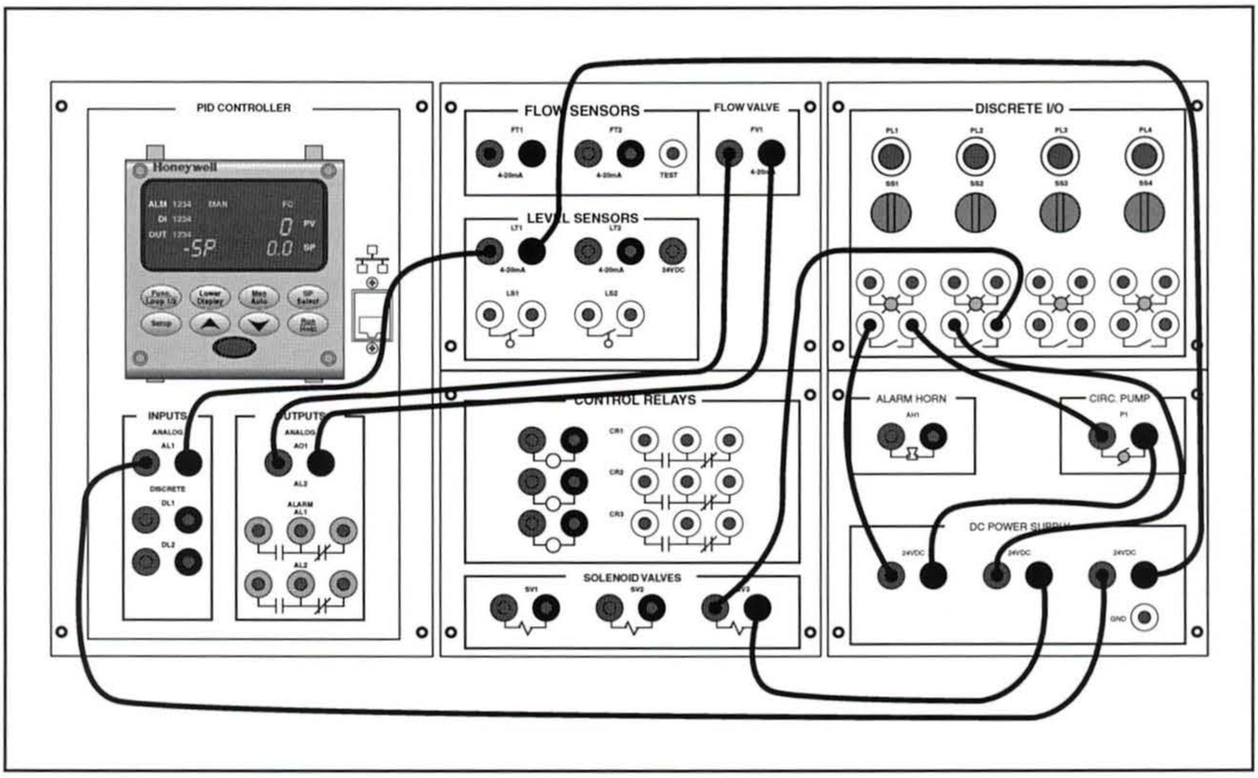

Figure 86. Connections for Closed Loop Level Control

Figure 87 shows the P&ID for the T5552. The active components and wiring are highlighted.

