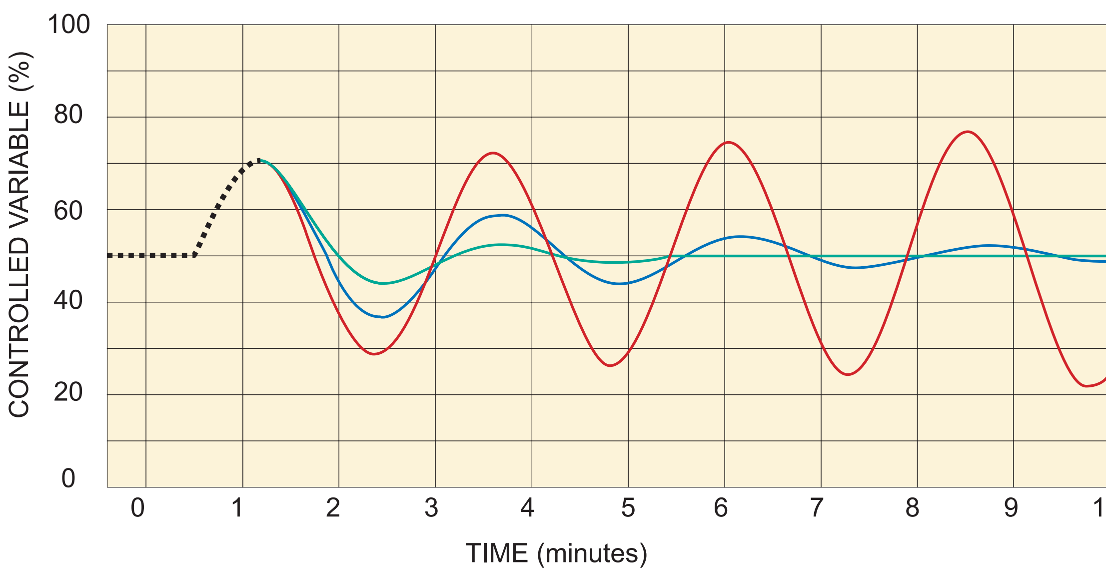
Training Module

Describe Process Control Modes and Process Control Technology



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- Training Module and Self-Check
- Blank Answer Sheet
- Knowledge Check and Answer Key

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HDC Human Development Consultants Ltd.

Website: **www.hdc.ca**
E-mail: **marketing@hdc.ca**
Phone: **(780) 463-3909**

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Contents

Contents (continued)

Prerequisite—Describe Basic Instrumentation and Process Control Strategies

Training Objectives

Upon completion of this training kit, you will be able to:

- Describe feedback control modes and their effect on process response
- Describe the applications of feedback control modes
- Describe the role of operations personnel in tuning controllers
- Describe the purpose and importance of automatic and manual process control
- Describe the features of pneumatic, electronic, and computer-based single control loops
- Describe the role of operations personnel in monitoring single control loops
- Describe the purpose and importance of plantwide control
- Describe the role of operations personnel in monitoring plantwide process operations

1 Introduction

Process control loop strategies (feedback control, feedforward control, feedback-feedforward control, and cascade control) were described in the training kit *Describe Basic Instrumentation and Control Strategies*. This training kit *(Describe Process Control Modes and Process Control Technology)* describes three feedback control modes and process control loop technology.

In the past, process industries made widespread use of feedback control loops. Today, feedback control continues to be widely used because of the corrective action flexibility offered by its three control modes (proportional, integral, and derivative). Each control mode responds differently to error and gives a specific type of corrective action response.

Early feedback control loops that appeared more than 50 years ago were completely pneumatic systems. Over the years, single process control loops evolved: pneumatic systems gave way to electronic systems. Then, in turn, electronic systems gave way to microprocessor technology.

Competition in the process industries has demanded that process facilities operate with improved efficiency, with greater accuracy of production, and with lower operating costs. This competition, together with the introduction of the computer into process control, has driven changes in plantwide monitoring and control of process operations. With plantwide monitoring and control, operations personnel can monitor plant operations and individual control loops from a centralized location. At the same time, computer-generated optimization decisions are automatically implemented to maintain peak process efficiency.

