# A Process Control Primer

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# About This Publication

The automatic control of industrial processes is a broad subject, with roots in a wide range of engineering and scientific fields. There is really no shortcut to an expert understanding of the subject, and any attempt to condense the subject into a single short set of notes, such as is presented in this primer, can at best serve only as an introduction.

However, there are many people who do not need to become experts, but do need enough knowledge of the basics to be able to operate and maintain process equipment competently and efficiently. This material may hopefully serve as a stimulus for further reading and study.

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# Table of Contents

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# Figures and Tables, continued

# Chapter 1 – Introduction to Process Control

## 1.1 Overview

### What's in this chapter

This chapter contains the following information:

### Introduction

The type of control to be discussed is the kind involved in the so-called "Process Industries", such as chemicals, petroleum, metals, paper, textiles, food, and water management.

Examples are the refining of crude oil into fuel oils and gasoline; the conversion of wood pulp into paper; the extraction of metals from ores; the heat treating of metals; the production of glass; and the processing of municipal and industrial water supplies.

### Processes

Since the type of equipment we will discuss is the kind used in the measurement and control of industrial processes, identification of these processes will aid our understanding of what this equipment is and what its purposes are.

Processes involve the handling of large quantities of raw materials in a continuous or semi-continuous (batch) stream, modifying the raw materials through either chemical or mechanical changes to make a product that has more value than the original materials.

### Physical quantities

The measurement and control of such physical quantities as Pressure, Flow, Temperature, and Liquid Level are subjects with which we will be dealing.

The physical quantities we measure and control are known as "Process Variables", often abbreviated PV.

# 1.2 Control Systems

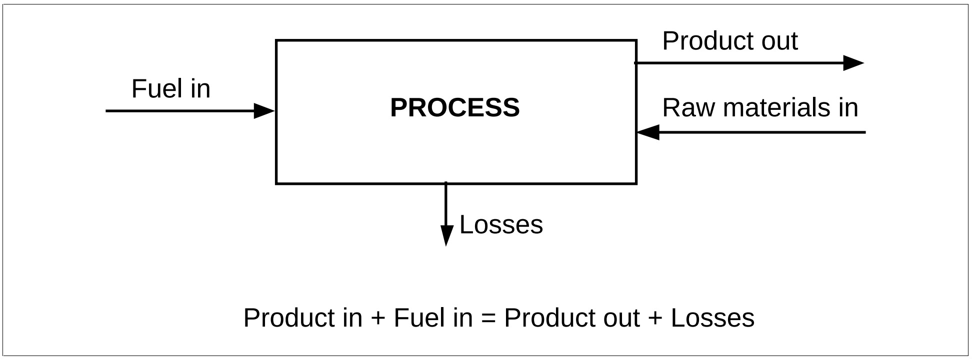
**Why is control necessary?**

Among other things, a process is a system for the transfer of energy. Whenever the distribution of energy is modified or disturbed, the variables in the system will change value. It is usually difficult to measure energy directly, but we can use variables that are more readily measured, such as Temperature, Pressure, and Flow.

When these measured variables change in a process, we know that the energy distribution has changed somewhere. Important to us is the fact that the product will also change and may become off-specification. That is, its quality may deteriorate.

Automatic control becomes necessary whenever energy changes may be expected that are large enough to push the measured variable outside it allowable tolerance. Figure 1-1 shows a typical process energy flow.

Figure 1-1 Process Energy Flow



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**Disturbances**

These energy variations are called disturbances, upsets, or load changes. We can classify possible disturbances into four categories.

Table 1-1 lists these disturbances and their definitions.

Table 1-1 Control Disturbances

| Disturbance | Definition |
|---|---|
| **Change in Setpoint** | The setpoint is the desired value of the measured variable. Its value establishes the level of energy flow in steady state conditions. Any change in its setting will require a completely new energy picture. For instance, a higher temperature for the product out will require the control system to provide a higher rate of fuel flow. |
| **Change in Supply** | This is a variation in any of the energy inputs to the process. A variation in the supply pressure of the fuel, for instance, or a variation in the temperature of the raw materials, would be supply changes. |
| **Change in Demand** | This is a disturbance in the output flow of energy. The most common source of such a disturbance is a change in the production rate itself. If the front office asks for more output and the production rate is increased, the energy would certainly have to be increased. |
| **Environmental Changes** | Ambient temperature or atmospheric pressure also affect the energy balance. If the equipment is outdoors, the wind velocity and direction may also play a part in altering these energy requirements. |

# 1.3 Feedback Control Loop

**Overview**

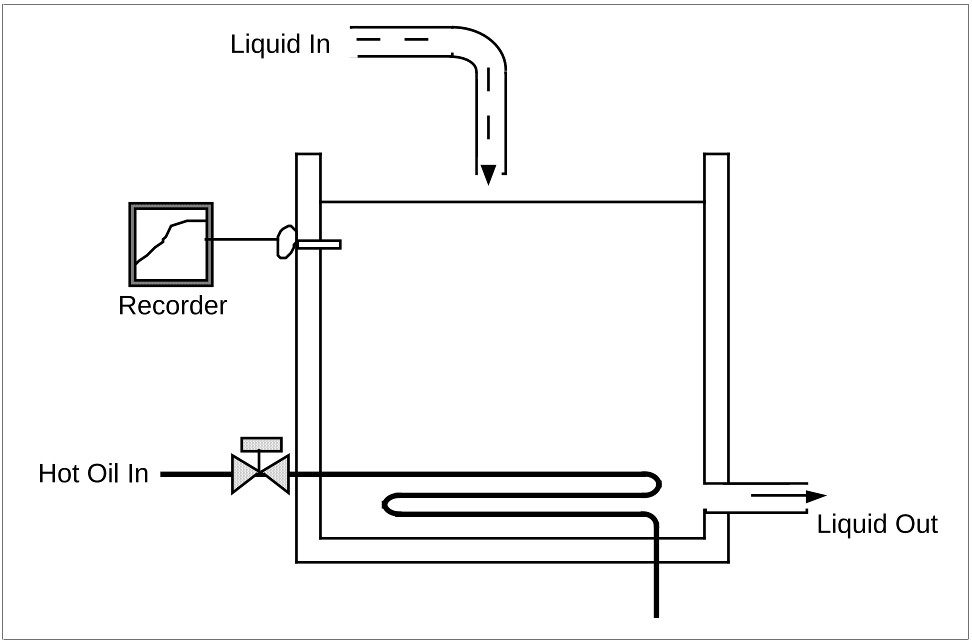
In the process industries, control systems were put to practical use long before the theory of their operation or methods of analyzing their performance were available. Processes and control systems were determined by intuition and accumulated experience. This approach, unscientific as it was, was successful.

Tolerance to the intuitive approach is diminishing today, but it is still a valid way to obtain knowledge of the basics of the subject, so we'll start by considering a simple process and the way a human operator might handle its control.

**Process heater example**

Suppose there exists a process such as shown in Figure 1-2.

Figure 1-2 Process Heater



A source of liquid flows into the tank at a varying flow rate. There is a need to heat this liquid to a certain temperature. To do this, there is hot oil available from another part of the plant that flows through coils in the tank and heats the liquid.

By controlling the flow of the hot oil, we can obtain the desired temperature. The temperature in the tank is measured and read out on a recorder mounted within the view of the valve on the hot oil line.

The operator has been told to keep the temperature at a desired value (SETPOINT) of 300°. He compares the reading on the recorder with this mental target and decides what he must do with the valve to try to bring the temperature of the liquid to the desired value (setpoint). In reading the actual value of the temperature and mentally comparing it with the desired value, the operator is providing FEEDBACK.

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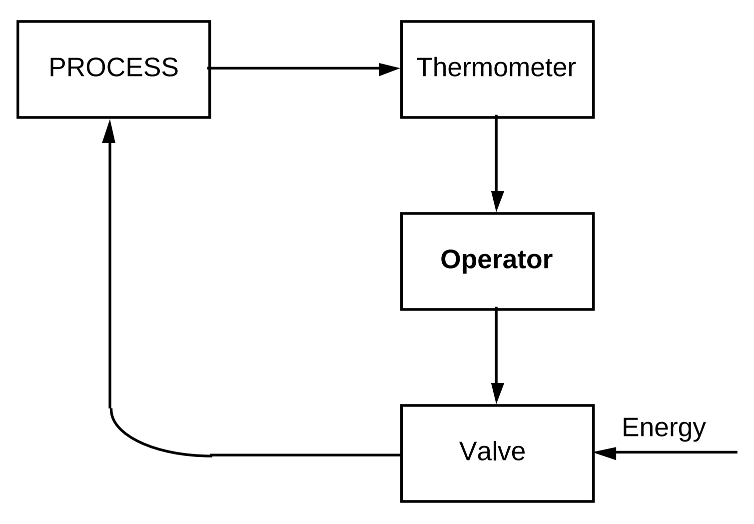
**Block diagram of system with operator**

Figure 1-3 is a block diagram of this system, including the operator, and shows the flow of information between components.

Figure 1-3 Block diagram of system with operator



This is not a very detailed block diagram, but we can see here an interesting feature of this type of control - information flows in a loop.

The operator, to be sure, is a part of the loop, so it is not automatic control, but it is *Closed Loop Control*. or *Feedback control*, because the results are measured, compared to the desired results, and the valve is manipulated accordingly.

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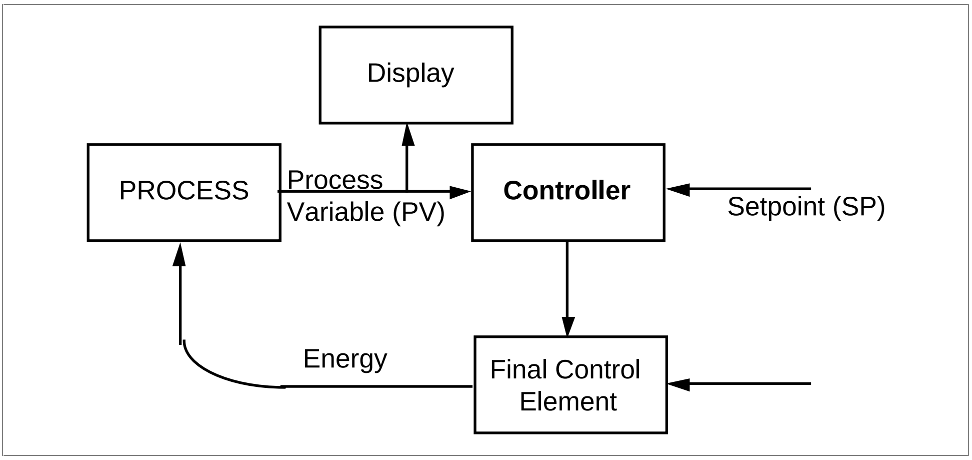
**System with automatic control**

If we wish to replace the operator with an automatic system, we will need a device that will compare the measured variable with the desired value (setpoint) and initiate control action according to what this comparison shows.

Figure 1-4 shows a control loop with such a device.

Figure 1-4 Block Diagram of System with Automatic Controller



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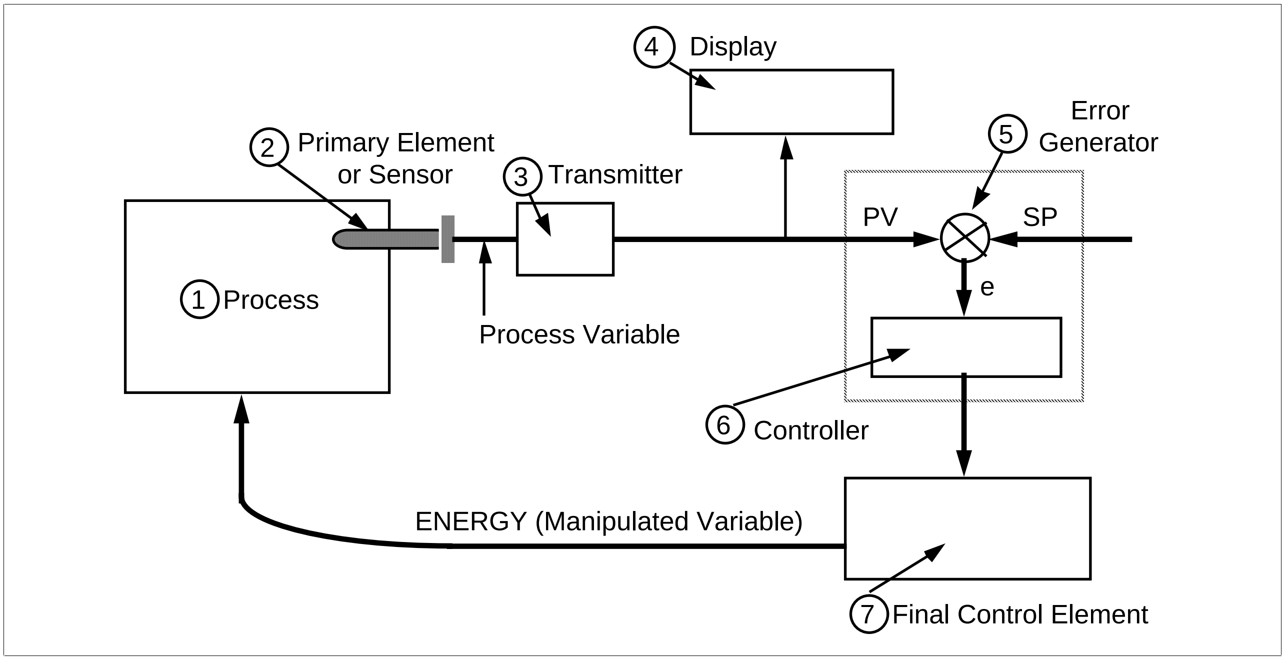
**Definition of components of a feedback control loop**

Every new technical field starts out with a language barrier of sorts. Words perfectly familiar in one field suddenly take on a new meaning in another. So, it becomes necessary from time to time to establish some definitions.

Figure 1-5 shows the components of a *feedback control* loop. This a more "hardware" oriented version of Figure 1-4.

Table 1-2 defines each of the components.

Figure 1-5 Feedback Control Loop Components



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**Definition of components of a feedback control loop, continued**

Table 1-2 Component Definition

| Key | Component | Definition |
|---|---|---|
| 1 | **Process** | The manipulation of raw materials to derive a more valuable product. |
| 2 | **Primary Element or Sensor** | A device that converts the Process Variable (PV) energy into a measurable form.<br>Examples: Thermocouple; Orifice Plate; Bourdon Tube; Float; Filled Thermal System.<br>*PV = The variable being measured and controlled* |
| 3 | **Transmitter (Optional)** | Changes the value of the Process Variable into a standard signal for transmitting over distances. |
| 4 | **Display (Optional)** | Shows the value of PV and Setpoint; or sometimes Setpoint and Deviation. |
| 5 | **Error Generator** | Detects the difference between the SETPOINT and PROCESS VARIABLE. It can be mechanical, pneumatic, or electric.<br>The **difference** between the *Setpoint* and *Process Variable* is called the **ERROR** or **DEVIATION**.<br>Note: In the actual hardware, sometimes the error generator is incorporated as part of the controller, and sometimes it is a separate unit. |
| 6 | **Controller** | A logic device that changes its output in accordance with the error signal it receives from the Error Generator.<br>The manner in which it changes its output is built into it through a system of logic called *Modes of Control.*<br>Information that the controller needs from the error generator is:<br>• Polarity (sign) of the error<br>• Size of the error<br>• Rate of change of the error |
| 7 | **Final Control Element** | This is the element which directly changes the value of the manipulated variable.<br>Examples:<br>• Pneumatic diaphragm valve<br>• Motorized valve<br>• Contactor<br>• Silicon Controlled Rectifier(SCR)<br>• Rheostat |

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**Closed Loop versus Open Loop**

The notion of **FEEDBACK** is crucial to automatic control. Unless the results of the control manipulations can be compared against objectives, there is no way to arrive at a logical control strategy.

When feedback exists, the system is said to be operating in a **CLOSED LOOP** fashion.

Sometimes, control systems operate on information not directly obtained from the Process Variable.

For example:
If the liquid level in a tank were to be controlled, it would be feasible to do so just by adjusting the output flow in proportion to the input flow. There is no closed loop with respect to liquid level; just a relationship between a flow and a valve position which indirectly, but not infallibly, establishes a level.

When a quantity is being controlled indirectly in this fashion, it is considered to be **OPEN LOOP** control.

# Chapter 2 – Process Characteristics

## 2.1 Overview

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**What's in this chapter?**

This chapter contains the following information:

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**Introduction**

To an automatic controller, everything surrounding it in the loop looks like the process. This embraces instrumentation external to the controller as well as the components of the process itself.

**The instrumentation**

The instrumentation is made up of the primary elements, transmitters, transmission systems and final control elements, etc. The instrumentation will be discussed later. Its effect on the controller is predictable, and in some cases, adjustable.

**The process**

The process consists of piping, vessels, reactors, furnaces, distillation columns, etc.: in general, the equipment in which mass, heat, and energy transfer takes place.

Each process is highly individualistic in its effect upon its control.

The effects from the process are, moreover the dominant ones, and in many cases impractical to change or adjust.

**Two effects for consideration**

Every process exhibits two effects which must be taken into consideration when automatic control equipment is being selected. These are:

- changes in the controlled variable due to altered conditions in the process, generally called ***load changes,*** and
- the delay in the time it takes the process to react to a change in the energy balance, called ***process lag***.

Load changes have been noted earlier, just enough to define and categorize them according to their source, but here we will look at them in more detail.

In order to discuss the subject further, we must first define just what “Process Load” is.

## 2.2 Process Load

**Definition**

PROCESS LOAD is the total amount of control agent (energy) required by a process at any one time to maintain a balanced condition.

In a heat exchanger, for example, in which a flowing liquid is continuously heated with steam (the control agent), a certain quantity of steam is required to hold the temperature of the fluid at a given value when the fluid is flowing at a particular rate. This is the *Process Load*.

**Effect on the final control element**

Process load is directly related to the setting of the final control element.

Any change in process load requires a change in the position of the final control element in order to keep the controlled variable at the setpoint.

What changes the position of the final control element?

*The Controller does.*

**Properties of load changes**

The two prime properties of load changes which need to be considered in the application of automatic controllers are:

1 - the **size** of the load change
2 - the **rate** of the load change

Load changes in a process are not always easy to recognize.

Table 2-1 gives some examples of load changes.

Table 2-1 Examples of Load Changes

| Load Change Example | Reason |
|---|---|
| **Greater or less demand for control agent by the controlled medium** | In the heat exchanger cited above, a change in the rate of flow of the fluid to be heated, or a change in the temperature of the incoming fluid, contribute load changes because a change in the quantity of steam is needed for either.<br>Similarly, when a carload of bricks is added to a kiln, or when new material is added to a cooking vessel, there is a *load change*. |
| **A change in the quality on the control agent** | If a gas heated process is operating at a certain temperature and the BTU content of the fuel gas changes, then more or less gas must be burned to maintain the same temperature, even though nothing else changes. Changes in steam pressure also result in *load changes*. |
| **Changes in ambient conditions** | These are especially significant in outdoor installations where heat loss from radiation may be large. |
| **If a chemical reaction will cause heat to be generated (exothermic) or absorbed (endothermic)** | This is also a *load change* because the position of the final control element must be adjusted to compensate for this generation or absorption of energy. |
| **If the setpoint were changed** | This would obviously require a change in the amount of energy input to the process. |

## 2.3 Process Lags

**What are they?**

If we could have it our way, any load change or disturbance would be met with an instantaneous response that would completely and immediately bring the process to its new condition of equilibrium.

This, however, is difficult, if not impossible to achieve in any physical system.

The response may start immediately, but it will require a certain amount of time to complete its effect.

The delay is the *Lag of the System.*

**Example**

Suppose we have a valve in a pipe leading to a tank. If we want to raise the level in the tank to a new value, we will open the valve. But, the level does not immediately change to the higher value.

It may start immediately, but it will not reach the new value until some time later, a time dependent on the size and shape of the tank and the flow through the valve, among other things.

**Causes**

PROCESS LAGS are primarily the result of three PROCESS CHARACTERISTICS:

1. CAPACITANCE
2. RESISTANCE
3. DEAD TIME

## 2.4 Capacitance

**Definition**

The CAPACITANCE of a process is a measure of its ability to hold energy with respect to a unit quantity of some reference variable.

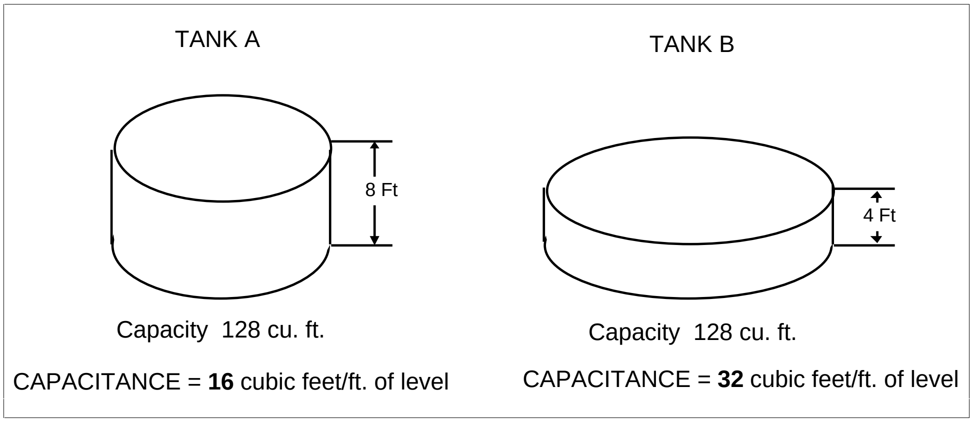
It is related to capacity but is not the same thing – two processes with the same capacity might have very different capacitances.

**Illustrations**

Some illustrations will serve to explain this concept.

First, look at the two tanks in Figure 2-1.

Figure 2-1 Capacity versus Capacitance



Although both tanks have the same liquid volume capacity (128 cu. ft.), they do not have the same capacitance with respect to liquid level.

Tank B has twice the liquid volume capacitance with respect to liquid level that tank A has: 32 cubic feet per foot versus 16 cubic feet per foot.