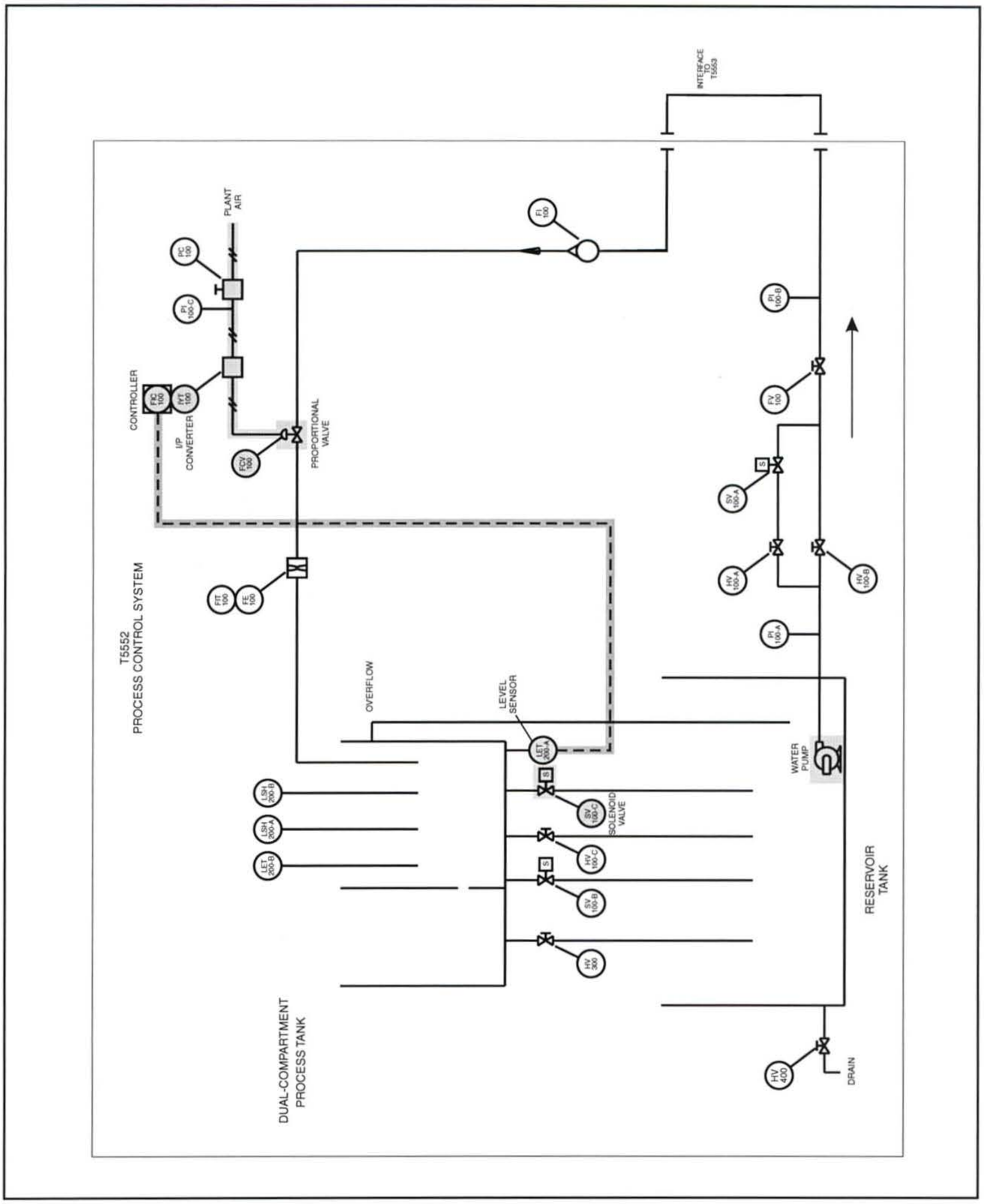

Figure 87. T5552 P&ID

❑ 3. Remove the lockout/tagout.

❑ 4. Perform the following substeps to start up and set the controller for proportional-integral-derivative (PID) control.

A. Turn on the main circuit breaker and allow the controller to complete its diagnostic test.

B. Use the **Lower Display** key repeatedly to scroll through the values until the set point value is displayed.

C. Press the up ▲ and down keys ▼ to change the set point value to **5.00**.

D. Program the controller according to the parameters listed in the table.

SETUP GROUP	PARAMETER	SETTING
INPUT 1	IN1 TYPE	1-5 V
	XMITTER 1	LINEAR
	IN1 HIGH	27.7
	IN1 LOW	0.0
	BIAS IN1	-1.6
	FILTER 1	1
CONTROL	PB or GAIN	GAIN
	MIN or RPM	MIN
	ACTION	DIRECT
ALGORITHM	CONT ALG	PID A
TUNING	GAIN	30.0
	RATE MIN	1.5
	RSET MIN	0.25

E. Press the **Lower Display** key to exit the setup menu.

F. Switch the controller to the automatic mode by pressing the **Man/Auto** key.

When the controller is in the automatic mode, an A appears in the upper left portion of the display.

❑ 5. Perform the following substeps to control the process using proportional-integral-derivative (PID) control and observe how long it takes to bring the process under control after a disturbance.

During the process, you will record the displayed PV every five seconds until the process is steady. This will allow you to later plot the response of the system for different settings.