In the process industries, newer process control technology has not eliminated older generation control. Because newer control technology does not automatically provide better control, companies may not replace older generation process controls until a cost-benefit analysis demonstrates a clear payback of installing newer technology. To achieve maximum benefits when newer process control technology is installed, the newer control systems must be customized to specific process applications.

This module describes:

- the three feedback control modes (proportional, integral, and derivative)
- the effect of the feedback control modes on the control response to error. (Each mode responds to error differently to give a specific type of corrective action response).
- the methods used to tune a feedback controller to produce a good, prompt response to errors
- the evolution of single loop controllers from pneumatic to microprocessor-based
- the role of operations personnel in monitoring the performance of single control loops

- the evolution and type of plantwide control systems
- the role of operations personnel in monitoring plantwide process operations

2 Feedback Control Modes

A feedback controller responds to disturbance-induced errors by issuing a corrective output signal to its final control element (typically a control valve) so that the controlled variable is restored to setpoint. If the process controls allow a controlled variable to deviate too far above or below setpoint, the following losses to personnel, equipment, the environment, and the business operation can result:

- the safe operation of the process may be impaired
- the outlet products from the process may not meet stringent sales specifications and therefore may be non-marketable or of lower sales value
- the production of off-spec products could trigger the production of unwanted chemical by-products, process equipment damage, and environmental contamination
- the off-spec products from the process may upset the steady operation of downstream processes and trigger costly downtime

For process controllers, control modes determine the relationship between the error and the size of the corrective action output signal. Control modes define the numerical relationship between error and the corrective action output signal sent to the final control element.

This section describes the following control modes:

- proportional control
- integral control (also known as reset control)
- derivative control (also known as rate control)

NOTE

In the following sections that describe proportional, integral, and derivative control, the term *control valve* has been used instead of the more generic term final control element. Using the more specific term (i.e., *control valve*) allows more concrete descriptions. In addition, most final control elements used in the process industries *are* control valves.

NOTE

A common abbreviation for Proportional, Integral, and Derivative control is *PID* control. This abbreviation should not be mistaken for the *P&ID* abbreviation for Piping and Instrumentation Drawings.

2.1 Proportional Mode

Proportional control is the feedback control mode where the size of the corrective action output signal is directly proportional to the size of the error that is currently present.

NOTE

error currently present = setpoint – controlled variable's present value

With proportional control, the position of the control valve (as modulated by the corrective action output signal) is proportional to the error currently present. The ratio (of the corrective action output signal to the present error) determines how aggressively proportional control works to reduce error:

- when the ratio is large, the corrective action for a given error is larger
- when the ratio is small, the corrective action for a given error is smaller

There are two ways of expressing how aggressively proportional control works to reduce error:

- gain
- proportional band (PB)

Gain

Gain is the ratio by which an error signal is amplified into a corrective action output signal in order to position a control valve.

Gain is defined as follows:

$$\text{Gain} = \frac{\text{position change at control valve (in percent)}}{\text{percentage error}}$$

In the above gain description, the two percentages are described as follows:

- position change at control valve (in percent)—for a pneumatic control valve, a final control element position of 0% means that the valve is at minimum stroke position, 50% means mid-stroke position, and 100% means maximum stroke position. For the gain equation, a change in a control valve's stroke position from 30% to 90% represents a 60% position change (90% – 30% = 60%)
- percentage error—the present error expressed as a percentage:

$$\text{percentage error} = \frac{\text{setpoint – controlled variable's present value}}{\text{control range}} \times 100\%$$

NOTE

Control range is the measurement range of the primary element. The primary element is designed to accurately measure the controlled variable only within a given range. (Control range is also known as the *span of measurement.*)

The setpoint is within the control range. The setpoint is often set at the midpoint of the primary element's control range so that an equal amount of accurate measuring capability is available above and below setpoint.