On the other hand, if tank A is filled with a liquid requiring 200 BTU to raise its temperature one degree F, and the liquid in tank B needs only 100 BTU, the thermal capacitance per degree F of tank B would be half that of tank A.

It is necessary to specify capacitance very precisely:

CAPACITANCE may be likened to inertia; in other words, it acts like a flywheel.

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### Principles of large capacitance

Two principles emerge relating capacitances to control in the face of load changes:

> LARGE CAPACITANCE tends to keep the controlled variable constant despite load changes.
>
> LARGE CAPACITANCE tends to make it difficult to change the variable to a new value.

### Effects of large capacitance

The overall effect of large capacitance on control is generally favorable, but it does introduce a time lag between control action and result.

When a liquid is heated in a vessel, it takes some time for the liquid to reach a higher temperature after the heat supply is increased. How much time it takes depends primarily on the thermal capacitance of the liquid relative to the heat supply.

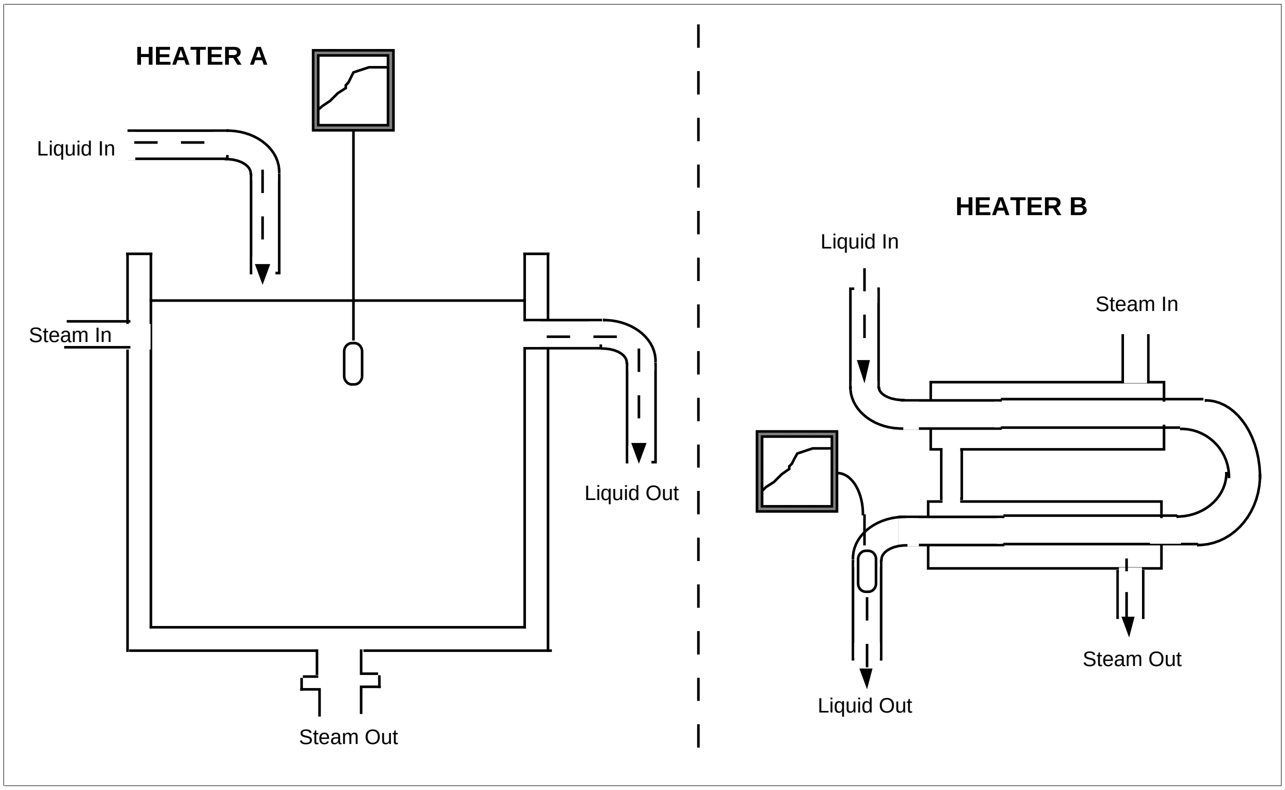
Capacitance does influence the corrective action required of an automatic controller, and so it is a major factor in the analysis of any process and control loop.

### Heater example

Look at the two heaters in Figure 2-2.

Both these heaters are used to raise the temperature of the liquid coming in.

Figure 2-2 Process Heaters



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**Heater example, continued**

In heater A, heat is applied to a jacketed vessel containing a considerable amount of liquid. The relatively large mass of the liquid exercises a stabilizing influence, and resists changes in temperature which might be caused by variation in the rate of flow, minor variations in heat input, or sudden changes in ambient temperature.

Heater B illustrates a high velocity heat exchanger. The rate of flow through this heater may be identical with that of heater A, but a comparatively small volume is flowing in the heater at any one time.

Unlike heater A, the mass of liquid is small, so there is less stabilizing influence. The total volume of liquid in the heater is small in comparison to the rate of throughput, the heat transfer area, and the heat supply.

Slight variations in the rate of feed or the rate of heat supply will be reflected almost immediately in the temperature of the liquid leaving the heater.

On the other hand, if a change in temperature of the liquid output was desired, which heater would give the most rapid change?

> Heater B would give the most rapid change if the setpoint were changed.

**Dimensional units for capacitance**

Table 2-2 lists the dimensional units for capacitance as they relate to control applications.

Table 2-2 Dimensional Units for Capacitance

| Type of Process | Dimensional Unit |
|---|---|
| Thermal | BTU/deg. |
| Volume | Cu Ft./Ft. |
| Weight | Lb/Ft. |
| Electrical | Coulomb/Volt (or Farad) |

# 2.5 Resistance

**Definition**

The second process characteristic, RESISTANCE, is best defined as "opposition to flow".

It is measured in units of the potential that is required to produce a unit change in flow.

Examples are the differential pressure required to cause a quantity of flow through a pipe or valve, or the BTU/sec required to cause a change in temperature through the wall of a heat exchanger.

**When do you see resistance**

Resistance enters the picture whenever energy is transferred from one capacity to another. In the case of a heat exchanger, there is a transfer of heat from the steam line to the fluid line. The transfer is never instantaneous, it is always resisted to some extent by components of the system.

**High thermal resistance versus low thermal resistance**

If a material is being heated in a process with high thermal resistance, it will take a large amount of control agent (energy) to change the temperature of the material than in a process with low thermal resistance.

Since it is up to the automatic controller to see that this amount of control agent is provided, the thermal resistance of a process will exert a strong influence on the proper selection of the proper controller.

**Dimensional units for resistance**

Table 2-3 lists the dimensional units for resistance as they relate to control applications.

Table 2-3 Dimensional Units for Resistance

| Type of Process | Dimensional Unit |
|---|---|
| Thermal | Deg/BTU/Sec. |
| Fluid | PSI/Cu. Ft./Sec. |
| Electrical | Volts/Coulombs/Sec. (Ohms) |

# 2.6 Dead Time

**Definition**

A third type of lag, DEAD TIME, is caused when there is time interval between the initiation of some action and the detection of the action. This is also known as TRANSPORT LAG, because often the time delay is present as a result of having to transport material that has been acted upon to a new location where the results of the action can be measured.

Mixing processes are often subject to dead time because the mixture takes a while to become homogeneous.

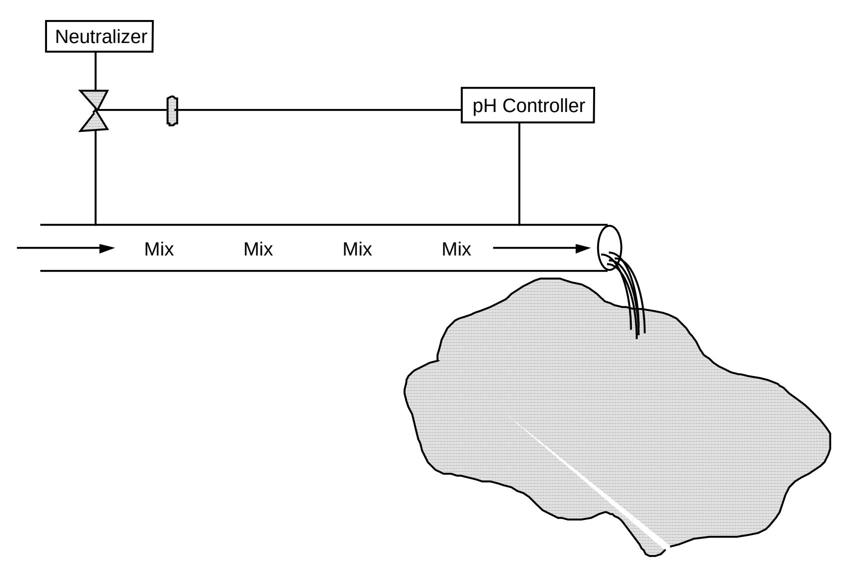
**Example of dead time**

Suppose, for example, we are concerned with the pH of water from a plant being put into a local stream.

Acid or base is added to neutralize the flow as shown in Figure 2-3. Because of the mixing required before a representative measurement of pH can be taken, there is a time delay; control action cannot take place during this delay. The controller is helpless during that time.

Figure 2-3 shows a mixing process illustrating dead time.

Figure 2-3 Mixing Process Illustrating Dead Time



**How to eliminate dead time**

Dead time introduces more difficulties in automatic control than any other lags, and every effort should be made to keep it to a minimum. Sometimes it may be possible to measure closer to the point where the process is in action.

For example, a thermometer located 50 feet downstream of the outlet from a heat exchanger may have been placed there out of convenience and could be moved closer.

In the mixing example above, it might be necessary to determine what in the incoming flow is causing the need for neutralizer to vary and keying from that with a more complex multi-loop system.

# 2.7 Process Reaction Curve

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**Introduction**

How does a given process respond to a change with all these lags involved? This is an important consideration in the application of a control system for optimum results. Although process hardware may vary considerably from process to process, it turns out that there is a limited number of ways in which signal timing is affected.

These can be realized by looking at the process output change that results from a sudden change (step change) in energy input to the process. If energy is suddenly increased, the output temperature will undoubtedly be raised in time.

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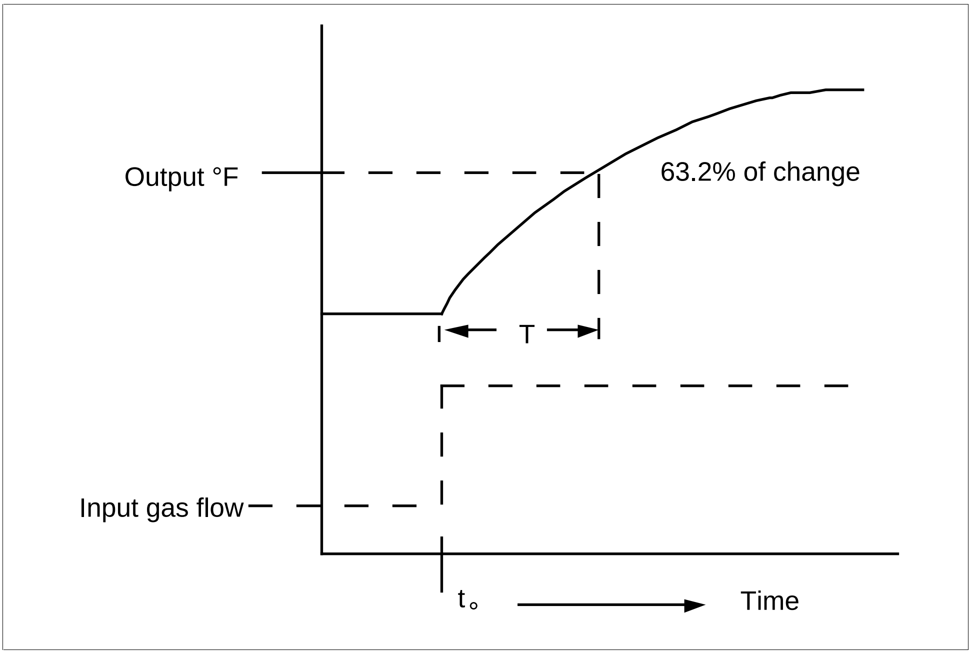
**First order lag**

Figure 2-4 shows the simplest response encountered, one called FIRST ORDER LAG. This type of response can result from liquid level in a single tank or a bare thermocouple.

Figure 2-4 First Order Lag



A first order system is characterized by being able to store energy in only one place. All first order responses are basically similar in shape but they can vary in size of output change and in the length of time required to make the change.

The size comparison between input and output is called GAIN.

The length of time is basically defined by the TIME CONSTANT, which is the time required for the variable to reach 63.2% of the distance to the final value. Also, 98% of the distance is reached in four time constants.

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**Second order lags**

SECOND ORDER LAGS are the response of a system with two places to store energy. A thermocouple in a well is an example.

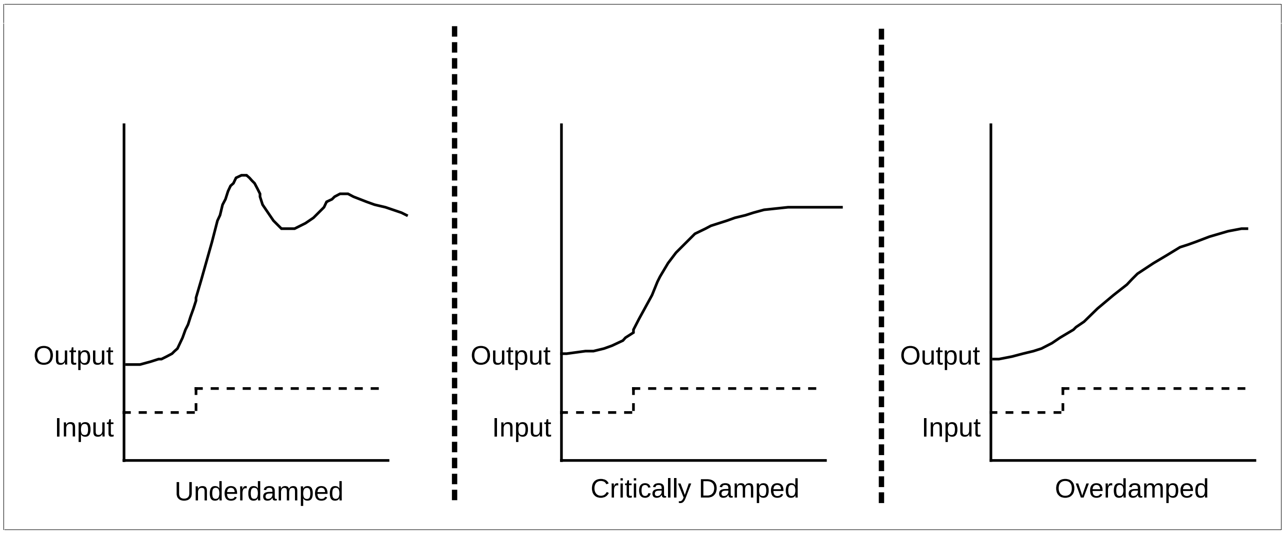
In second order lags, there is much less uniformity in the shape of the reaction curve from process to process. There are now two time constants combining to influence the curve shape in regard to time, and a new concept, the DAMPING factor which influences the curves characteristic shape.

Second order systems are capable of oscillation. This ability to oscillate is defined by two terms which characterize second order systems:

- *Natural Frequency* - the frequency at which the system will oscillate, and
- *The Damping Factor* - which describes how quickly the oscillations will die out.

Figure 2-5 shows examples of second order lags.

Figure 2-5 Second Order Lags



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**Damping factor**

The ***underdamped*** curve in Figure 2-5 shows a rapid change to the new value, but then overshooting the final value and temporary oscillation.

The ***critically damped*** curve shows the fastest rise without overshooting.

The ***overdamped*** curve shows a relatively slow rise – most processes respond this way.

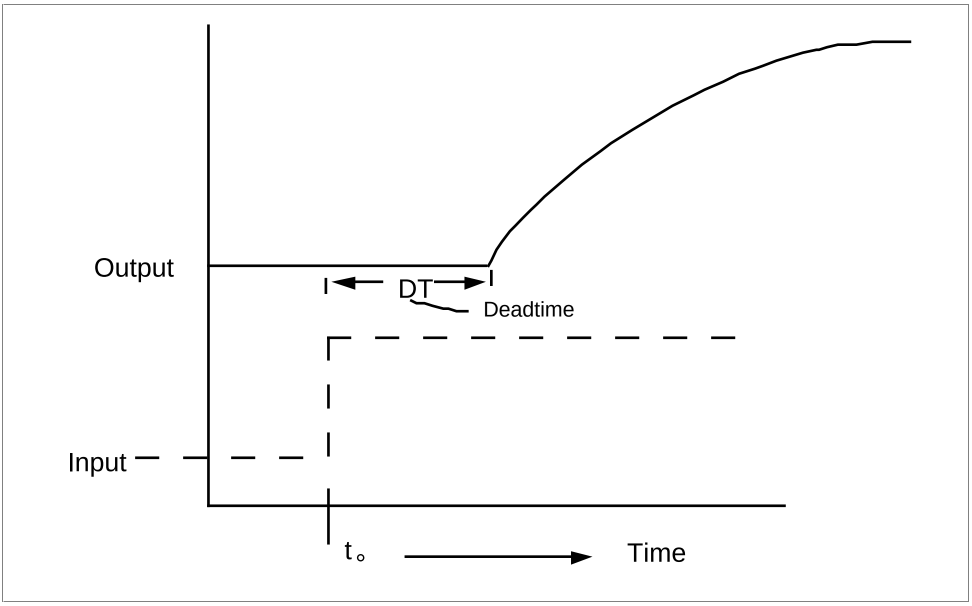
In all cases, the start of the curve is gradual.

**Dead time**

Because dead time is a condition of no response at all for a given time interval, it shows up on the reaction curve as a straight line delaying whatever other lags are present.

Figure 2-6 shows a response incorporating dead time and a first order lag.

Figure 2-6 Dead Time and a First Order Lag



# Chapter 3 – Modes Of Control

## 3.1 Overview

**What's in this chapter?**

This chapter contains the following information:

**Introduction**

In our chapter covering the feedback control loop, we defined a controller as a logic machine that changes its output in accordance with the error signal it receives from the error generator.

The change in output from the controller repositions the final control element, which, finally, adjusts the flow of energy into the process.

The manner in which the energy flow is adjusted in response to the error signal has been built into the controller through a system of logic called its

**MODE OF CONTROL**.

**Modes of control**

On the market today, there are basically four kinds of logic (or control):

- **On-Off**
- **Proportional**
- **Integral** (Reset)
- **Derivative** (Rate)

Some of these modes will appear in combination in various controllers.

# 3.2 On-Off Control

**Introduction**

The simplest mode of control is **ON-OFF**, in which the final control element has but two positions:

- Fully open (ON) and,
- Fully closed (OFF)

Another way to state this is: ON (100%) and OFF (0%)

**Example**

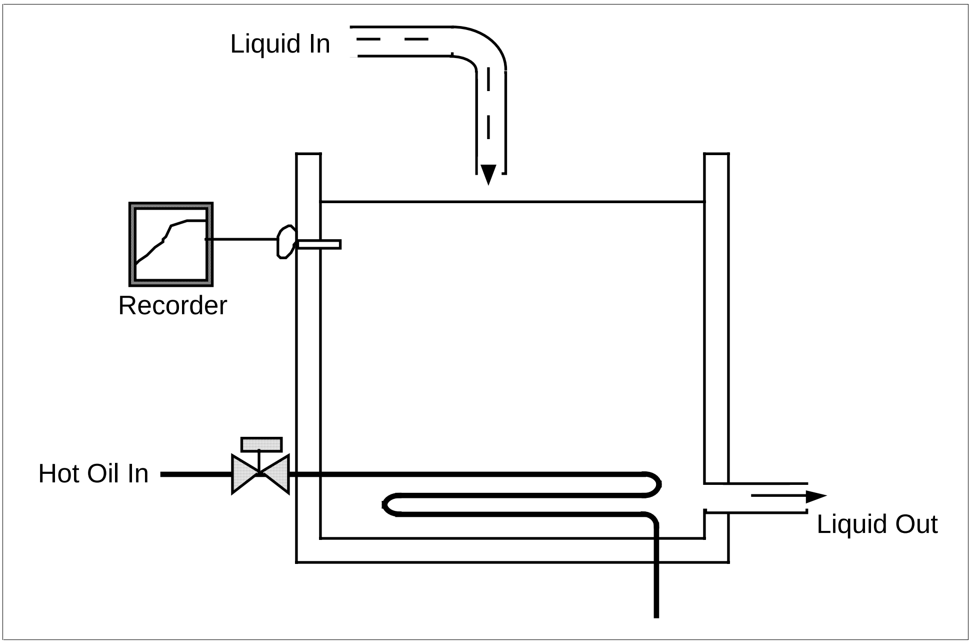
If the process shown in Figure 3-1 in which a liquid is being heated by hot oil flowing through coils, drops below the SETPOINT of 300°F, ON-OFF control would open the valve all the way (100%). This admits hot oil faster than is necessary to keep the liquid at 300°F, and as a result the liquid temperature will rise above 300°F.

When it does, ON-OFF control will close the valve all the way (0%) and stop the flow of hot oil.

With no oil flowing, the temperature of the liquid will drop, and when it drops below 300°F, the control will open the valve and the cycle will be repeated.

This cycling is an ever present feature of ON-OFF control because the only two energy input levels are TOO MUCH and TOO LITTLE.

Figure 3-1 Process Heater



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**Appeal and limitations**

The appeal of ON-OFF control lies in its simplicity. A large amount of ON-OFF control is in use.

Its principle limitation is the inevitable cycling it causes in the process.