A. Start the circulation pump (**SS1** is in the **ON** position).

B. Open the solenoid drain valve (**SS2** in the **ON** position).

C. When the controller makes the first adjustment to the output, record the PV value every five seconds until the system becomes steady. Record your readings in a table similar to the one shown in figure 88.

This will take several minutes.

PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 88. PV Table

D. Once you have taken your readings, close the solenoid drain valve (SS2 off) and turn off the pump (SS1 off).

E. Open the process tank manual drain valves to drain the tank. When the tank is empty close the valves.

F. Change the proportional gain setting to **40**.

G. Change the derivative (rate) setting to **2.0**.

This equates to 2 minutes.

H. Change the integral (reset) setting to **0.1**.

I. Turn on the pump (SS1 on), open the solenoid drain valve (SS2 on), and repeat substep 5C for the new settings.

PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 89. PV Table

J. Once you have taken your readings, close the solenoid drain and turn off the pump.

K. Open the process tank manual drain valves to drain the tank. When the tank is empty, close the valves.

L. Change the derivative (rate) setting to **0.1**.

This equates to 6 seconds (1/10 of a minute).

M. Turn on the pump, open the solenoid drain valve, and repeat substep 5C for the new derivative setting.

PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL RESPONSE							
TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING	TIME (seconds)	PV READING
0		75		150		225	
5		80		155		230	
10		85		160		235	
15		90		165		240	
20		95		170		245	
25		100		175		250	
30		105		180		255	
35		110		185		260	
40		115		190		265	
45		120		195		270	
50		125		200		275	
55		130		205		280	
60		135		210		285	
65		140		215		290	
70		145		220		295	

Figure 90. PV Table

❑ 6. Perform the following substeps to shut down the T5552.

A. Place selector switch **SS1** in the **OFF** position (up).

This stops the circulation pump.

B. Place selector switch **SS2** in the **OFF** position (up).

This closes the drain solenoid valve.

C. Press the **Man/Auto** key on the controller to switch the controller to the manual mode.

D. Open both of the manual drain valves on the process tank to completely drain the tank. When the tank is empty, close both valves.

E. Turn off the main circuit breaker.

F. Disconnect the control circuit.

❑ 7. Perform the following substeps to plot the response of the system for each of the derivative settings.

A. Create a graph of PV vs. time, similar to figure 91, on a piece of graph paper.

You will use this to plot the response of the system for all of the PID settings in this skill.