PROPORTIONAL CONTROLLER OPERATING EXAMPLE

For example, a proportional pressure controller is operating as follows:

- the gain is set to 3
- the control valve is initially at the 28% stroke position
- the pressure setpoint is 46 psig
- the controlled variable's present value is 43.5 psig
- the primary element's control range is 60 psig

Given that the controlled variable is not at setpoint, the final position of the controlled variable can be determined as follows:

- the current error is **2.5 psig** *(46 psig setpoint – 43.5 psig present value)*
- the percentage error present is **4.17%** *(2.5 psig error ÷ 60 psig control range)*
- the proportional action will move the control valve by **12.5%** *(4.17% percent error x gain of 3)*. The control valve moves by a factor of 3 in comparison to the percentage error present.
- the final stroke position of the control valve is **40.5%** *(28% starting stroke position + 12.5% stroke position change)*

Proportional Band

In addition to gain, the concept of proportional band (PB) can be used to define the aggressiveness of proportional control. Proportional band is the inverse of gain. Proportional band is described by the following equation:

$$\text{Proportional Band} = \frac{\text{percentage error present}}{\text{position change at control valve (in percent)}} \times 100\%$$

In the above equation, the percentages are defined as in section 2.1.1.

Gain and proportional band are related:

$$\text{Proportional Band} = \frac{100\%}{\text{Gain}}$$

Using the same input and output variables, there is a more common method of describing proportional band. Proportional band is the percentage of the control range by which the controlled variable must change in order to cause the control valve to modulate fully from the minimum to maximum stroke position:

$$\text{Proportional Band} = \frac{\text{portion of control range in use that fully modulates control valve}}{\text{full control range}} \times 100\%$$

PROPORTIONAL CONTROLLER OPERATING EXAMPLE

As a continuation of the example presented in section 2.1.1:

- the proportional band is **33.3%** *(100% ÷ gain of 3)*
- with a 33.3% proportional band in conjunction with a 60 psig control range, the control valve moves fully from 0% to 100% stroke position over a range of **20 psig** *(20 psig ÷ 60 psig = 33.3% proportional band).* Only 20 psig of the primary element's 60 psig control range is used to fully modulate the control valve.

Proportional Control Behavior

A controller equipped only for proportional mode control **cannot** restore a controlled variable to setpoint. When a disturbance occurs, proportional control tries to restore the controlled variable to setpoint. However, the controlled variable stabilizes at a value different from the setpoint by an amount known as the offset (as described in Appendix 1 at the end of this module).

NOTE

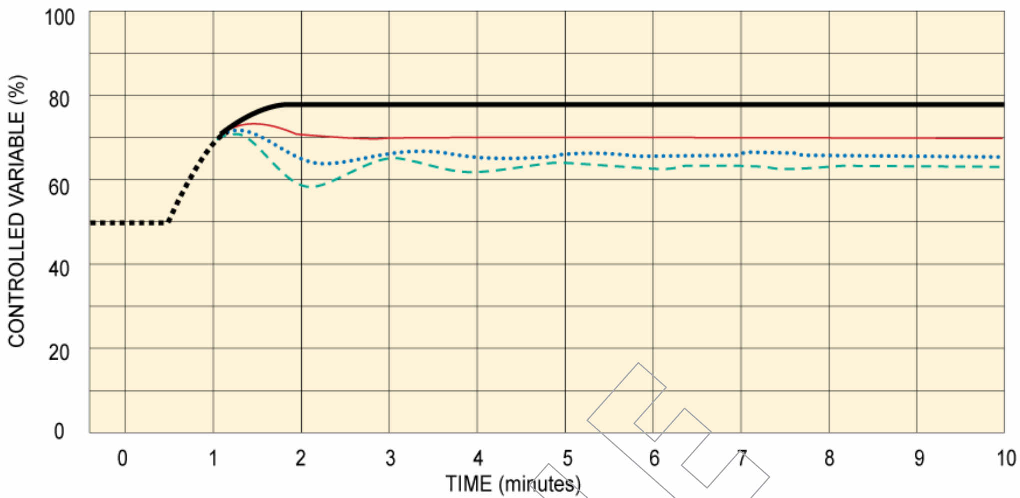
A moderate amount of offset can be tolerated for some control loops.