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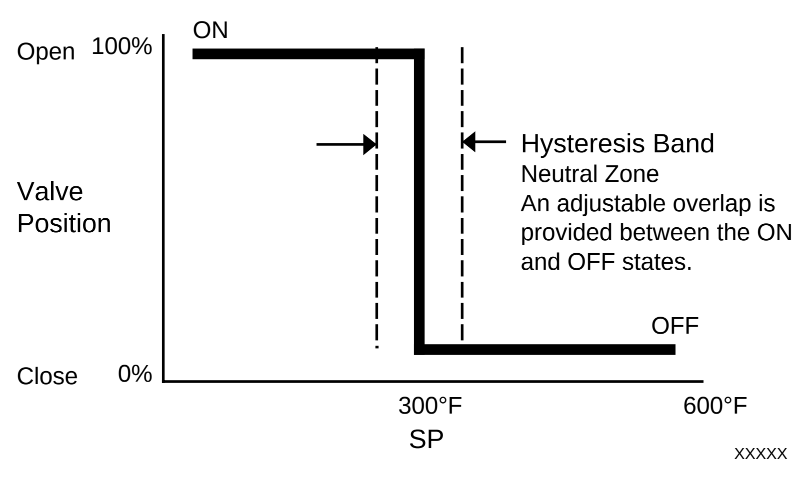
**Graphical illustration of ON-OFF control**

Graphically, ON-OFF control is illustrated as shown in Figure 3-2.

Sometimes as shown, there is a neutral zone (Hysteresis Band) around the setpoint. In other words, an overlap (can be adjustable) is provided between the ON and OFF states. This is often intentional to keep the components from wearing due to opening and closing too often.

Figure 3-2 On-Off Control Action



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**Mathematical expression**

*The control engineer analyzing this mode of control would express it mathematically as follows:*

*Let E = SP – PV*

*where*

*E = Error*
*SP = Setpoint*
*PV = Process Variable*

*Then*

*Valve Position (V) is*
*OPEN when E is +*
*CLOSED when E is –*

# 3.3 Proportional Control

**Introduction**

Since the cycling found in processes using ON-OFF control is due to the rather violent excursions between ALL and NOTHING, could we not eliminate the cycling by maintaining a steady flow of hot oil that was just sufficient to hold the temperature of the liquid at 300°F? For each rate of flow of liquid in and out of the tank there must be some ideal amount of hot oil flow that will accomplish this. This suggests two modifications in our control mode.

We must:

1. Establish some steady flow value for the hot oil that will tend to hold the temperature at the setpoint, and
2. Once this flow value has been established, let any error that develops cause an increase or decrease in hot oil flow.

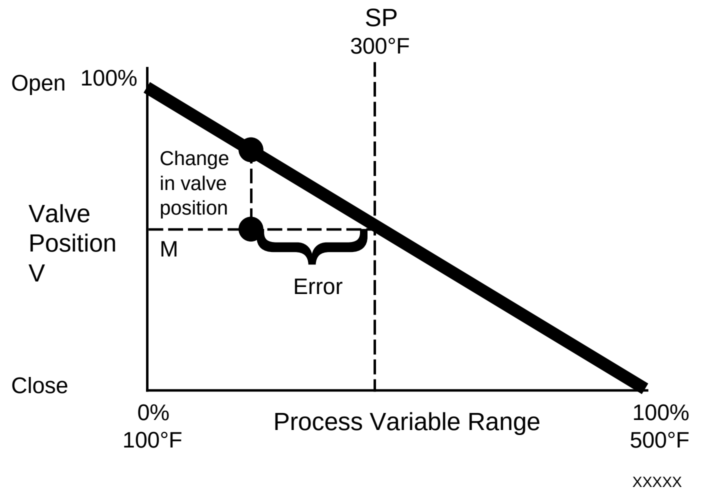
This establishes the concept of **PROPORTIONAL CONTROL**. Corrective action is now *proportional* to the amount of deviation between process variable and setpoint.

But now we need a different kind of control valve on our process. It must be capable of being positioned to any degree of opening from fully closed to fully open. This will generally be either a pneumatic diaphragm or electric motor operated valve.

**Graphical illustration of proportional control**

Graphically, proportional control can be illustrated by Figure 3-3. The amount of control action (valve change) for a given error can be quite variable, but in this figure it is shown as one to one. The valve would move 1% of its travel for a 1% change in error.

Figure 3-3 Proportional Control Action



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**Mathematical representation**

*The control engineer would describe this mode mathematically as follows:*

$$V = K(E) + M$$

*where*

*E = Error*
*K = Proportional Gain*
*M = A Constant which is the position of the valve when the error is zero*

**What is proportional band?**

The proportional gain, or just **GAIN**, is a measure of how sensitive the valve change will be to a given error. Historically, this proportionality between error and valve action has gone under various names, such as throttling range and gain, but mostly it has been called **PROPORTIONAL BAND**, or just PB. It is the expression stating the percent change in error required to move the valve full travel.

**Examples**

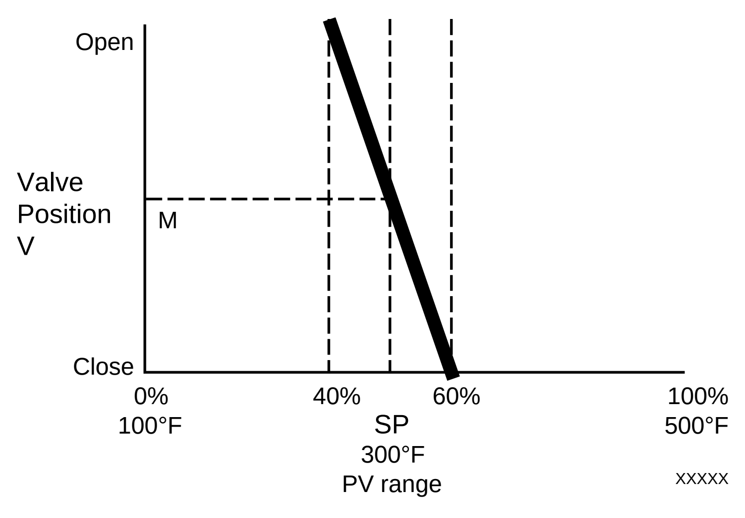
On the basis of the above definition, look at the graphs in Figures 3-3, 3-4, and 3-5.

The Proportional Band in Figure 3-3 is 100% and the Gain is 1

The Proportional Band in Figure 3-4 is 20% and the Gain is 5.

The Proportional Band in Figure 3-5 is 200% and the Gain is 0.5.

Figure 3-4 Proportional Band 20%



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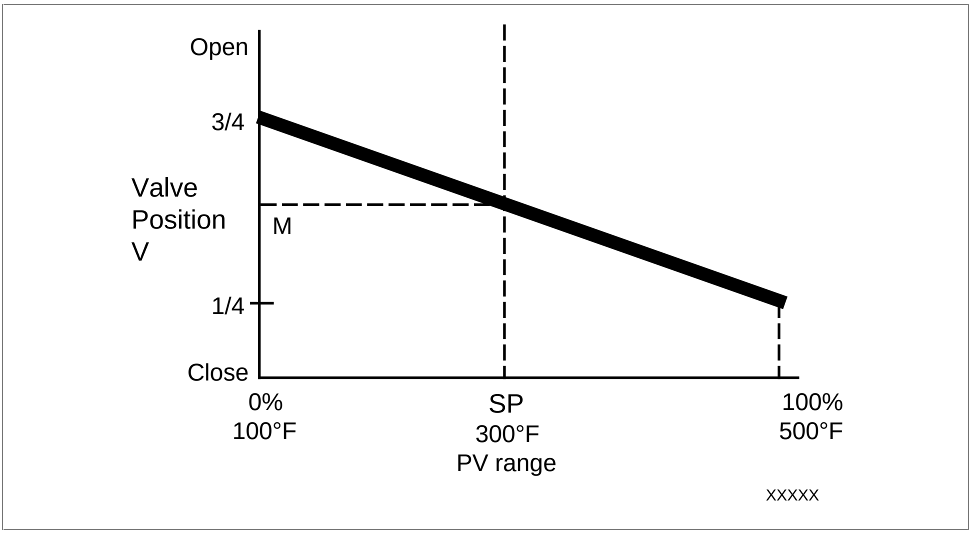
**Examples, continued**

Figure 3-5 Proportional Band 200%



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**The relationship of PB to Gain**

Proportional band can be related to Gain as follows:

$$\text{Gain, K} = \frac{100\%}{\text{PB}}$$

The more modern way of looking at this mode of control is to think in terms of gain (K), but in the field it will most often be called proportional band (PB).

The M factor has to be that valve position which supplies just the right flow of hot oil to keep the temperature at the setpoint. It is often called the manual reset term.

A controller designed to provide proportional control must have two adjustments, one for the K and one for the M (manual reset).

---

**Proportional control limitations**

There is, however, a rather serious limitation to proportional control. If there are frequent load changes to the process, it will hardly ever keep the process variable at the setpoint. The reason is that there is only one valve position for each value of the process variable.

But, if there are load changes like a change in flow rate of liquid such that more hot oil than before is needed to maintain the 300•F, this controller has no way of providing it except through the manual reset adjustment.

## 3.4 Proportional + Reset (Integral) Control

**Introduction**

A proportional controller does not change the position of the valve enough to keep the process variable at the setpoint when a load change occurs, as has been explained previously in “Proportional Control Limitations”.

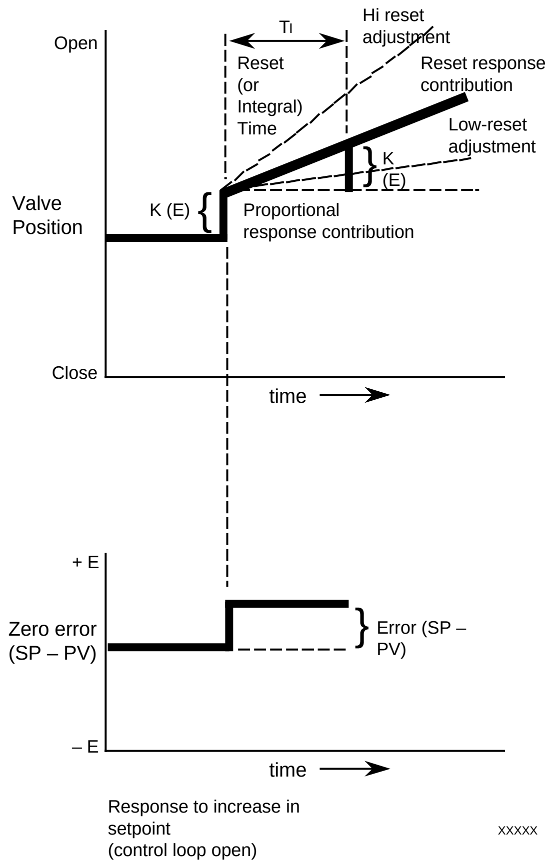
**Reset action** (more properly “Automatic Reset”) will sense that an error, or offset, is present after proportional action has taken place and continue to change the valve position further in an attempt to eliminate the error completely. Controllers with automatic reset will move the valve at a speed proportional to the size of the error present.

**Graphical illustration of proportional + reset control**

Graphically, the **Proportional plus Reset** modes are illustrated in Figure 3-6. Assume a step change in setpoint at a point in time, as shown. First, there is an immediate change in valve position equal to K(E) due to the Proportional Mode. At the same time, the Reset Mode, sensing there is an error, begins to move the valve at a rate proportional to the size of that error.

Since the illustration pictures a constant error, the valve rate will be constant. It will be seen that after an interval of time, $T_I$, a change in valve position equal to the original proportional change has taken place. $T_I$ is called the **Reset Time**.

Figure 3-6 Proportional Plus Reset Control Action



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**Reset Time/Repeats per Minute**

An adjustment that is made to a reset controller determines the slope of the reset response portion of the graph. The dotted lines in Figure 3-6 show other settings of the reset adjustment.

When time is used to express reset action it is called the **Reset Time**.

Quite commonly, its reciprocal is used, in which case it is called **reset in "Repeats per Minute,"** abbreviated R/M or RPM. This term refers to the number of times per minute that the reset action is repeating the valve change produced by proportional control alone. Modern control experts call $T_I$ **integral time**.

## 3.5 Proportional + Rate (Derivative) Control

**Introduction**

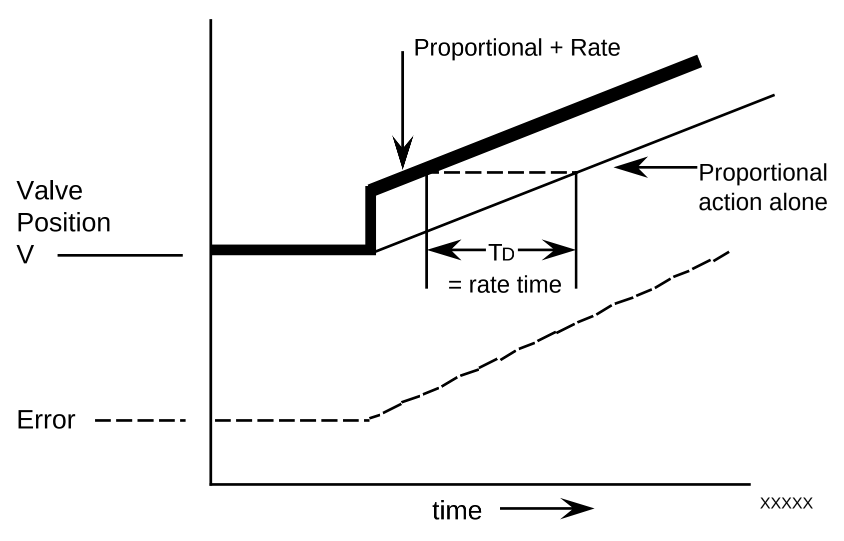
It seems reasonable that a process with a rapidly changing error would benefit from additional control action. The rate, or derivative, mode of control does just that. The movement of the valve is proportional to the rate of change of error or process variable. This additional correction exists only while the error is changing. It disappears when the error stops changing even though the error is not zero.

**Graphical illustration of proportional + rate control**

Graphically, the **Proportional plus Rate** modes are illustrated in Figure 3-7.

It can be seen on this graph that the valve position change with rate action exceeds that which it would have been with proportional action alone. It can also be seen that on a ramping error, the valve reaches any given position at an earlier time than it would have with proportional action alone. This difference in time is the Rate Time, or Derivative Time, TD.

Figure 3-7 Proportional plus Rate Control Action



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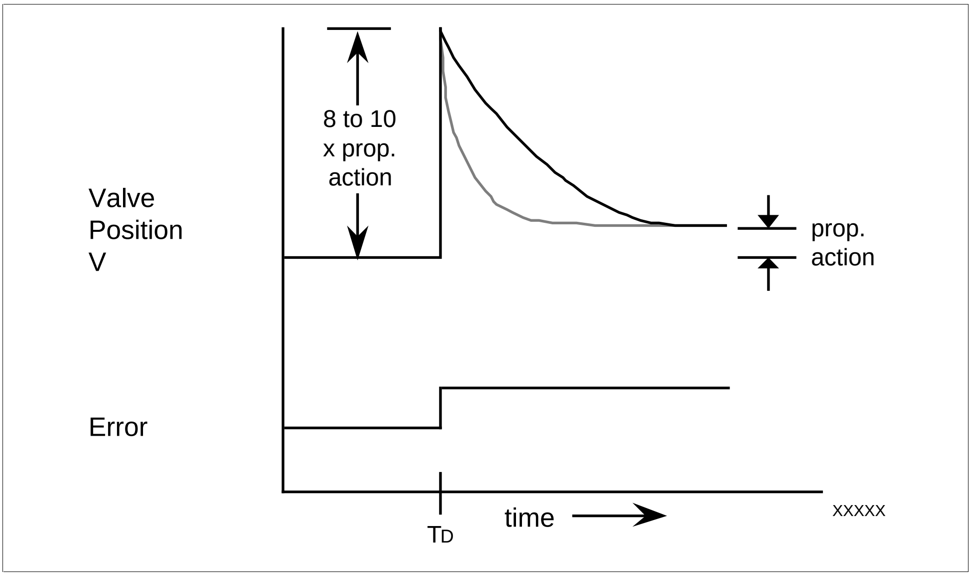
**Rate time**

Controllers with this mode of control are designed with an adjustment on the amount of **rate action**. This adjustment is made in terms of rate time. Longer rate times increase the amount of rate action.

It is also of interest to consider rate action in response to a step change in error, as is illustrated in Figure 3-8.

Changes in rate time here show up in the length of time for the decay of the valve position to the position it would have assumed with proportional action alone.

Figure 3-8 Rate Action Response to a Step Change



# 3.6 Proportional + Reset + Rate (3 Mode) Control

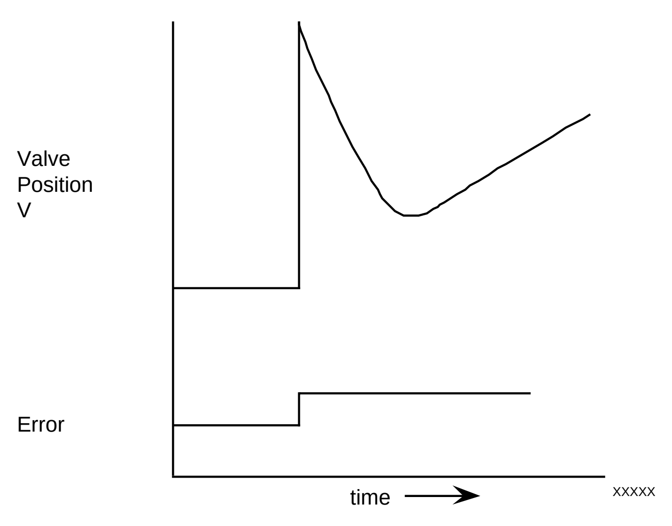
**Introduction**

Finally, the full **three mode controller** is achieved by combining the three modes simultaneously. Thus the valve position will be determined by adding the effects of the three modes.

**Graphical illustration of three mode control action**

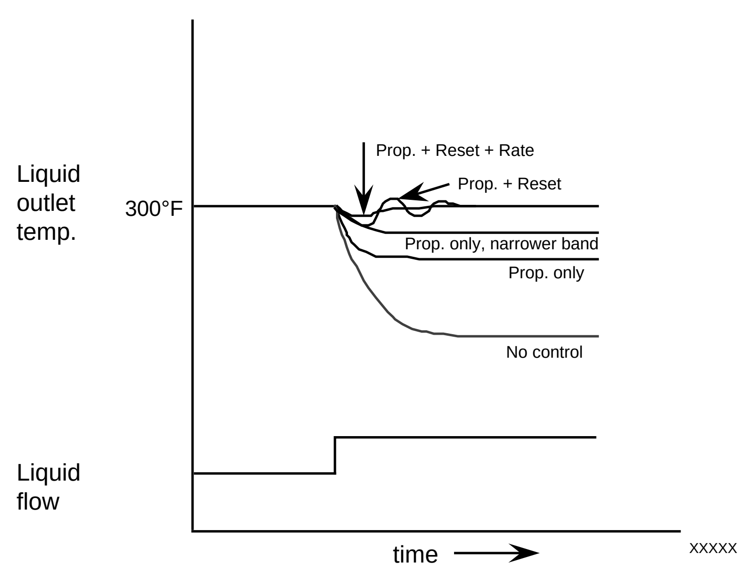
Graphically, its response to a step change in error is illustrated in Figure 3-9.

Figure 3-9 Three Mode Control Action



The graph in Figure 3-10 illustrates how an increase in the flow of the liquid to be heated will be responded to by the various control modes in terms of the process variable, liquid outlet temperature.

Figure 3-10 Response to Increase in Liquid Flow



## 3.7 Controller Selection Guidelines

**Introduction**

The selection of the proper modes of control to use on a particular process is a complex matter, but there are a few general statements that can be made for guidance.

**ON-OFF**

Popular because of its simplicity. In general it functions satisfactorily if the process has a large capacitance and minimum dead time. It will accommodate load changes to some extent, but such changes should not be rapid or large. Cycling at the new load will have a different average value depending on the direction of the load change.

In industry, ON-OFF control is ideally suited, for example, to the control of temperature in a cooking kettle where the only load changes are due to changes in ambient temperature. The capacitance is large and the load changes are small.

**Proportional**

Proportional control reduces cycling below that of ON-OFF control. It does a particularly good job when process capacitance is large and dead time small. These characteristics promote stability and allow the use of a narrow proportional band, which gives faster corrective action and less offset.

When the process has these favorable characteristics, proportional control can even make moderate load changes tolerable. When the proportional band must be made wider, however, even a small load change leads to offset.

**Proportional plus reset**

The primary advantage of proportional-plus-reset is that it will eliminate offset with load changes. It can be used even when process capacitance is small and load changes are large.

The main limitation of a proportional-plus-reset controller is its inability to prevent overshoots due to reset accumulation. When reset action responds to a large enough error or one that exists for a long time, by putting the valve into saturation (either fully open or fully closed), it is subsequently unable to change the direction of the valve motion until the error changes sign, that is, until the process variable crosses the setpoint. This is usually too late to prevent overshooting of the process variable.

It is a problem found particularly in the start-up of processes, but any large or rapid load change may cause it.

*Continued on next page*

**Proportional plus reset and rate**

Rate action can be very useful in minimizing overshooting of the process variable when the controller is trying to compensate for large or rapid load changes. It is also useful in preventing overshoot of the process variable in the start-up of batch processes.

On very slow moving processes rate will have minimal affect. On noisy processes, such as flow, rate will amplify the noise and result in continual overcorrection. It has been most widely used for temperature control, and least on pressure or flow applications. In recent years, however, its use has been more widespread across all control applications.

**Summary**

Each mode of control is applicable to processes having certain combinations of characteristics. The simplest mode of control that will do the job is the best to use. Table 3-1 summarizes the guidelines for selection of control modes from various combinations of process characteristics.

Table 3-1 Application of Control Modes

| Mode of Control | Process Reaction Rate | Dead Time | Load Changes |
|---|---|---|---|
| ON-OFF | Slow | Slight | Small and slow |
| Proportional | Slow or moderate | Small or moderate | Small, infrequent |
| Proportional plus Rate | Slow or moderate | Moderate | Small, faster |
| Proportional plus Reset | Fast | Small or moderate | Slow, but any size, frequent |
| Proportional plus Reset and Rate | Fast | Moderate | Fast |

# Chapter 4 – Algorithms

## 4.1 Overview

**What's in this chapter?**

This chapter contains the following information:

**Introduction**

The topic table lists the algorithms resident in the microprocessor memory of most Honeywell controllers. The selection of an algorithm is part of the configuration process of the controller.