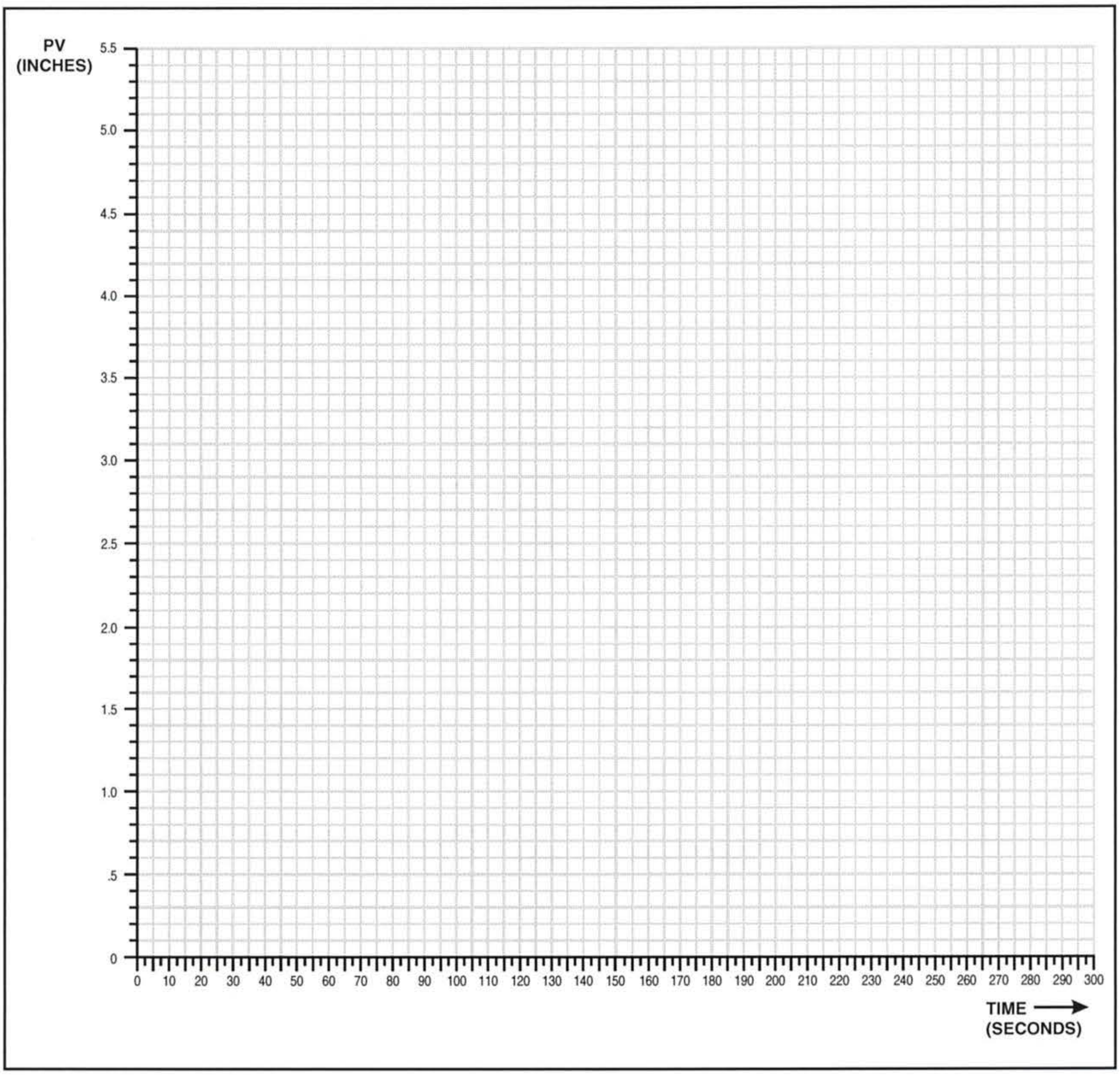

Figure 91. Graph of PV vs. Time

B. Plot the response of the system using the data you collected in step 5C.

C. Create another graph of PV vs. time on a different piece of graph paper.

D. Plot the response of the system using the data you collected in step 5I.

You should notice that the system responds faster with no offset.

E. Create a third graph of PV vs. time on another piece of graph paper.

F. Plot the response of the system using the data you collected in step 5M.

The ideal response of system using PID control should resemble the output shown in figure 92. Compare your results to this response curve.

Ideally, there should be limited overshoot and no offset.

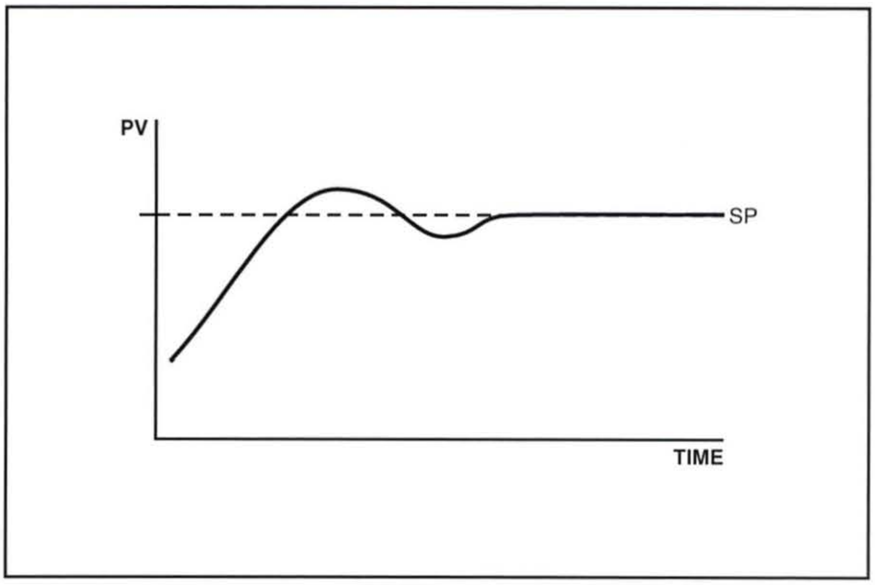

Figure 92. Ideal Response for PID Control

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, which are typically slow to react.

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 _______ that smooths out step changes in error.

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

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

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

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