As shown in Figure 1, if a proportional mode controller is set with a low gain (i.e., wide proportional band), the control loop is more stable but less sensitive to errors. With a low gain, the controller counters the disturbance with less aggressive corrective control valve action:

- The controlled variable will stabilize at a large offset.
- The controlled variable experiences less (if any) oscillations.

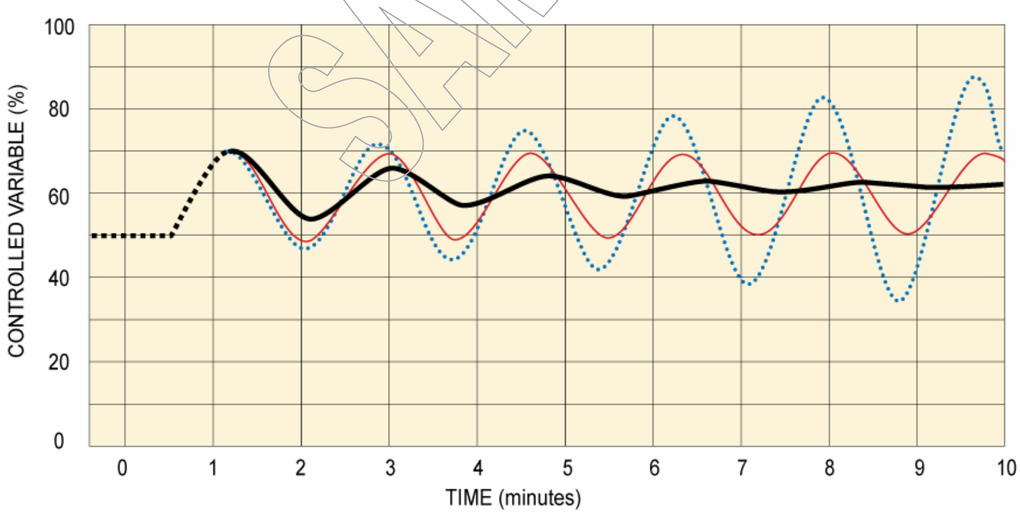
Figure 1—Proportional Control Behavior

These 2 drawings progressively show how a controlled variable changes in response to proportional control for an example process where the controller has a setpoint of 50% and a sudden load disturbance occurs.



In drawing 1 above:

- the black (*thick, solid)* line shows that with a low gain, the response of the controlled variable is slow but stable. The controlled variable stabilizes at a high offset (i.e., a final value of 78% as compared to the 50% setpoint)
- the red (*thin, solid)*, blue (*thin, dotted)*, and green (*thin, dashed)* lines show that as gain rises, the response is more aggressive. Oscillations begin but the offset is lower.



Drawing 2 above shows the effects of even higher gain:

- the black (*thick, solid)* line shows that with higher gain, the controlled variable begins to oscillate more heavily (but the oscillations gradually reduce)
- increasing gain eventually results in the red (*thin, solid)* line where the controlled variable is in a perfect oscillation
- increasing gain further makes the process unstable (the blue (*thin, dotted)* line). The controlled variable is driven by the overly-aggressive controller into ever-increasing oscillations.

If a proportional mode controller is set with a high gain (narrow proportional band), the control loop is less stable but is much more responsive and sensitive to errors. The controller counters the disturbance with more aggressive corrective control valve action:

- The controlled variable will stabilize at a small offset.
- The controlled variable experiences more oscillations.

For a proportional controller, setting the gain too high (proportional band too low) makes the control loop too sensitive to errors. This over-sensitivity results in an unstable control loop: even small errors trigger the controller to respond with severe over-corrections—the controlled variable cycles in ever-increasing oscillations.

2.2 Integral (Reset) Mode

Integral (or reset) control is the feedback control mode where *the size of the corrective action output signal is based on the magnitude and duration of the error. Integral control can also be described as follows: the speed (rate) at which the corrective action output signal changes is proportional to the error.*

Integral control is able to continuously apply a corrective control action that is based on the magnitude of the error currently present and the incremental time the error has persisted.

End of Sample

A full licensed copy of this kit includes:
• Training Module and Self-Check
• Knowledge Check and Answer Key
• Blank Answer Sheet