# 4.2 On-Off

### Introduction

**ON/OFF** is the simplest control type. The output can be either ON (100%) or OFF (0%). The Process Variable (PV) is compared with the setpoint (SP) to determine the sign of the error (ERROR = PV-SP). The ON/OFF algorithm operates on the sign of the error signal.

In Direct Acting Control, when the error signal is positive, the output is 100%; and when the error signal is negative, the output is 0%. If the control action is reverse, the opposite is true. An adjustable overlap (Hysteresis Band) is provided between the on and off states.

### How it works

In the implementation of the on-off algorithm, the process variable is compared with the setpoint to determine the sign of the error. When the error is positive, the output relay is on; and when the error is negative, the output relay is off. The output relay is switched on or off when the error passes through zero; that is, when the process variable equals the setpoint.

The algorithm includes an operator-adjustable hysteresis band between the on and off states. The hysteresis band alters the basic equation slightly by causing the output relay to be switched at an error signal slightly above and below zero.

### Hysteresis band

Figure 4-1 shows the switching operation of an output relay through its associated hysteresis band. Hysteresis band (h) is expressed as a percent of the total PV range. As shown in the diagram, if the error signal is greater than or equal to half the positive hysteresis band ($\frac{h}{2}$), the output is on. If the error is less than or equal to half the negative hysteresis band ($-\frac{h}{2}$), the output is off. If the error signal is less than the positive hysteresis band but not less than or equal to the negative hysteresis band, the output remains in its present state. This latter condition allows an error that is decreasing from a large positive value not to switch the output until the value is less than or equal to half the hysteresis band.

Increasing the hysteresis band produces two effects:

1. Increases the time between switches.
2. Increases the amplitude of the limit cycle.

**ATTENTION** Increasing the hysteresis band by a factor of two results in an approximate doubling of the time between switches and the amplitude of the limit cycle.

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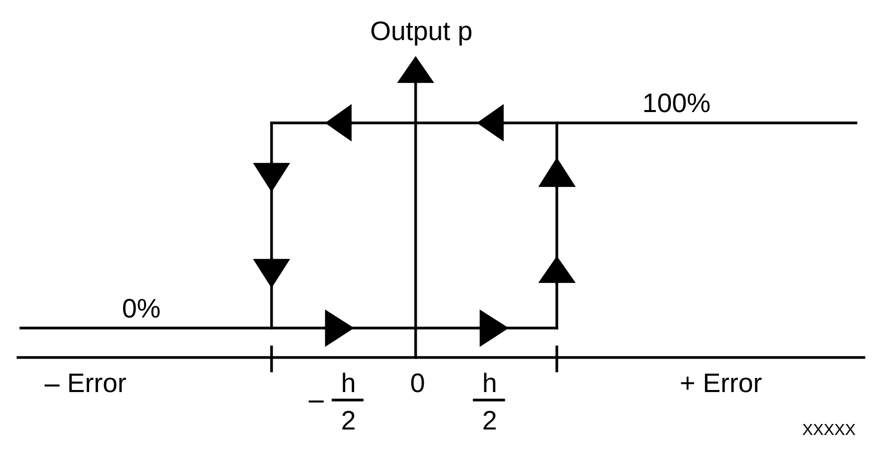
**Hysteresis band, continued**

Figure 4-1 Switching Action of On-Off Control

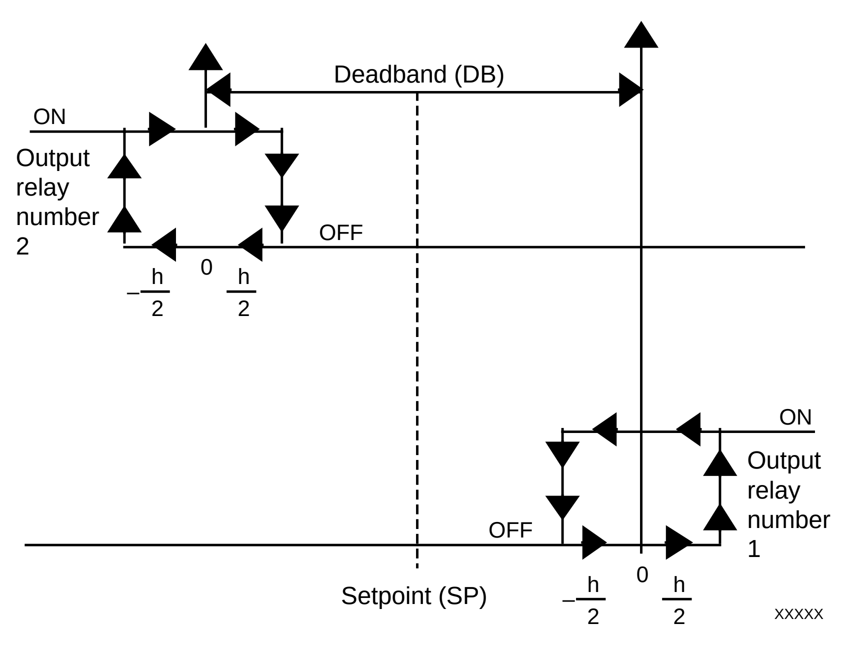


**Duplex On-Off control**

The on-off control algorithm is extended to switch a second output relay for duplex on-off control. The switching action associated with each individual output relay does not change; however, an operator-adjustable deadband changes the respective zero error switching point for each output relay relative to the setpoint, as shown in Figure 4-2.

Deadband is also expressed in terms of a percentage of the total PV range. Figure 4-2 shows the relay action of a controller configured for duplex HEAT-COOL control. In this case relay number 1 would control a heater and relay number 2 would control a cooler. When the PV is near the setpoint in the deadband, neither relay is ON.

Figure 4-2 Switching Action of Duplex On-Off Control



# 4.3 PID-A Algorithm

### Introduction

**PID-A** is normally used for three-mode control. This means that the output can be adjusted somewhere between 100% and 0%. It applies all three control actions — Proportional (P), Integral (I), and Derivative (D) — to the error signal.

**Proportional (Gain)** — regulates the controller's output in proportion to the error signal (the difference between Process Variable and Setpoint).

**Integral (Reset)** — regulates the controller's output to the size of the error and the time the error has existed. (The amount of corrective action depends on the value of proportional Gain.)

**Derivative (Rate)** — regulates the controller's output in proportion to the rate of change of the error. (The amount of corrective action depends on the value of proportional Gain.)

### How it works

In the "A" form of the PID equation, *all three modes—proportional, integral, and derivative—act on the error*. Figure 4-3 shows the implementation of the difference equations for the three modes when all three are active.

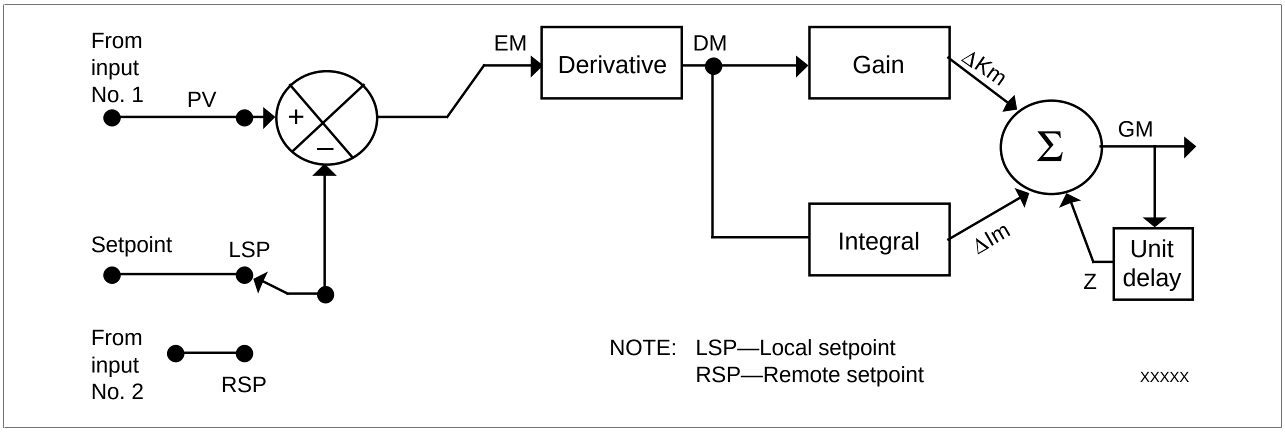
As shown in the diagram, the process variable (PV) is compared with the present setpoint (LSP or RSP) to obtain the present error (Em). The present error is then applied to the derivative block which contributes a rate action component to the signal.

The present output from the derivative block (Dm) is then simultaneously applied to the gain and integral blocks to separately include these functions in the signal.

The present changes in output from the gain block (ΔKm) are then combined with the present change from the integral block (ΔIm) to obtain the present output error (Gm) from the PID algorithm.

The PID-A equation is also used in various forms to provide additional variations of control, including PI control, PID or PI duplex control, and optional integral limiting inside the proportional band.

Figure 4-3 Implementation of PID-A Equation



NOTE: LSP—Local setpoint
RSP—Remote setpoint

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**PID-A control variations**

The two-mode PI control variation is obtainable from the PID-A equation. The desired control variation can be implemented by adjusting the unwanted derivative tuning constant to zero. This will cause the derivative contribution to be removed from the error by adjusting the rate time to zero.

Integral action may be removed by adjusting the integral time to zero. This is not recommended except for making process response measurements for determination of optimum tuning constants.

**PID-A duplex control**

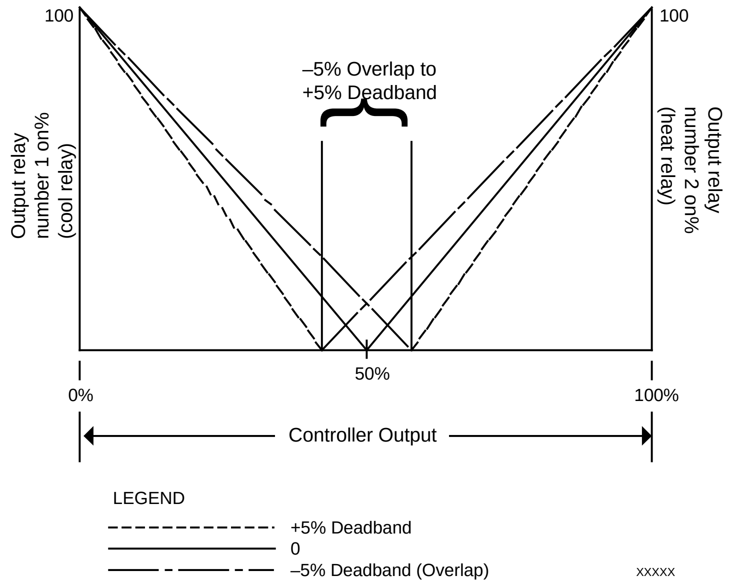
The PID-A equation will provide PID-A duplex control whenever the output is configured for duplex operation. In the duplex application, the PID algorithm will operate the two control relays for variations of the heat and cool applications.

The PID algorithm computation is the same, but independent gain, integral time and rate timing constants entered by the operation are used for calculation during the respective heating or cooling cycle.
As shown in Figure 4-4, the heat and cool cycles are centered on the 50% output point (midpoint). Without a deadband-overlap setting, 50% output represents a static condition; no heat or cool action. The PID equation uses the normal tuning constant for outputs above 50%, but uses the cool tuning constants for outputs below 50%. 0% output represents full cool action (output relay number 2 full ON), and 100% output represents full heat action (output relay number 1 full ON).

The deadband-overlap is operator-adjustable from 5% around midpoint to 25% deadband between the heat and cool cycles.

**ATTENTION** Cycle time is also independently adjustable for output relay number 1 and output relay number 2.

Figure 4-4 Typical Relay Operation in PID-A Duplex Control



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**PID-A with integral action inside the proportional band**

The PID-A equation is also used to obtain a control variation that conditionally includes integral action. In this variation of the PID form, the integral component is eliminated from the computation if the present error (Em) is greater than one-half of the proportional band. The proportional band represents the percent change in error required to move the final control element full scale. The relationship between gain (K) and proportional band (PB) is expressed as:

$$K = \frac{100\%}{PB\%}$$

Elimination of the integral component from the computation reduces the overshoot at the process. Thus, when the PV exceeds the proportional band, the control action is two-mode PD.

## 4.4 PID-B Algorithm

**Introduction**

**PID-B** Unlike the PID-A equation, the controller gives only an integral response to a setpoint change, with no effect on the output due to the gain or rate action, and it gives full response to PV changes. Otherwise controller action is as described for the PID-A equation.
See note on PID-A.

**How it works**

In the “B” form of the PID equation, *the proportional and derivative modes act on the process variable and the integral mode acts on the error*. In this equation, setpoint changes do not cause bumps in the output. Figure 4-5 shows the implementation of the difference equations for the three modes when all three are active.

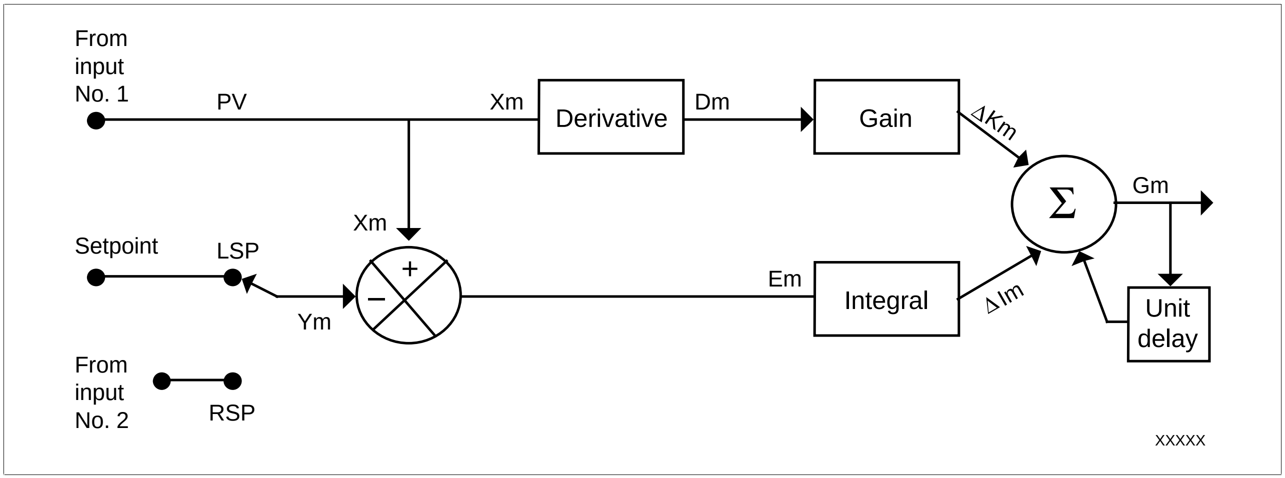
As shown in the diagram, the present process variable (Xm) is simultaneously applied to the derivative block and also compared with the present setpoint (Ym).

The derivative block contributes a rate action component to the process variable and routes its output (Dm) to the grain block where the appropriate proportional action is computed for the signal.

The comparison of the present process variable with the present setpoint (either LSP or RSP) produces the present error (Em) which is then routed to the integral block where the appropriate reset action from the error is computed.

The present change in output from the gain block (ΔKm) is then combined with the present change from the integral block (ΔIm) to obtain the present output error (Gm) from the PID algorithm.

Figure 4-5 Implementation of PID-B Equation



**PID B control variations**

Control variations for PID-B are identical with those available for PID-A.

**PID duplex control**

The PID-B equation will provide PID duplex control whenever dual output relays are configured. The description of PID duplex control using the “B” equation is identical to that provided for the “A” equation.

# 4.5 PD-A + Manual Reset

**Introduction**

**PD WITH MANUAL RESET** is used whenever integral action is not wanted for automatic control. The equation is computed with no integral contribution. The MANUAL RESET, which is operator adjustable, is then added to the present output to form the controller output.
Switching between manual and automatic mode will not be bumpless.
If you select PD with Manual Reset you can also configure the following variations

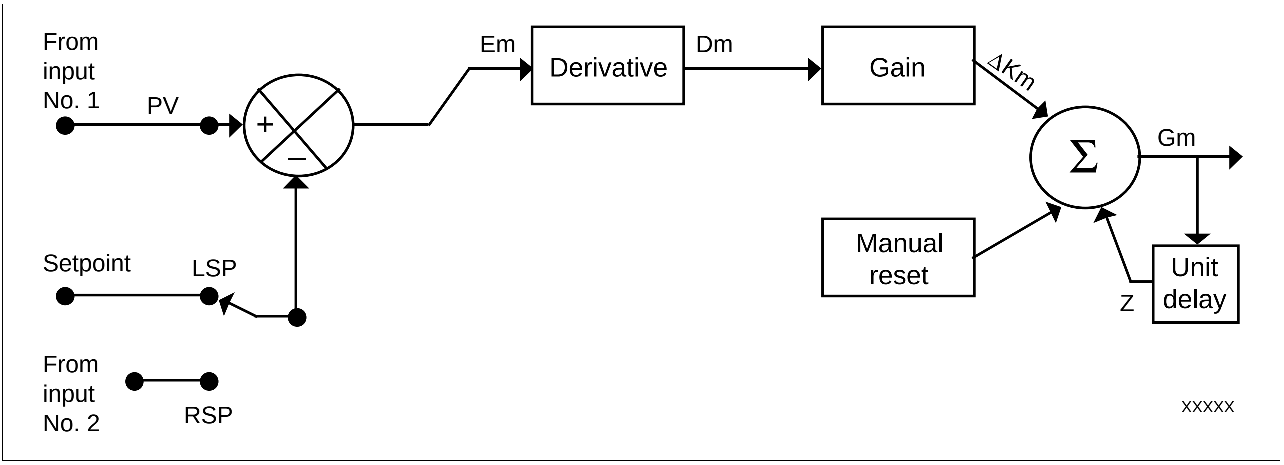
- PD (Two Mode) control,
- P (Single Mode) control.

Set Rate (D) and/or Reset Time (I) to 0.

**How it works**

This algorithm is a variation of the PID-A equation. (See Figure 4-6.) The equation is computed with no integral contribution. The manual reset, which is operator-adjustable, is then added to the present output error (Km) to form the controller output (Gm).

Figure 4-6 Implementation of PD-A with Manual Reset Equation



# 4.6 Three Position Step Control

**Introduction**

**THREE POSITION STEP** - The three position step control algorithm provides proportional control for forward and reverse rotation of a motor without the use of a feedback slidewire.

**How it works**

The algorithm develops stepped, output control signals by integrating the relay switching action of duplex on-off control with an internal, filter feedback signal that is based on the state of the output relays.

Derivative and integral control elements are included in the algorithm to produce output control pulses that are proportional to the magnitude and duration of the error (process variable minus setpoint).

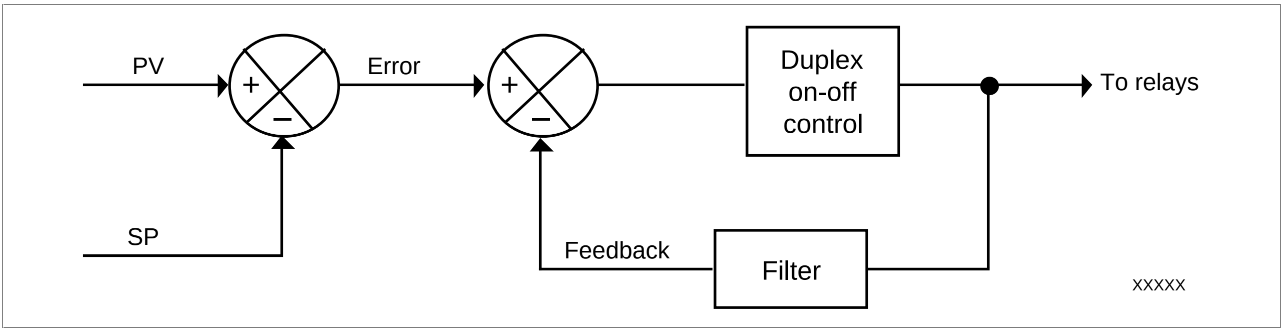
Figure 4-7 illustrates the relationship between the duplex on-off control and the internal, filter feedback signal used to produce the three position step control form.

The effect of this control action is that the on and off times of the output relays change in proportion to the error signal combined with the Rate and Integral time constants of the controller.

This algorithm is a modified ON-OFF duplex algorithm where the error signal includes a relay feedback signal. The error is PV–SP–F where F is the feedback signal. F is the output of a filter which charges and discharges depending on the status of the output relays.

When relay number 1 is on, the filter charges toward 100%; when relay number 2 is on, the filter charges toward –100%; and when both relays are off, the filter discharges toward 0%.

Figure 4-7 Relationship of Duplex On-Off Control and Filter Feedback Signals in Three Position Step Control Algorithm



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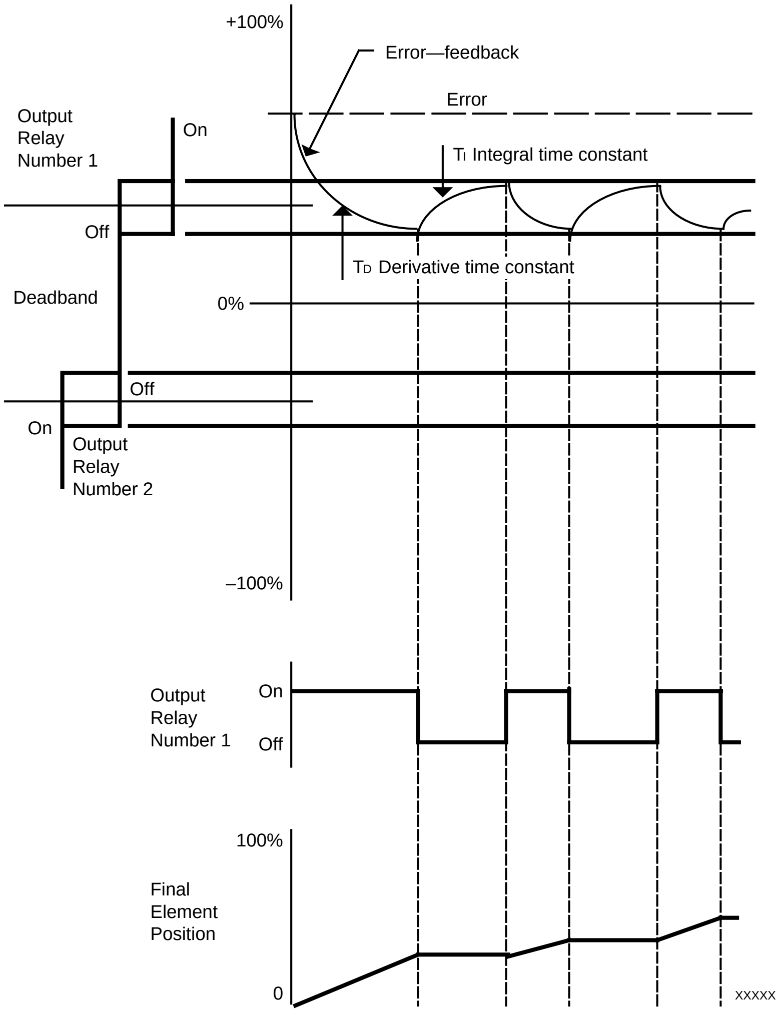
**Output characteristics of Three Position Step Control**

The rate at which the filter charges is determined by the Rate of the controller, and the discharge rate is determined by the Integral time. Thus, relay on and off times change in proportion to the error signal and the Rate and Integral time constants entered by the operator.

The values of the Rate and Integral time constants are entered in minutes. Figure 4-8 illustrates the profile of a typical output signal derived from the control action of one relay and the corresponding rotational action it produces at the motor. The second relay produces identical results except in the reverse direction.

The algorithm includes computations for the hysteresis of each relay and the deadband between them. Deadband and hysteresis values are operator-adjustable through the data entry keyboard. (NOTE: Refer to the descriptions provided for the on-off and duplex on-off control algorithms for further information regarding hysteresis and deadband.)

Figure 4-8 Output Characteristics of Three Position Step Control for Constant Error



# 4.7 Computations Associated With PID Equations

**Initialization**

Various computations that are not an integral part of the PID difference equations include:

- Initialization computations,
- Output limiting computations,
- Reset limiting computations, and
- Ratio and bias on remote setpoint computations.

These associated computations complement the PID algorithms and have related operator-adjusted parameters to meet specific control requirements.

**Initialization computations**

Various computations are performed to balance the control action at the time of the manual-to-auto or auto-to-manual transfer. This is done so that there is no bump (kick) in the controller output at the time of the transfer. When transferring from manual to auto, the output remains constant and the integral action acts to remove the error between the setpoint and PV. In the PD-A with manual reset equations there is no integral action and the output remains constant. For proper operation of PD-A with manual reset on power up in automatic mode, this output value should be adjusted in the automatic mode.

When the Honeywell controller is powered up, the output value is initialized to 0 for this PID equation except for PD-A with manual reset or duplex configurations. The output for PD-A with manual reset is initialized to the manual reset value plus gain time error and is therefore not bumpless at power on. The output is initialized to 50% for duplex forms in order to start control action in bumpless fashion with both output relays off in the Heat-Cool application.

**Output limiting computations**

Normally, limits are placed on controller outputs. These limits are initially 0% and 100% for the relay output low and high limits respectively. These limits may be adjusted in the controller by the operator within this range. Current and position low and high output limits may be set between –5% and +105% respectively.

**Reset limiting computations**

These computations limit the integral contribution in the present output calculation to only the portion needed to reach the reset limit.

*Continued on next page*

**Ratio and bias on remote setpoint computations**

These computations are implemented in ratio and constant bias functions in the second input signal before it is applied to the control equation, so that bumps are eliminated when switching between automatic remote and local setpoints. Ratio and bias are separately adjusted through the data entry keyboard. During the automatic remote setpoint mode of operation, the remote setpoint (RSP) is calculated as:

$$RSP = (R)\,(IN2) + B$$

*where:*

RSP = Remote setpoint
IN2 = Second input signal (%)
R = Ratio coefficient
B = Bias constant (engineering units)

The operator can configure the controller for remote setpoint with manual or automatic bias calculation. With auto bias, the bias coefficient is automatically calculated for bumpless transfer to the automatic remote setpoint mode. The equation for this calculation is:

$$Bias = LSP - (R)\,(IN2)$$

*where:*

LSP = Local setpoint

To prevent bumping the output when the mode is transferred from automatic remote setpoint to automatic local setpoint, the last value of the control setpoint is used as the local setpoint.

**Weighted average computations**

When Weighted Average is configured, the controller will combine the two inputs and compute a PV for the control algorithm. The PV is formed by the following equation:

$$PV = \frac{\text{Input 1} + (\text{Ratio x Input 2})}{1 + \text{Ratio}}$$

Both inputs must have the same range in engineering units.

# Chapter 5 – Controller Tuning

## 5.1 Overview

**What's in this chapter?**

This chapter contains the following information:

**Introduction**

When you tune a controller, there are some things to consider:

- Process Characteristics - Gain, Time Constants, etc.
- Desired response - Minimal overshoot

Basically, controller tuning consists of determining the appropriate values for the Gain (PB), Rate (Derivative), and Reset (Integral) time tuning parameters (control constants) that will give the control you want. Depending on the characteristics of the deviation of the process variable from the setpoint, the tuning parameters interact to alter the controller's output and produce changes in the value of the process variable.

Since each parameter responds to a specific characteristic of the deviation, you may not need a combination of all three. It depends on the process characteristics and the desired control response.

**Tuning technique**

You can estimate a starting point and the tuning parameters required to give the desired controller response and with some experience, become proficient with this method.

An alternate approach is to rely on a tuning technique. In practice, tuning techniques usually do not give exactly the type of response desired; thus, some final adjustments to the tuning parameters must be made.

However, you should at least obtain a reasonable starting point from which the desired response characteristics can be obtained.

# 5.2 Manual Tuning

**Tuning goals**

Essentially, most Manual Tuning criteria strive to arrive at a compromise with three basic goals:

1. Minimum deviation following a disturbance.
2. Minimum time interval before return to the setpoint.
3. Minimum offset due to changes in operating conditions.

There are also diverse methods for finding the controller settings that will satisfy these goals. Some are more precise than others, but all result in approximations which provide a good starting point from which fine tuning can be done.

**Methods**

We will consider here two different methods:

- **Reaction Curve Method**
- **Ultimate Cycling Method**

The two require differing amounts of information about the process. As you would suspect, the more process information that can be incorporated, the more precise will be the results. Both of these methods are based on conducting a few simple tests in the field. They can be validated against theory.

*Continued on next page*

**Method 1 Reaction curve method**

Table 5-1 lists the steps for tuning using the reaction curve method.

Table 5-1 Reaction Curve Method

| Step | Action |
|---|---|
| **1** | Put the control loop on manual control. |
| **2** | Give the valve a small step change. |
| **3** | Record the response of the process. Subsequent steps can be shown best by referring to an example. See Figure 5-1. |
| **4** | Draw a tangent to the steepest portion of the curve. This determines slope R and time L. |
| **5** | Measure L in minutes. |
| **6** | Calculate $R = \frac{\Delta PV}{\text{Min.}} \times \frac{1}{\Delta P}$<br>*where:*<br>$\Delta PV$ = percent change in process variable<br>$\Delta P$ = percent change in valve position<br>(This specifies the reaction rate in percent of scale per minute for change in $\Delta P$ in percent.) |
| **7** | The controller settings are given in terms of R and L as in Table 5-2. |

Table 5-2 Controller Settings

| Mode of Control | PB (%) | Reset R/M | Rate (min.) |
|---|---|---|---|
| Proportional | 100RL | — | — |
| Proportional plus Reset | 110RL | $\frac{0.3}{L}$ | — |
| Proportional plus Reset and Rate | 83RL | $\frac{0.5}{L}$ | 0.5L |

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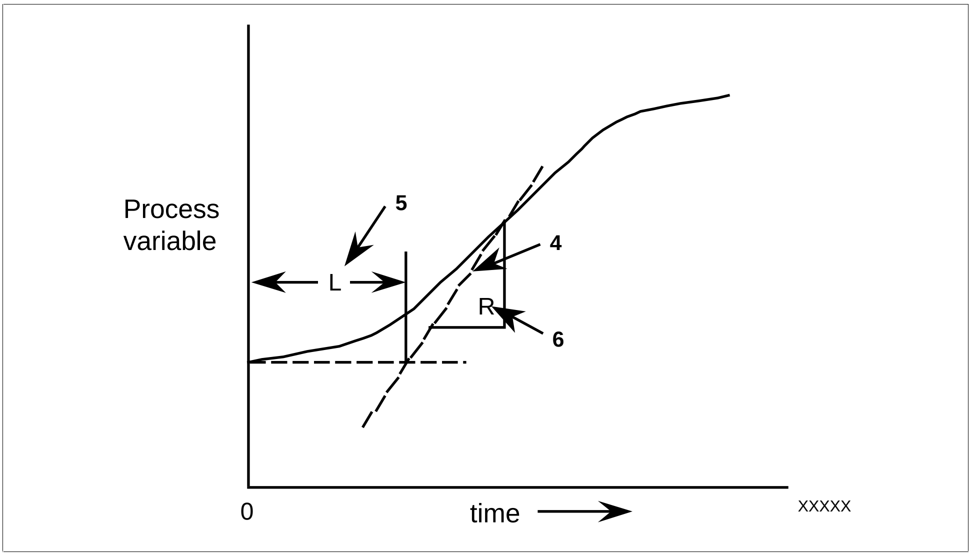
**Process reaction curve**

Figure 5-1 is an illustration of a process reaction curve.

Figure 5-1 Process Reaction Curve



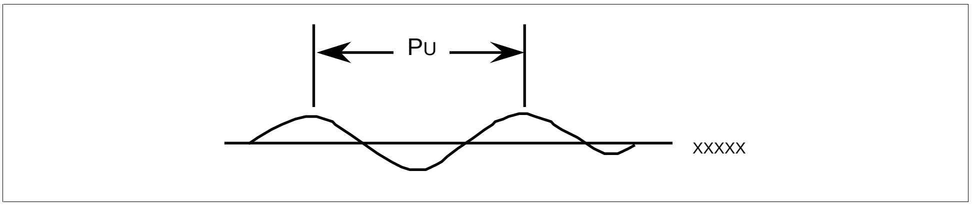
**Method 2 Ultimate cycling method**

Table 5-3 lists the steps for tuning using the ultimate cycling method.

Table 5-3 Ultimate Cycling Method

| Step | Action |
|---|---|
| **1** | Place control on proportional only. |
| **2** | Narrow the proportional band until a small uniform cycling starts and continues. |
| **3** | Note the PB. This is the ultimate PB, $PB_U$. |
| **4** | Measure the period of cycling. This is the ultimate period, $P_U$. See Figure 5-2. |

Figure 5-2 Ultimate Period



From this point there is a choice of three criteria.

- **Quarter amplitude decay**
- **Tuning for minimum overshoot**
- **Fast response to a load change**

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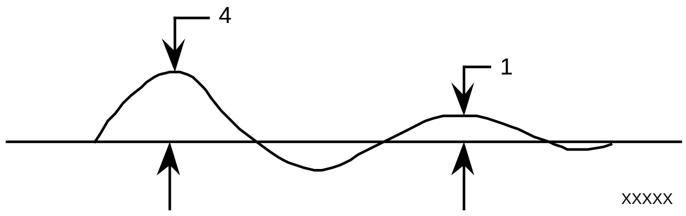
**Criterion #1**

***Quarter Amplitude Decay***
With this criterion, cycles caused by a disturbance decay with each succeeding cycle have an amplitude 1/4 the previous one. See Figure 5-3.

Figure 5-3 1/4 Amplitude Decay

| Mode of Control | PB | Reset | Rate |
|---|---|---|---|
| Proportional only | $2PB_U$ | — | — |
| Proportional + Reset | $2.2PB_U$ | $\frac{1.2}{P_U}$ | — |
| Proportional + Reset + Rate | $1.7PB_U$ | $\frac{2}{P_U}$ | $\frac{P_U}{8}$ |



**Criterion #2**

***Tuning for Minimum Overshoot (less cycling than Criterion #1)***
Three-mode controller only.

$$PB = 5PB_U$$

$$\text{Reset} = \frac{3}{P_U}$$

$$\text{Rate} = \frac{P_U}{2}$$

**Criterion #3**

***Fast Response to a Load Change***
Three-mode controller only.

This produces overshoot on start-up, so it is recommended for continuous processes rather than batch processes.

$$PB = 3PB_U$$

$$\text{Reset} = \frac{2}{P_U}$$

$$\text{Rate} = \frac{P_U}{3}$$

*Continued on next page*

**Correcting incorrect settings**

It is also important to be able to recognize the characteristics of the settings on the chart record in order to optimize them.

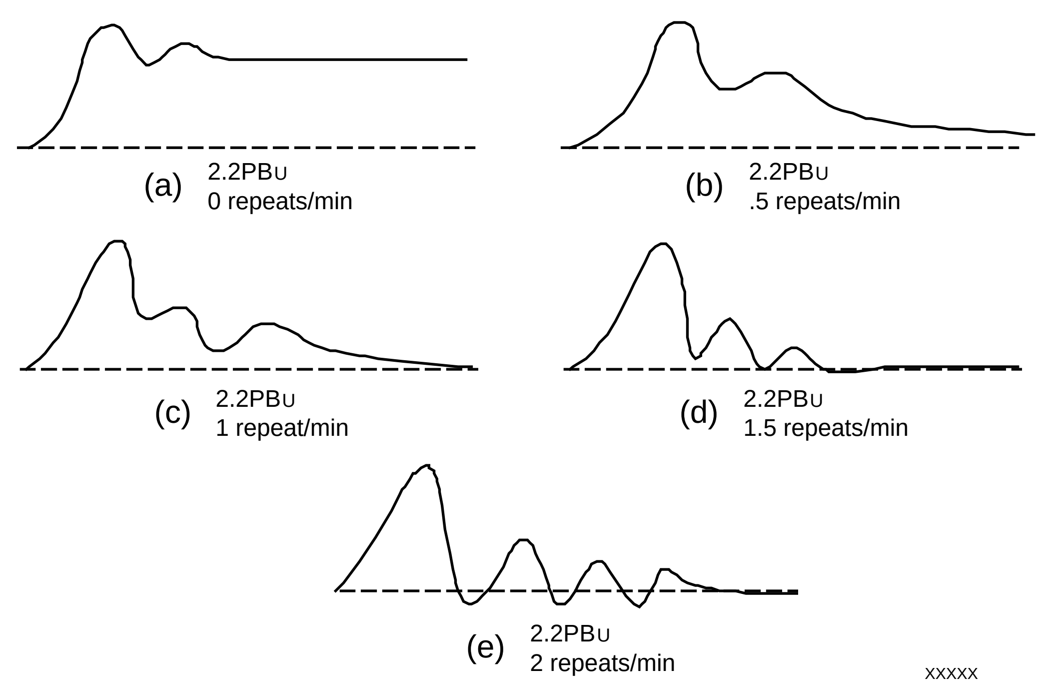
In Figure 5-4 (a) to (e) the effect of reset adjustment on control is shown.

**Curve (a)** - This is the result of a load change with a reset setting of zero repeats per minute, in other words, proportional action only.

**Curve (b)** - When some reset is added, 0.5 repeats per minute, the slow return to setpoint results.

**Curve (c), (d), (e)** - As the reset is increased to 1, 1.5, and 2 repeats per minute the return becomes more rapid. The response, however, also becomes more unstable and oscillates for a longer period of time. Of all the curves shown, Curve (d) probably would be considered the optimum because it is a reasonable compromise between speed of return and period of oscillation.

Figure 5-4 Effect of Reset Adjustment on Recovery from Load Change



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## 5.2 Manual Tuning, Continued

**Correcting incorrect settings, continued**

In Figure 5-5 (a) to (d) the effect of rate mode is shown.

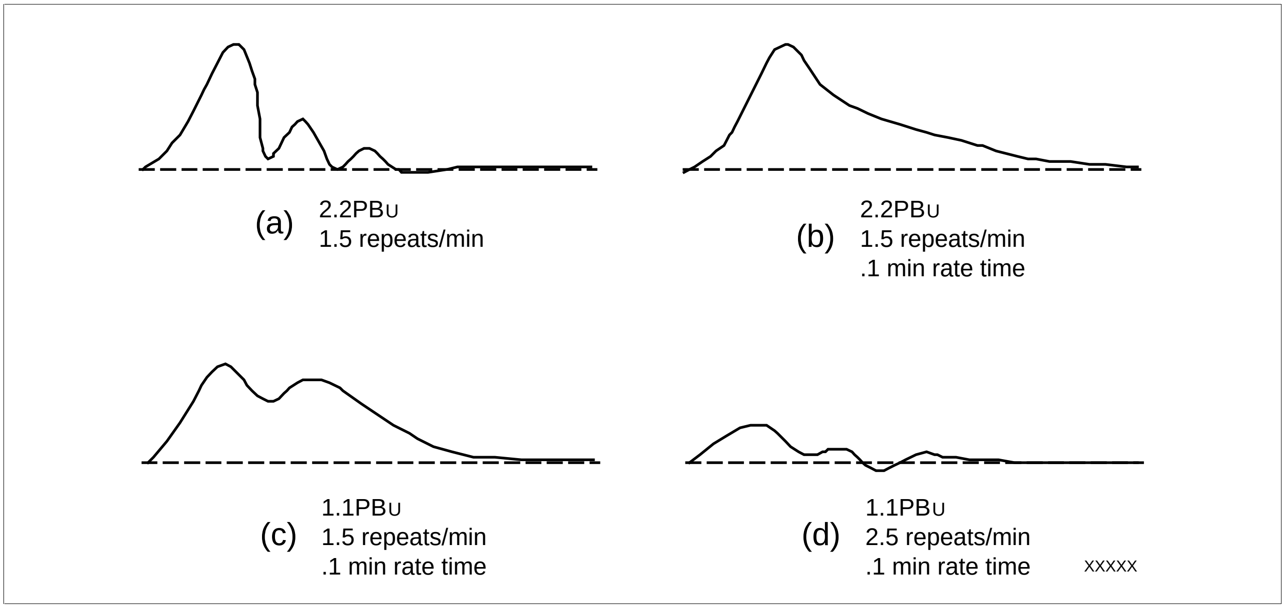
**Curve (a)** - This is a duplicate of 5-4 (d), the optimum curve for proportional-plus-reset.

**Curve (b)** - Without altering the settings of these two modes, but adding the rate mode with rate time of 0.1 minute, the recovery curve is changed to that shown. Because of the increased stability of this response it is possible to narrow the proportional band.

**Curve (c)** - We can see the resulting response when the proportional band is narrowed to half the value it had in curve (b). Less deviation is apparent now, but the amount of time to return to the setpoint is still excessively long. This can be shortened by increasing the reset.

**Curve (d)** - This shows the reset increased to 2-1/2 repeats per minute, giving the optimum response with the three-mode controller.

Figure 5-5 Effect of Rate Adjustment on Recovery from Load Change



## 5.3 Accutune II™

**Introduction**

Honeywell's ACCUTUNE II tuning algorithm for their UDC Controllers incorporates new **Fuzzy Overshoot Suppression**, **TUNE (Demand)** Autotuning, or **Setpoint** Autotuning. These provide faster tuning, reduced overshoot, ability to tune integrating type processes, and the ability to retune while at a fixed setpoint.

There are two types of Accutune from which to choose:

- **(TUNE) Demand Tuning** - Tuning is done on demand. The operator simply enters the desired setpoint and initiates the tuning through the operator interface.
- **(SP) Setpoint Tuning** - SP tuning will continually adjust the Gain or Proportional Band (P), Reset (I), and Rate (D) tuning constants in response to setpoint changes.

**How "Demand" tuning works**

Honeywell's "Demand" tuning provides foolproof, trouble-free on-demand tuning in their controllers. No knowledge of the process is required at start-up. The operator simply enters the desired setpoint and initiates the tuning. The UDC controller immediately starts controlling to the setpoint while it identifies the process, calculates the tuning constants and enters them into the Tuning group, and begins PID control with the correct tuning parameters.

This works with any process, including integrating type processes, and allows retuning at a fixed setpoint.

**How "SP" tuning works**

"SP" tuning will continually adjust the Gain or Proportional Band (P), Reset (I), and Rate (D) tuning constants in response to setpoint changes.

SP Tune handles all Local and Computer Setpoint changes. It uses time domain analysis, and the rule based expert system techniques to identify the two most dominant process lags plus any dead time.

It then automatically readjusts the PID parameters as necessary. It does this while controlling the setpoint in automatic (closed loop) control mode.

These calculated PID values can be changed, if desired, by disabling SP Tune and entering different values.

Tuning can be aborted by pushing Manual key to return to manual mode.

Two criteria are available — "Normal" and "Fast" through configuration. "SP" tuning can be done for applications using Duplex (Heat/Cool) control.

## 5.3 Accutune II™ Duplex Tuning

**Introduction**

Duplex control provides a unique tuning problem because these applications use one controller with a single process variable, controlled by two different final control elements that have different dynamics and Gain impact on the Process variable.

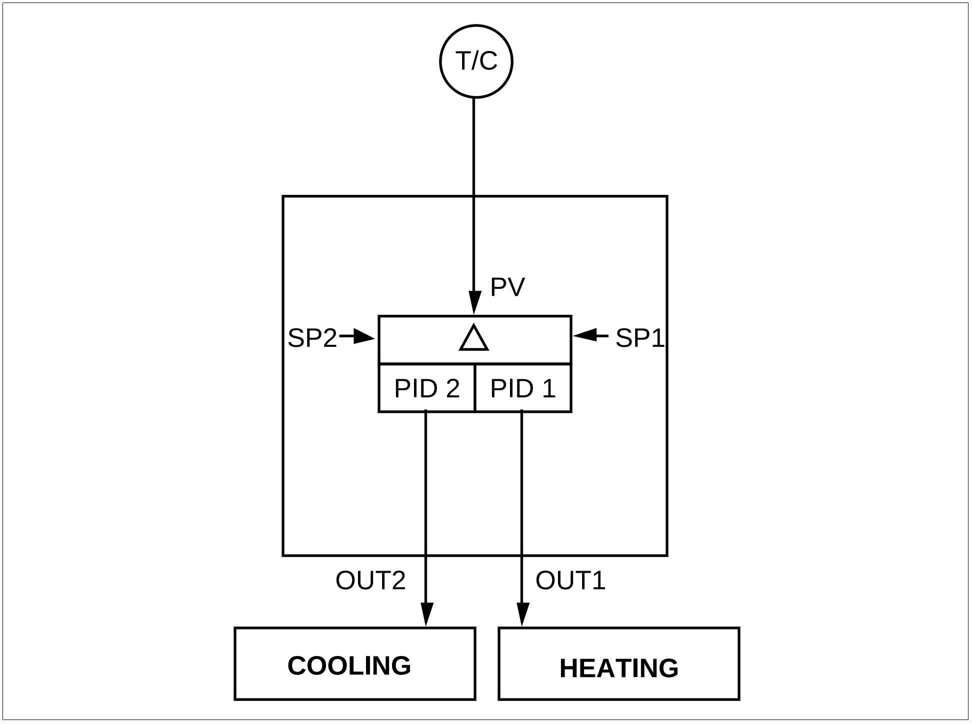
Duplex control processes include temperature control with heating and cooling, RH control via humidify / de-humidify, and pH control with acid and base additives. This requires a simple way to start up and tune both operating regions, for example, the heating zone and the cooling zone.

Duplex control is often referred to as “heat/cool control” in the industrial marketplace.

**Typical heat cool application**

Figure 5-6 shows a typical duplex control Heat/Cool application. Note that the output types may be current or relay.

Figure 5-6 Typical Heat/Cool Application



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**Accutune II**

Accutune II has an On-demand tuning algorithm that speeds up and simplifies start-up without needing any knowledge of the process.

It can be initiated at the touch of the keypad on the controller, and separate PID values are accurately determined for each zone (Heat/Cool).

It applies to any output type, and it works with integrating type processes.

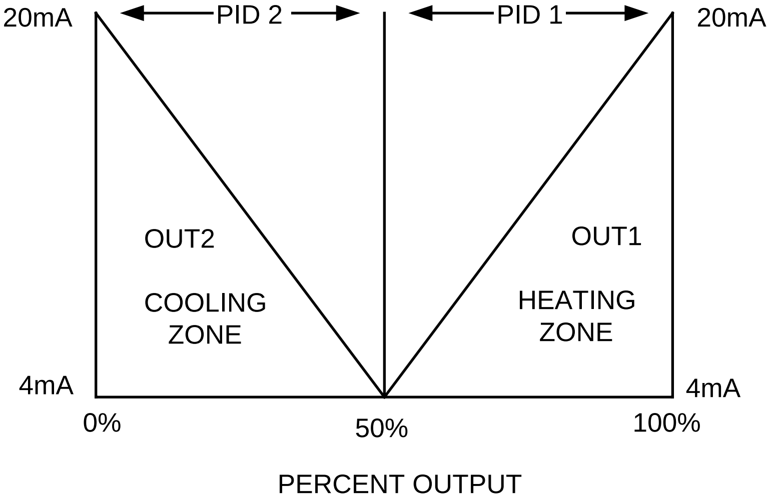
**How Accutune for Duplex works**

Figure 5-7 illustrates the relationship between the Heating and Cooling outputs and tuning parameters. It assumes both outputs are 4-20 mA current signals.

During tuning, Accutune II assumes Setpoint 1 will cause a heating demand, and the calculated PID parameters will be automatically entered as PID SET 1.

Likewise, it assumes tuning at Local Setpoint 2 will cause a cooling demand, and the cooling PID parameters will be entered as PID SET 2.

Figure 5-7 Relationship between Heat/Cool Outputs and Tuning



# 5.5 Fuzzy Overshoot Suppression

**Introduction**

Fuzzy Overshoot Suppression minimizes overshoot after a setpoint change or a process disturbance. This is especially useful in processes which experience load changes or where even a small overshoot beyond the setpoint may result in damage or lost product.

**How it works**

The fuzzy logic observes the speed and direction of the PV signal as it approaches the setpoint and temporarily modifies the internal controller action as necessary to avoid an overshoot. This allows more aggressive tuning to co-exist with smooth process variable response.

There is no change to the PID algorithm, and the fuzzy logic does not alter the PID tuning parameters.

This feature can be independently enabled or disabled as required by the application to work with Honeywell's Accutune II Demand tuning or the SP Adaptive tuning algorithm.

# Chapter 6 – Advanced Control Concepts

## 6.1 Overview

**What's in this chapter?**

This chapter contains the following information:

**Introduction**

There is almost no limit to the degree of sophistication a control system can reach. it can start at the level of a purely manual control system using a human operator as the controller and advance to a totally unmanned operation under complete computer management.

In the previous chapters, you learned about the capabilities of a simple, feedback control loop using the logic of a PID (proportional, integral, derivative) controller. We saw that such a system has limits to its capability to perform. What if this limit does not meet your requirements?

In the material in this chapter, we will explain some advance control concepts that could be used to enhance the basic simple loop.

# 6.2 System Component Descriptions

**Introduction**

Table 6-1 lists the descriptions of the components to a Multi-loop system.

Table 6-1 System Component Descriptions

| Components | Description |
|---|---|
| 1. dp | The *differential pressure transmitter* measures the DP across a specially calibrated orifice in the flow vessel. From the fundamental formula Q = •DP, it can be found that the quantity of flow (Q) is a function of the measured DP. The transmitter linearly converts DP to a standard electric signal (E), therefore (%DP = %E). |
| 2. ¦ X | The *square root extractor* generates an output that will relate to changes of its input in the following manner:<br>$\% E_{out} = \bullet\% E_{in}$<br>With an input of 25%, the output will be 50%. When used with the dp transmitter and orifice, the output of the square root extractor will change the square root signal to a linear flow signal.<br>$Q = \bullet DP$, and $E_{out} = \bullet E_{in}$<br>since $\bullet E_{in} = \bullet DP$ (dp transmitter measures DP)<br>then substituting,<br>$Q = E_{out}$ |
| 3. I/P | The electropneumatic transducer or I/P converts a standard electric current input into a standard compressed air output. By utilizing its air supply (not shown) it can be the interface between an electric controller and a *pneumatic control valve.* |
| 4. Ratio Relay | Although shown as a separate device, the *ratio relay* is often contained within a single ratio controller. Ratio relays are adjustable gain units. The change in the output of the relay will be directly proportional to the size of the change in its input. With a ratio of 1, the output will be a direct reflection of its input, but with a ratio setting of .5, an input change of 0 to 100% will result in an output change of only 0-500%. A typical ratio range would be .3 to 3. Higher ratios of the controlled variables would be accomplished by using unequal pipe diameters, orifice diameters or dp transmitters.<br>$\text{Ratio Setting} = \frac{\text{Output Change}}{\text{Input Change}}$ |
| 5. High Selector<br>Low Selector | High signal selection is one of two functions available from a device known as a *signal selector.* The other function is low selection. The device, which is classified as an auxiliary, receives at least two inputs and is programmed to select the highest or lowest value input. The selected input is then delivered to the output without being altered. |

## 6.3 Simple Feedback Control

---

**Introduction**

A simple feedback control loop consists of one measuring element, one controller, and a single final control element. In many cases, the loop will be capable of maintaining the process variable at the desired setpoint.

However, in the event of certain process disturbances, the simple loop will not always be capable of good control. Even with optimum controller adjustments, frequent process disturbances can create undesirable deviations from the setpoint.

This condition takes place because the controller cannot react fast enough to prevent the deviation. The controller only responds when an error becomes evident and by then, it can be too late.

---

**Illustration of a feedback control loop**

To understand this problem, it is necessary to examine the action of a slow changing variable of a simple feedback control loop.

The diagram in Figure 6-1 illustrates a feedback loop used in controlling the product temperature in a gas-filled reheating furnace.

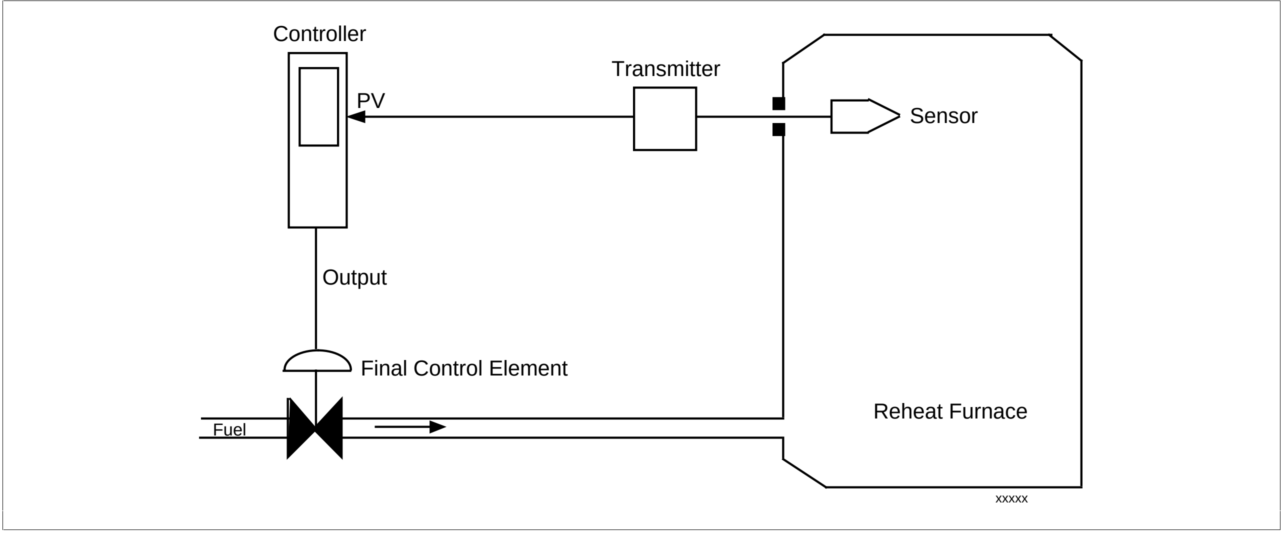
The thermocouple within the furnace generates a signal representing the value of the process variable. This signal enters the controller either as a direct millivoltage or a standard output signal from a field-mounted transmitter.

The local setpoint of the controller is adjusted to the desired value of the process variable and a sensitive device known as an error detector produces a signal representing the difference between these variables (PV and SP).

In an effort to nullify the error signal, the three mode controller produces a signal that will be a function of the polarity, magnitude, and rate of change of the deviation.

This output is of sufficient power to manipulate the position of the control valve, which in turn manipulates the amount of fuel entering the furnace.

Figure 6-1 Simple Loop



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**Slow acting processes**

In a steady state condition (all uncontrolled variables remaining constant) this control scheme should function favorably, but true steady state conditions are not found.

Process disturbances can enter the loop with a varying degree of impact. In applications of slow responding control variables (PV) and large disturbances, a multi-loop system may be required to minimize deviations.

**Factors determining fuel flow**

The flow of fuel through a modulating control valve will be determined by valve position and other factors such as fuel pressure, temperature, specific gravity, and so on. (For reasons of simplification, only valve position and fuel pressure will be examined at this time.)

If the fuel pressure should rise, the increased differential pressure across the control valve will result in a rise in fuel flow. With an increase in fuel flow, there will be a greater release of heat energy into the furnace. When news of the rise in temperature reaches the controller through the sensor and transmitter, it will readjust the control valve position as if the original valve position has been incorrect.

**Time factor**

Time elapses before the deviation is of great enough size to command that the controller take corrective action. A small amount of time elapses before the controller produces the correct amount of output, and due to the thermal inertial and energy holding ability of the slow acting process, a significant amount of time passes before the process responds to the readjusted valve position and returns to the setpoint.

The major problem in controlling the process variable during an unpredicted disturbance is the consumption of time. The controller will only change its output when an error has been detected . . . minutes after the disturbance has entered the process.

**What system to use?**

In this simple control loop, the system has been designed to control the process variable (temperature) by valve adjustment, although *heat supply* is actually the factor determining the temperature. A system which helps to overcome the serious time delays and poor control caused by fuel pressure and flow disturbances is called **cascade control**.

## 6.4 Cascade Control

### Introduction

The cascade loop is one of the most common multi-loop control systems in use today. The application of such a system can greatly decrease deviations of the primary variable and increase “line out” speed after a process disturbance has occurred.

### Reasons for considering cascade control

Some common reasons for considering cascade control exist in the previously discussed case involving the control of temperature in a reheat furnace.

In this example, fluctuations in fuel pressure created variations in the fuel flow. As the flow of fuel to the furnace changed, so did the amount of energy. The pressure fluctuations resulted in temporary deviations of the process variable, which could not be controlled adequately using only the simple feedback control loop. Avoiding the deviations was not possible because the disturbance entered the system without being detected, and once the error began developing, corrective action was initiated too late.

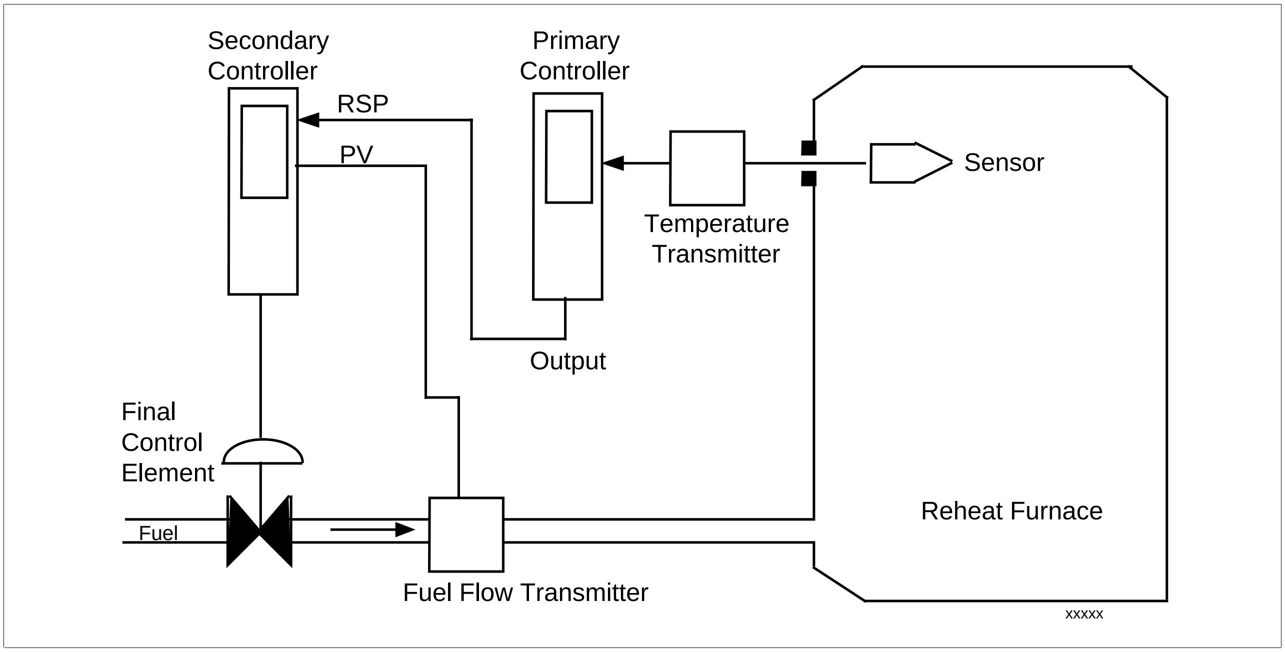
### Cascade control loop

In the simple loop shown in Figure 6-1, the output of the controller adjusted the final control element.

A c**ascade control** loop is shown in Figure 6-2. Note that the output of the temperature controller now adjusts the setpoint of a “secondary” controller, which in turn adjusts the position of the final control element.

The cascade loop shown in Figure 6-2 uses the “ground work” of the previously examined reheat furnace. The secondary variable used in this example is fuel flow.

Figure 6-2 Cascade Control Loop



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**How it works**

If the temperature of the product within the furnace is too high, the primary controller lowers its output, requesting a decrease in the fuel flow setpoint.

If the temperature drops, the device raises the setpoint of the secondary controller, which in turn increases the fuel flow to match its new setpoint.

In any case, the primary controller is controlling temperature by adjustments in the secondary controller’s setpoint.

Since the secondary controller is designed to measure and control fuel flow, the primary controller adjusts *fuel flow*, not valve position. Therefore, when a flow disturbance occurs, the fuel flow transmitter will notice it before it can adversely affect the process. The secondary controller will quickly readjust the valve position until flow once again matches the setpoint dictated by the primary.

**Secondary control loop**

The secondary control loop consists of a simple flow loop. This controller measures the flow of fuel and compares it to the value desired by the primary controller.

The function of the controller is to maintain the flow at the remote setpoint it receives. Note that with this configuration, deviations due to fuel should increase, there will be a rise in fuel flow rate.

Before this increased flow affects the temperature, it is detected by the secondary transmitter and thus, the secondary controller.

In an attempt to maintain a zero error between its PV and RSP (remote setpoint), the secondary controller quickly changes its output in a direction to reduce the fuel flow and reestablish a zero error. Because of the speed of response of this variable, as compared to that of the primary, the temperature changes very little.

**Conditions warranting cascade control**

The conditions existing in a simple feedback control loop that may warrant the consideration of cascade control are as follows:

1. Under control by the simple feedback control loop, the process variable is slow in responding to system disturbances and equally as slow in establishing a corrected output. This time consumption results in undesirable large deviations that optimum controller tuning cannot eliminate.
2. A change in the condition of the process causes serious upsets in the controlled variable.
3. The value of the variable other than the controlled one is being affected by the disturbance and there is a definite relationship between its value and the controlled variable.
4. The secondary variable is one that can be controlled. It responds swiftly to process disturbances and adjustments of the final control element. The value to which it is controlled must be dictated by the condition of the primary variable.

*Continued next page*

**Other points to consider**

In addition to the conditions given previously, some other points to consider about cascade control are:

1. In going to cascade control, at least two items of instrumentation must be added: A transmitter and sensor to measure the secondary variable and another controller.
2. The additional controller is a remote setpoint unit. This feature may call for a device that is slightly higher in cost as compared to a standard controller.
3. The secondary controller must be capable of controlling the secondary variable independently. In the previous example, the purpose of the secondary controller was to keep the flow at a desired level. Flow alone, as a major controlled variable, cannot be used because its value would not respond to PV load changes or changes in the setpoint. The controlled variable (temperature) is still of primary concern: The secondary is important only because its value affects the primary.

**How to choose a secondary variable**

In the cascade control loop previously introduced, it was noticed that the selection of fuel flow as a secondary variable was a good one. It should be obvious that to obtain the maximum benefits from a cascade control system, a wise choice of the secondary variable is a vital requirement.

How does one choose the most appropriate secondary variables? Application engineers have developed some “rules of thumb” for choosing the optimum secondary variable.

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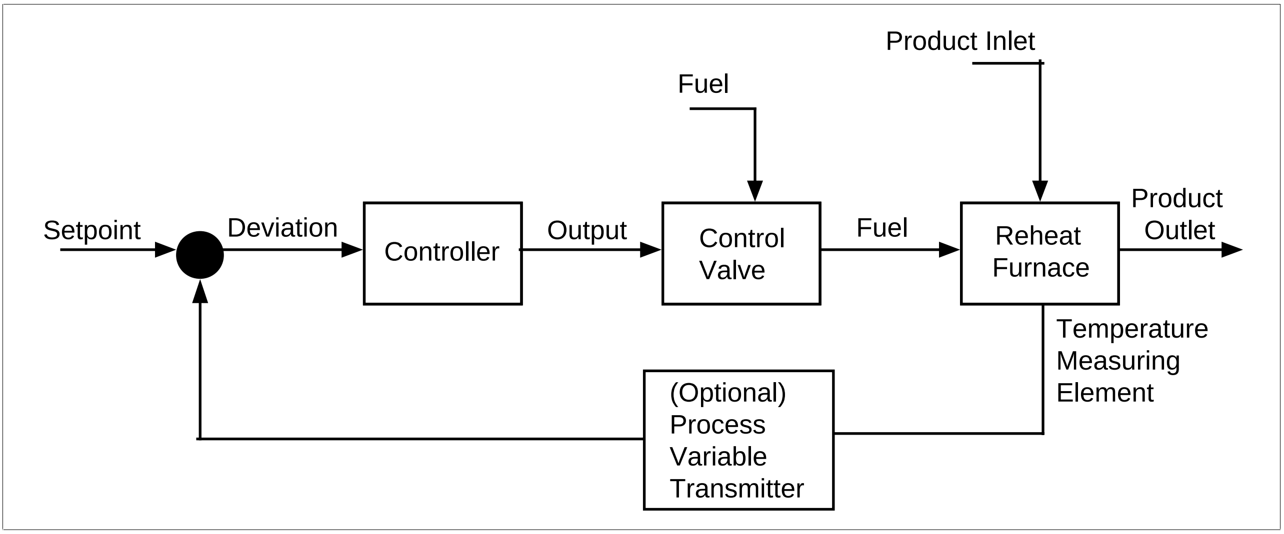
**Draw a simple block diagram**

To use these rules, begin by drawing a block diagram of the system to clarify its operation. A simple block diagram is shown in Figure 6-3.

Identify the point(s) of disturbance in the system. It may be helpful to divide the final control element block into two blocks: actuator and body (if a valve).

Figure 6-3 Simple Block Diagram



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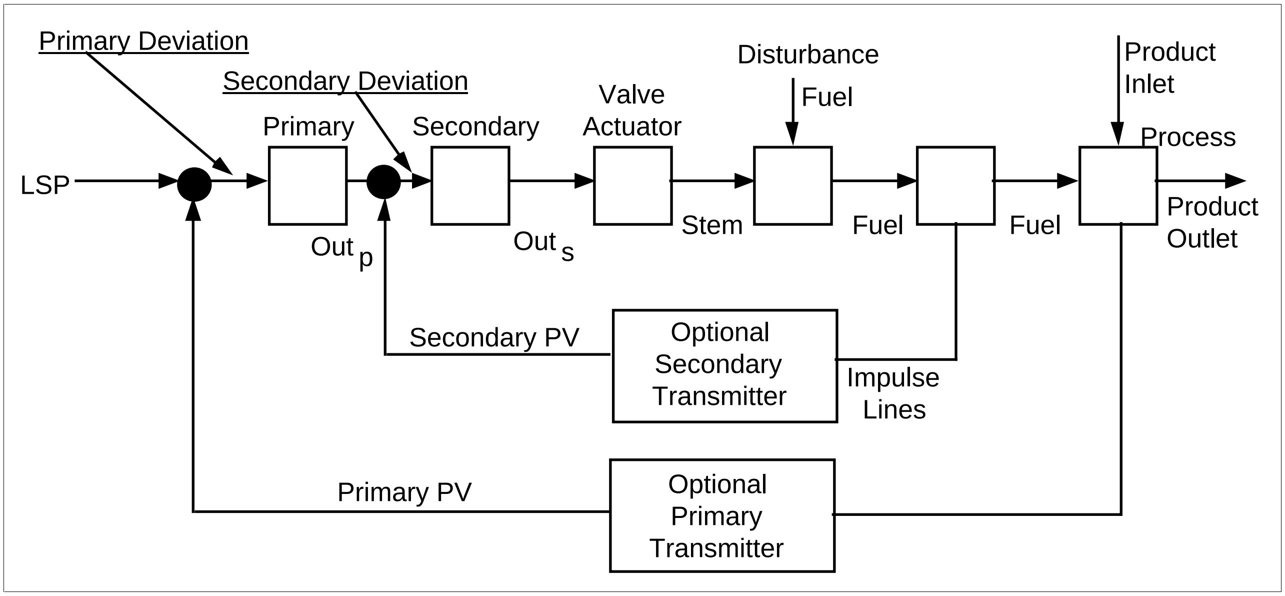
**Draw a detailed block diagram**

Next, draw a more detailed block diagram of the system in a cascade configuration, choosing one likely secondary variable, as shown in Figure 6-4. This figure depicts a completed diagram including all blocks existing between the measurement of the primary variable and the positioning of the final control device.

Figure 6-4 Cascade Control Loop



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**Rules for determining secondary elements and variables**

After the diagram has been made, plan possible alternates for placement of the secondary measuring element and selection of the secondary variable, using these five rules.

1. *Make the secondary loop include the input point of the most serious disturbances.* It is the effect of these disturbances which the cascade loop must be most successful in controlling.
2. *Make the secondary loop fast by including only minor lags.* When comparing the speed of response of the primary variable ($T_P$) to that of a possible secondary variable ($T_S$), the ratio of $T_P/T_S$ should preferably be at least 3. Ratios of 5 or 10 are even more desirable.
3. *Use a secondary variable with setpoint values that are definitely related to the value of the primary variable.* In undisturbed operation of the system, at line out, the relationship of the secondary setpoint to the primary variable should be represented by a single line. If the line is relatively straight rather than curved, this will simplify the tuning of the primary controller.
4. *If the secondary loop can remain relatively fast (see note 2), make it contain as many of the disturbance inputs as possible.* The improvements in close control after a disturbance has entered a cascade control loop will be roughly related to the gain settings of both controllers.

# 6.5 Predictive Feedforward Control

**Introduction**

In the previous section, cascade control systems were discussed. In these systems, the disturbance was noticed by the secondary sensor and controller, and brought under control before it could adversely affect the primary variable.

For cascade control to be a suitable option, the variable which is creating the disturbance (the secondary variable) *must be controllable.*

For example, in the reheat furnace of the previous discussion, the changes in fuel flow were causing process upsets. In this example, fuel flow could be controlled. In other words, it can be sensed by the secondary transmitter, and controlled in an on-going fashion by the secondary controller which manipulates the final control element.

It is the disturbed variable's ability to be measured, compared to a remote setpoint, and continuously corrected by a final control element which makes it suited for cascade control.

**When to use feedforward control**

In some applications, a disturbance takes place which cannot be controlled (although it can be measured). An example of such an application could be the disturbance in the feed rate of product through a heat-exchanger.

In this case, cascade control could not be used. However, a system called *feedforward* can anticipate and compensate for the disturbance, although control of the disturbance is not possible.

The simple loop and the cascade loop are both types of "feedback" control. There are several inherent limitations to feedback control, which the feedforward system improves upon:

- All feedback control systems obtain control by measuring the error and supplying a restoring output. The system *depends* on an error to generate a corrective signal. Without the error, the controller output is stable. When the error becomes evident, the controller must slowly integrate for correction. With a steady state error, gain and derivative cease to offer a contributing factor to the output.
- All feedback control systems obtain the correct output by trial and error. The system will never know the correct output necessary to solve the problem. The basic operation of the system is shown in Figure 6-5.

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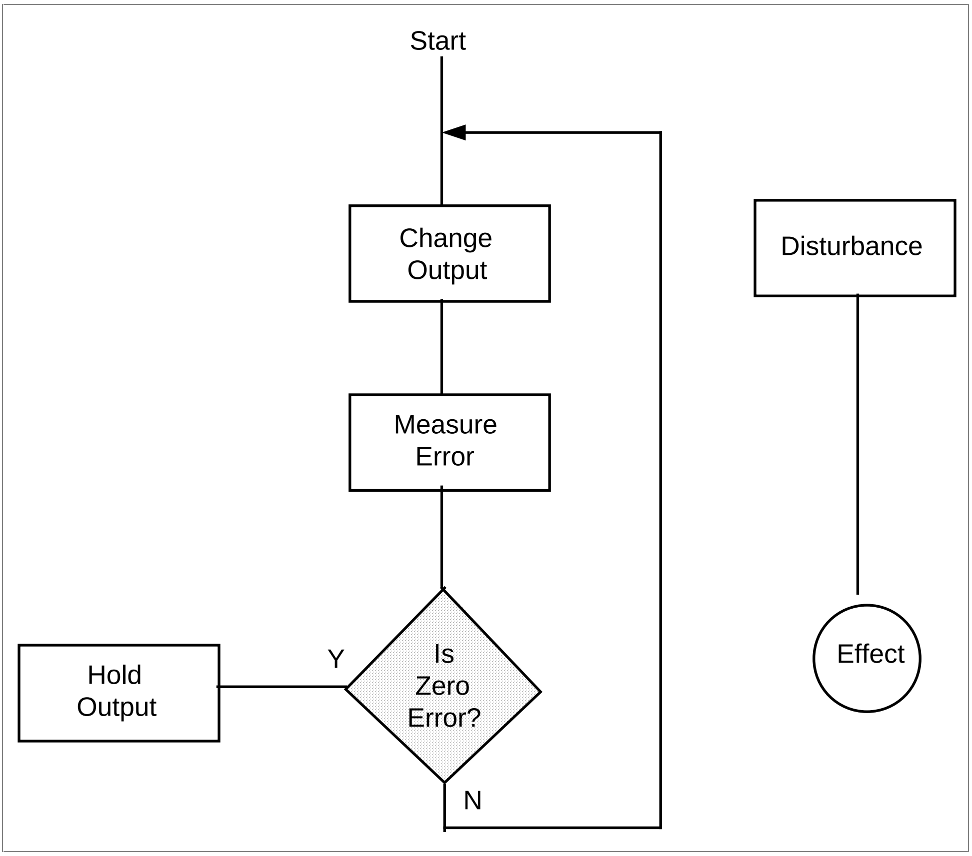
**When to use feedforward control, continued**

Figure 6-5 Trial and Error System



The simple flow diagram shown in this figure assumes that the controller output is changing in the correct direction.

Some degree of oscillation is common in any trial and error attempt at control.

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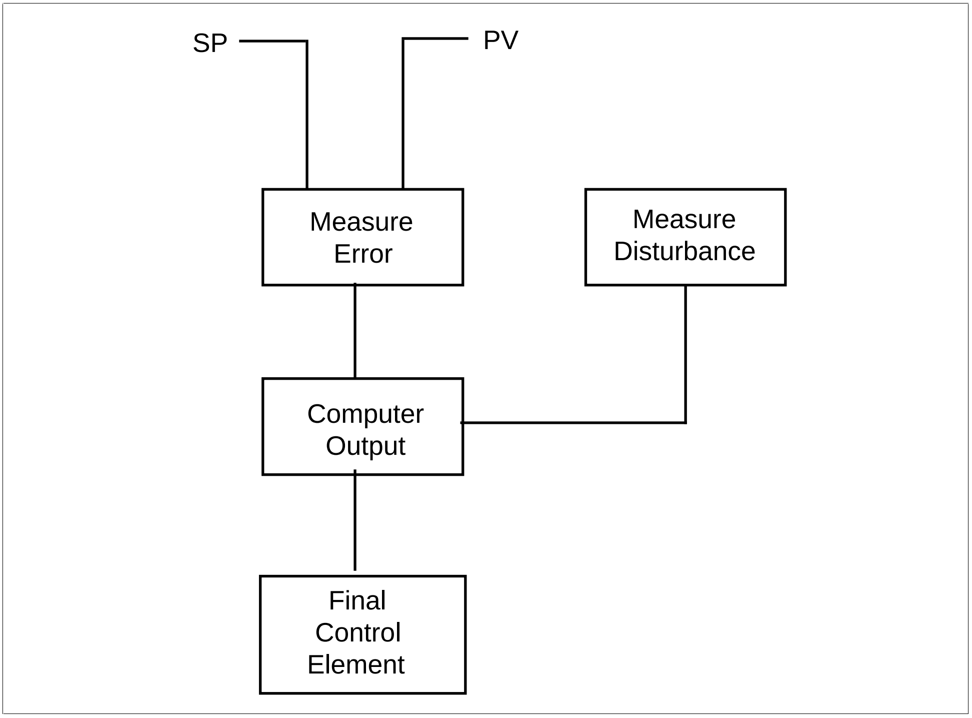
**An approach to feedback problems**

To find methods of solving some of the problems existing with feedback control systems, one would begin by considering a different approach. The approach would be to measure the principle factors that affect the process, and calculate the correct output to meet current conditions.

If a disturbance should occur, information will be fed to the final control device before the system senses that a problem has arrived. A flow diagram depicting this concept might appear as shown in Figure 6-6.

Figure 6-6 Feedforward Block Diagram



Note that in Figure 6-6, the system has no “return” of information. The correct output value is computed by changes in the setpoint, process variable, or fluctuations of external system disturbances.

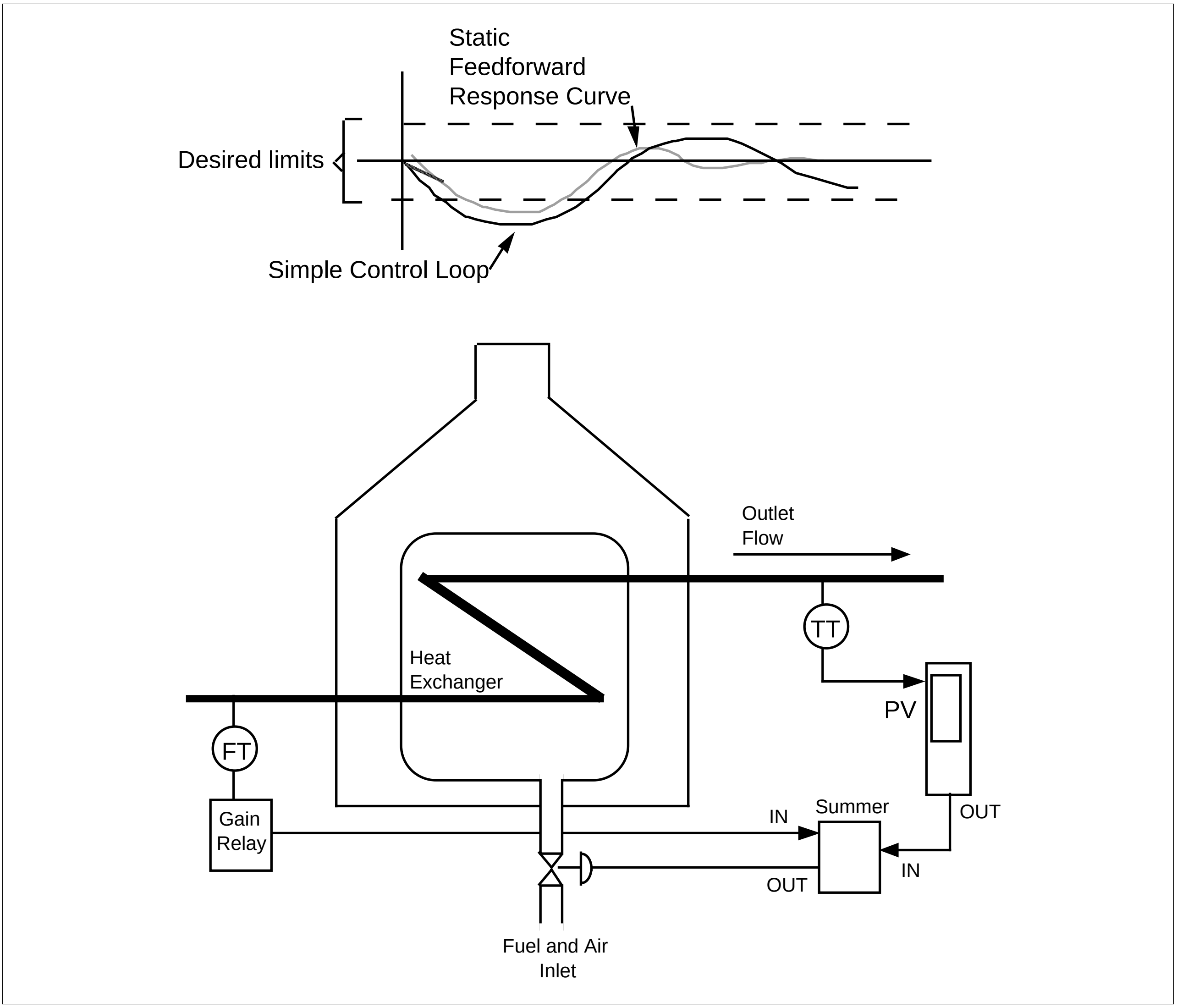
The process of feeding this information forward to compute the correct output value is known as FEEDFORWARD. The essential feature which distinguishes this system from feedback control loops is the forward flow of information. The feedforward scheme can produce tremendous improvements in control because in practice, it continuously balances the material or energy requirements of the process against the current demands of the load.

*Continued on next page*

**A simple feedforward control system**

Figure 6-7 depicts a simple feedforward control system. The loop is of the continuous form, wherein liquid is fed through a heat exchanger and is heated to a desired value. The controller output feeds the final control element through a summation auxiliary. The auxiliary is an analog adder that sums the values of its inputs.

Figure 6-7 A Static Feedforward System



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**A simple feedforward control system, continued**

The feedforward transmitter measures inlet flow to the heat exchanger, and its output is multiplied by the setting on the adjustable gain relay. The resulting feedforward signal becomes the second input to the summer.

If the influent feed rate should increase, the flow transmitter instantly feeds an increase signal to the summer. The magnitude of this signal will depend on the degree of feed flow increase and the gain set on the relay. The feedforward signal will increase the output from the summer and produce an immediate change in valve position. The increased fuel inlet can now prevent large deviations of the feed temperature from occurring.

**Static systems**

Feedforward strategies that compute corrective output values in a manner independent of time are known as *static* systems. The computed output was instantaneous and is designed to anticipate current demand changes. Figure 6-7 is an example of a static system.

## 6.6 Dynamic Feedforward Control

---

**Introduction**

Applications often exist, as in the previous example, where predictive feedforward strategies will offer a dramatic improvement in control of the process variable. Yet, even more improvement is sometimes obtainable by using **Dynamic Feedforward**.

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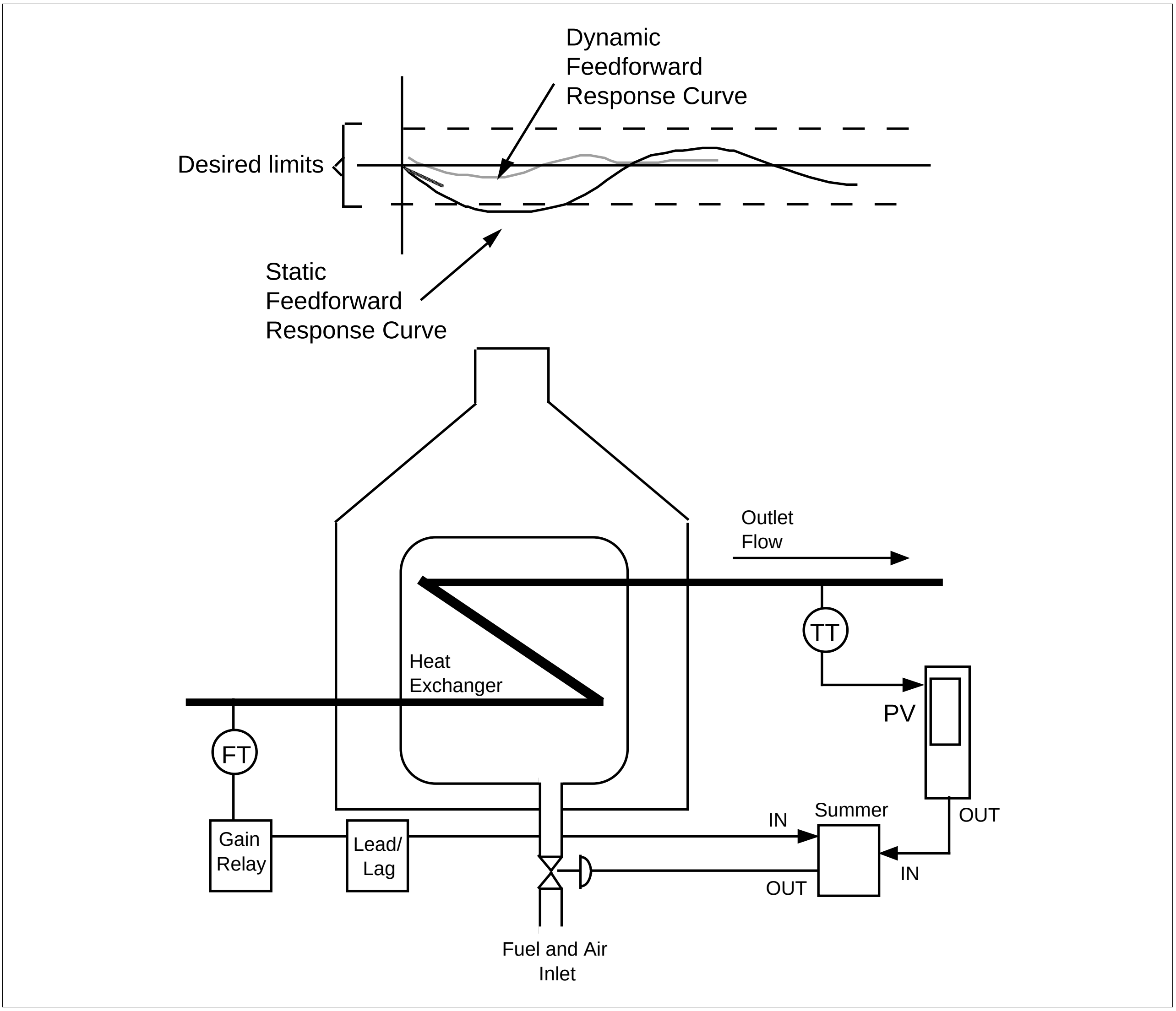
**Illustration of dynamic feedforward control**

An application of this system is shown in Figure 6-8.

Figure 6-8 Dynamic Feedforward System



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**How it works**

Assume that the increase of inlet feed had a much greater effect on product temperature. The alternative, in the static system, would be to increase the gain of the adjustable gain relay to cause a greater change in valve position. The stronger initial correction signal could create overcorrection—opening the valve too much, and causing a larger upset in the opposite direction. This deviation would have to be removed by the temperature controller.

The dynamic feedforward control system can provide more correction than the static system, yet not create the undesired overcorrection. With *dynamic* (or time variable) *feedforward*, the corrective signal will be momentarily large, then gradually cut back. By gradually cutting back the corrective signal, the process will not experience a large, sustained release of energy and overcorrection can be eliminated. The “time dependent” feedforward signal can be generated by another auxiliary device known as a Lead/Lag relay.

## 6.7 The Ratio Control Loop

**Introduction**

In many control applications, there are two or more inputs to a process which must be varied and controlled to meet process demand. The value of these variables (most often two flows) must be kept in a prescribed ratio to achieve a particular end product. The system which maintains this ratio is known as a **ratio control loop**. Some examples of ratio applications could be blending a base product with a thinner, water, and foaming agent, or air and fuel.

**Ratio control configurations**

There are two ratio control configurations that are commonly used: **Series** and **Parallel** configurations. There are definite advantages in choosing one over the other.

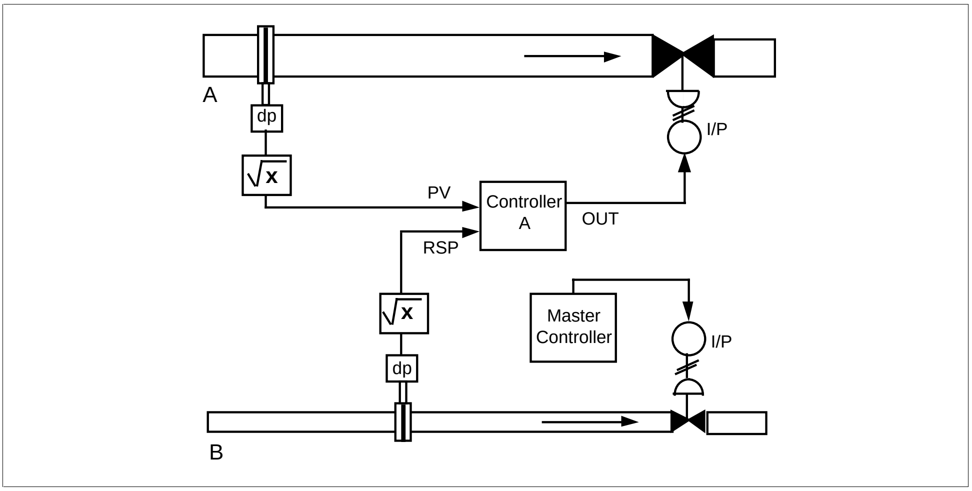
**Series configuration**

The **Series** system takes a “lead and follow” approach. According to the demand of the process, a master controller will control one of the variable (the “leader”) to a particular value. The “follower” variable will then be controlled by a remote setpoint controller to some predetermined ratio of the leader. This means that as the first input variable rises, so will the value of the second. If the leading variable falls to zero, so must the follower. This interaction is the primary characteristic of the **series ratio system**. These systems can be characterized by a definite interlock between the two controlled variables. This interlock can become a valuable safety feature.

**Series ratio system example**

Figure 6-9 illustrates the simplest method of accomplishing ratio control. The master controller, measuring the consistency of the final product blend, establishes the value of flow B. The flow is measured and its percentage equivalent becomes the setpoint of the flow A controller. Controller A is by necessity a remote setpoint controller, identical to the “secondary” controller of any cascade system. If flow B is 20%, then 20% becomes the setpoint for flow A.

Figure 6-9 Basic Series Ratio System



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**Series ratio system example, continued**

Notice that in Figure 6-9, the pipe for flow A is much larger than B. This will allow a “pre-set” ratio to be established.

For example, if the range of operation of pipe A is 0 to 1000 cfh and pipe B is 0 to 500 cfh, the A:B ratio of maximum flow capacity would be 2:1. The 20% fluid flow in pipe B would be 100 cfh, but in pipe A the flow would be 200 cfh.

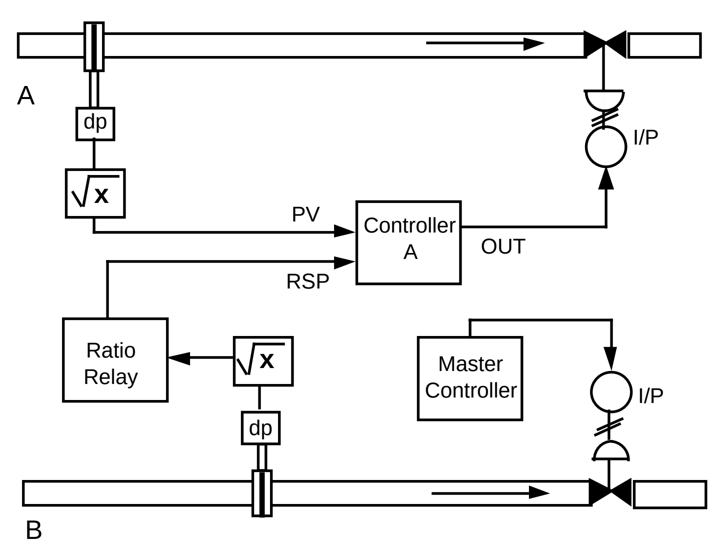
Since the value of A will be established by the value of B, the system is **serial.**

The ratio of flow is fixed by the scale ranges of both variables and cannot be changed without a major change in system hardware. If pipe A and B were the same size, the system shown in Figure 6-9 would only be capable of maintaining a 1:1 ratio, since there is no device in the system to multiply or divide flow B by some *gain* factor before sending it as a remote setpoint to controller A.

**Series system with ratio relays**

In the event that a ratio is desired other than the “pre-set” ratio established by the two pipe dimensions, another device must be added to the system. This device is called a “ratio relay” and is shown in the system in Figure 6-10.

Figure 6-10 Ratio Control System with Ratio Relay



This system provides one major advantage over the previous example. By using a device known as a **ratio relay** between the flow in pipe B and the flow A controller, the system will operate the same as example A, except that the ratio of the flows can be easily adjusted.

*Continued on next page*

### Series system with ratio relays, continued

The system remains serial because the value of flow B, although multiplied by the ratio, sets the value of flow A. Any fluctuations in flow B will be reflected in A. Note that the ratio, *as well as pipe size,* are now responsible for the actual ratio between the two flows.

For example, if pipe A and pipe B are the same size, and the ratio relay is set at “2”, then flow A will be twice as great as flow B. If pipe A is twice the size of pipe B, and the ratio relay is set at “2”, then flow A will be four times as great as flow B. If pipe A is one-third (.33) as great as pipe B, and the ratio relay is set at “.5”, then flow A will be (.33 x .5) or .165 times flow B, or about one-sixth of B.

### Parallel systems

The **parallel approach** to ratio control allows the master controller to set the value of both variables. Instead of one control system leading and the second one following, the parallel concept ties both systems to the direct command of the master. As process demand changes, the master controller adjusts the values of both control systems simultaneously.

Since both systems receive their setpoints from the master controller, they will respond to a change at the same time. How well the two systems are kept together will depend upon the *response characteristics* of each.

### Advantages of parallel ratio control

One of the advantages of parallel ratio control is that any noise occurring in the “leader” variable will not be reflected in the “follower”. Without the interlock, both systems are independent of one another.

This configuration can lead to yet another advantage. The simultaneous updating of both systems could result in a smaller deviation from the desired ratio during changes in process demand. The obvious disadvantage is loss of interlock safety. If one variable of a parallel system drops to zero, the second will not.

*Continued on next page*

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**Block diagrams of parallel ratio systems**

A simple block diagram of a parallel ratio system is shown in Figure 6-11, and a complete parallel ratio system is shown in Figure 6-12.

Figure 6-11 Parallel Ratio System Block Diagram

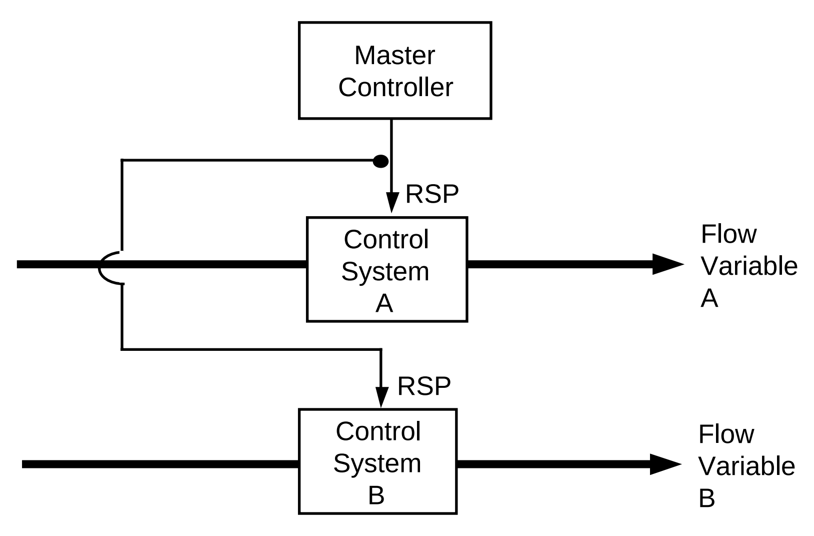
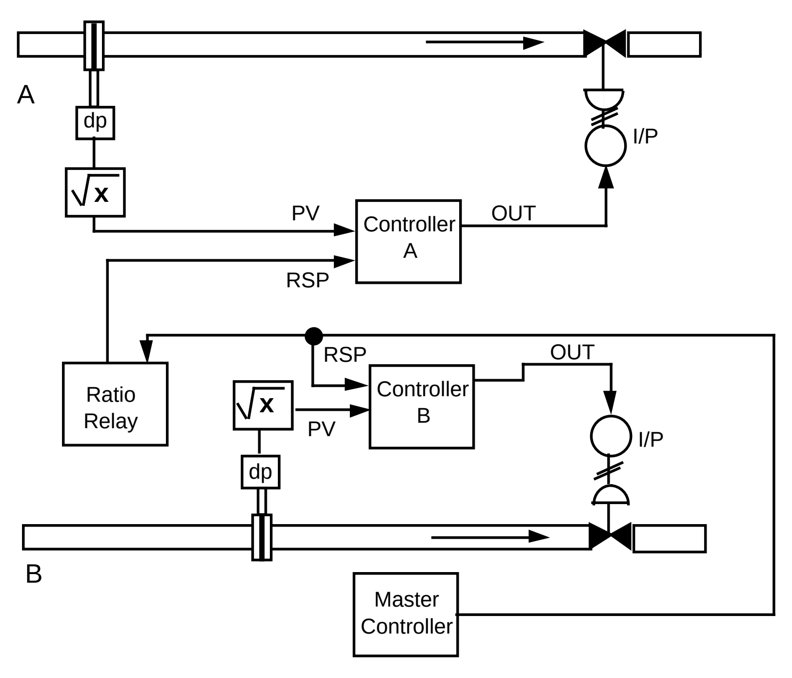


Figure 6-12 Parallel Ratio Control System



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**Parallel ratio system function**

This ratio control system has been designed so that instead of the master controller setting the value of flow B only, the master controller sets the flow values of both controllers.

Note that while in the series ratio system, the input to the ratio relay came from the flow B transmitter/square root extractor, in this system, the input to the ratio relay comes directly from the master controller. In the series ratio system, the RSP to controller A did not change until flow B *actually* changed, not when the master controller merely *called for* a change in flow B.

*In the parallel ratio system, the RSP to Controller A changes the moment the master controller calls for it.*

**Ratio relay adjustment**

The ratio of the two flows will be determined by the **ratio relay adjustment**. Since the master controller sends both setpoint commands in a parallel fashion to the flow controllers, both controllers will respond to a change at the same time. How well the flows track each other over changes in demand will again be determined by the two response characteristics.

**Parallel system disadvantage**

The parallel system will, in most cases, result in a better ratio control as process load changes occur. The basic disadvantage is the lack of flow interlock. If flow A should fall to zero in a fault condition, flow B will not be affected. Note that if an application arises where process personnel would like to momentarily interrupt one of the flows without affecting the other, this non-interlocked parallel system would offer such a possibility.

**Ratio system with interlock**

Some applications require that the ratio between the two flows never exceeds a set value in one direction, because the result may represent an uneconomical or unsafe condition.

A typical example of this is the air/fuel mixture in a burner. To keep the mixture from ever being too rich in fuel, an interlock system is used.

*Continued on next page*

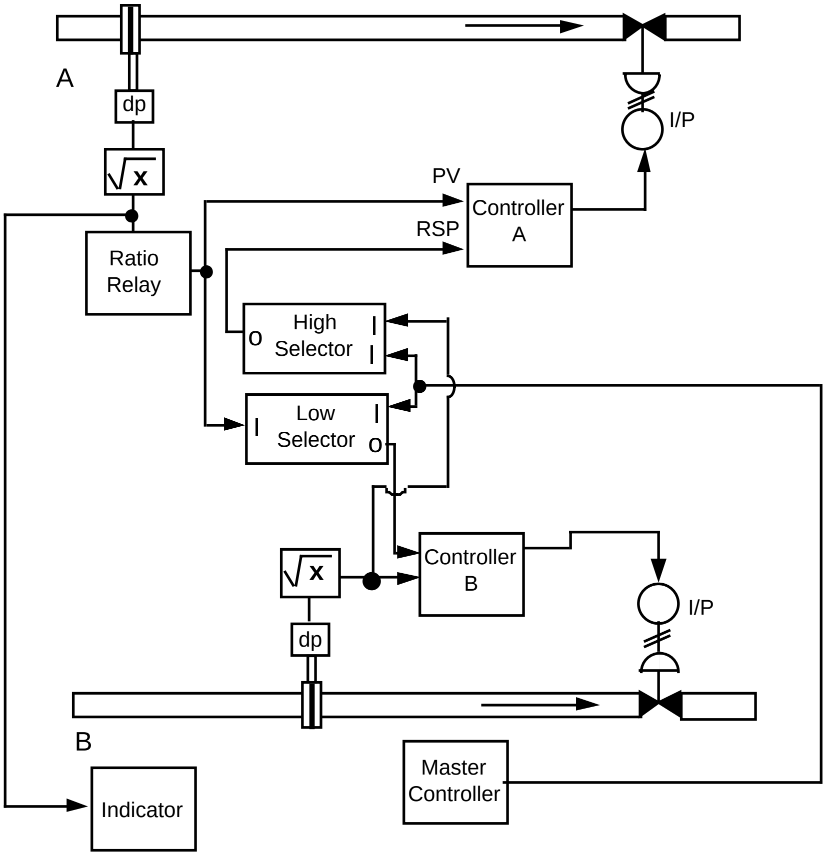
**Example of ratio system with interlock**

This system, shown in Figure 6-13, is capable of providing this form of interlock through the use of signal selectors.

In this example, if we use “X” to represent the desired ratio and A and B to represent the actual flows, then the ratio of the actual flow must be equal to or greater than the desired ratio. This is how the system must perform:

$$\frac{A}{B} \bullet X$$

Figure 6-13 Ratio System with Interlock



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# 6.6 The Ratio Control Loop, Continued

### Example of ratio system with interlock, continued

If we assume that the desired ratio has been met (A = X) then to satisfy the limits of the equation:

1) $$\boxed{\underline{\text{Holding}} \quad \frac{\text{A constant}}{\text{B cannot increase}}}$$

AND

2) $$\boxed{\underline{\text{Holding}} \quad \frac{\text{B constant}}{\text{A cannot decrease}}}$$

If a change in demand requires more of both fluids, note that to satisfy the first rule, flow B cannot increase unless flow A increases first. Conversely, to satisfy the second rule, if a decrease in both fluids is necessary, flow A cannot decrease unless flow B does so first.

Because the response times of both systems may not be equal, it is important to note that we cannot simply state that “one variable must change first”. We must ensure that one will lag the other, but accomplish this without the use of a time delay. A time delay may result in an increased offset from the desired ratio during changes in demand. (There may also be an unnecessary increase in system complexity.)

### Interaction and interlock between the two flows

In Figure 6-13, the interaction and interlock between the two flows can be achieved by allowing the master controller to set the flows in a parallel fashion.

The line between the flow B controller and its setpoint input from the master controller is bridged by a low selector. The other input to the selector is the PV of the flow A controller.

In the line feeding the setpoint input of the flow A controller, a high selector has been placed. The high selector has a second input, the flow measurement of controller B.

An adjustable ratio relay station has been placed in the PV input line to the flow A controller. In this way, the relay multiplies the actual PV of flow A times the ratio value. The controller then compares this value to its setpoint.

During a load change in the opposite direction, the converse will be true. With a decrease in demand, flow B must change first. After it has changed, flow A may begin changing.

In this example, the signal selectors will provide the interlock between flows that is necessary to keep the ratio on the safe side of the desired value at all times. When the system comes to a point of balance, all signal selector inputs will be equal. To display the actual value of flow A, an indicator has been added.

## 6.8 Analog Override Control Strategies

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**Introduction**

Override selectors are often used in applications that involve many controlled variables that are influenced by the value of a single manipulated variable. The function of the basic override selector will be to select either the highest or lowest value of its input, and channel this value to its output. Non-selected inputs will be open.

---

**How it works**

Assume that there are two inputs to an override selector. These inputs represent two process variables that are both affected by the value of one manipulated variable. However, the two process variables are affected in opposite directions by the same manipulated variable. That is, as the manipulated variable is changed in one direction, one of the process variables will increase as the other decreases.

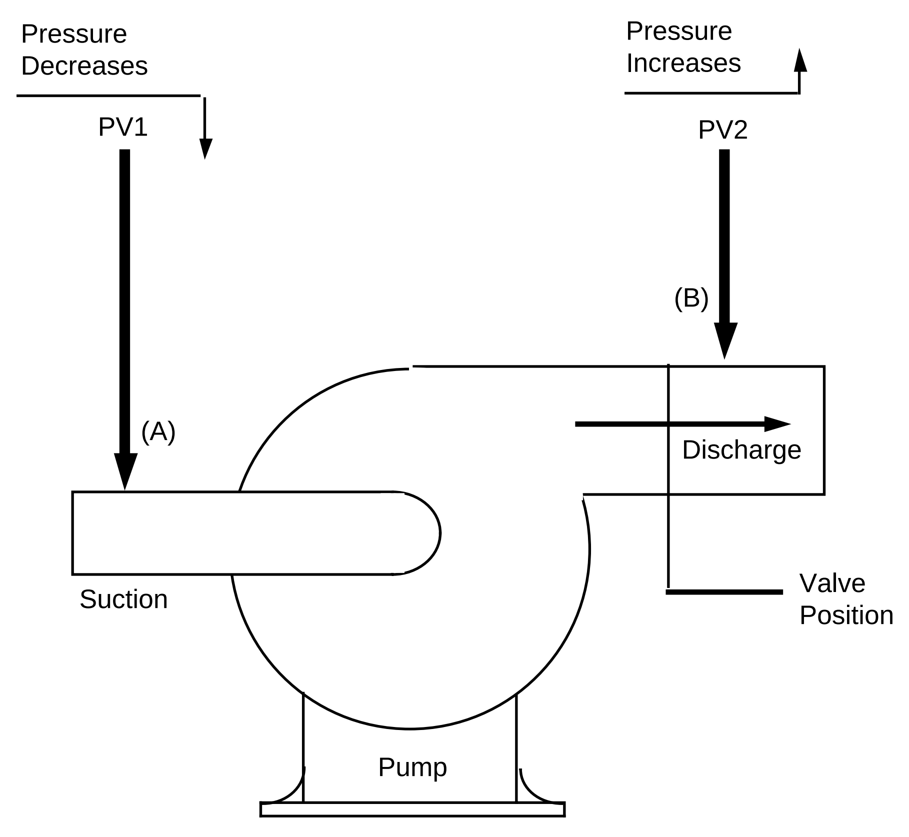
---

**Example**

A typical example of this would be the relationship between the position of a valve (manipulated variable), located on the discharge end of a compressor, and the suction (Process Variable 1) and discharge pressures (Process Variable 2) independently measured across the system.

Figure 6-14 illustrates this example.

Figure 6-14 Compressor Application



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**Example, continued**

With the pump running at a given speed, opening the valve would cause an increase in the suction measured at point A. If positive pressure is the measured variable, an increase in suction would be the same as a decreased pressure.

Although the upstream pressure (Point A) decreases due to an opening of the control valve, note that the same change in valve position will cause an *increase* in downstream pressure (Point B). This relationship between controlled and manipulated variables is a major reason why override strategies are frequently used in compressor and pump station controls.

---

**Objective of an override control system**

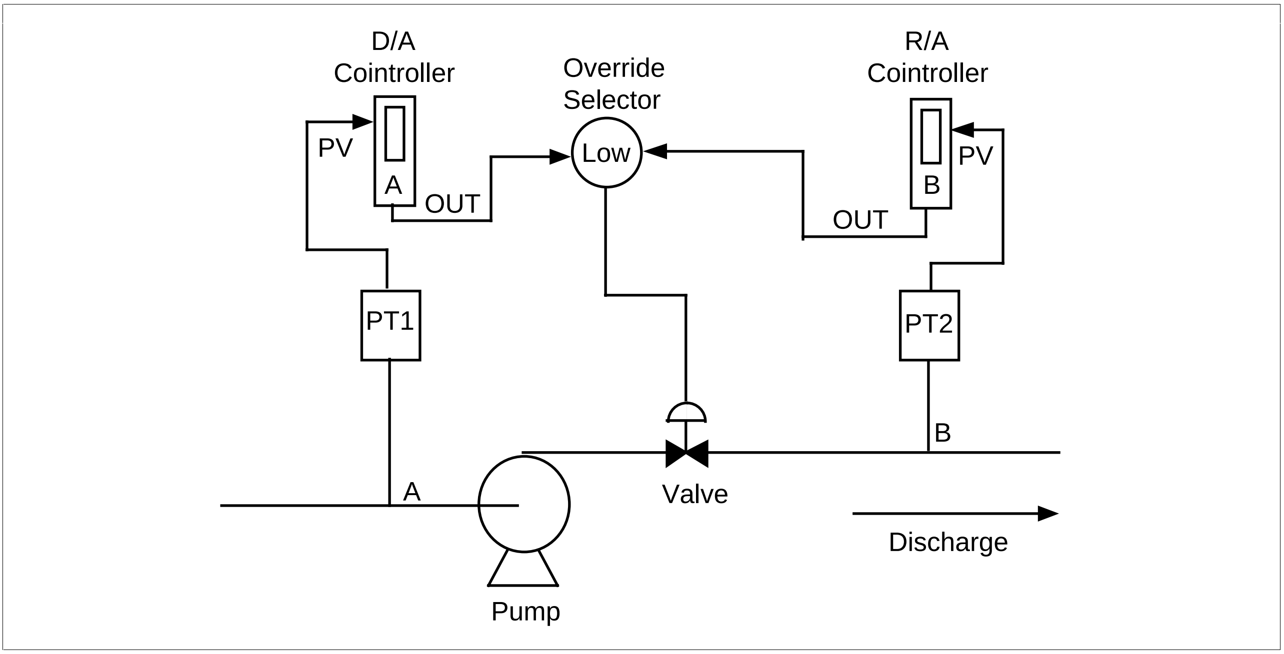
The objective of an override control system in compressor and pump control is as follows:

Maintain a given discharge pressure, but do not attempt to do so at the expense of drawing a dangerously high suction at point A. A high suction could cause compressor damage and/or pipe cavitation.

Figure 6-15 shows the control system which meets this requirement, using two controllers. The controller that is used to measure downstream suction is direct acting, while the other is adjusted to be reverse acting.

The outputs of both controllers feed the override selector, and it sends the signal of lowest value to the control valve. The valve is “air-to-open”, meaning that more output from the selector will open the valve more.

Figure 6-15 Analog Override System



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### Integral mode problems

A problem arises if either of the two controllers have the integral (automatic reset) mode of control. As mentioned earlier, non-selected inputs are “opened”. If the output of such a controller is not selected, integral wind-up will occur. To avoid this, one of two simple solutions can be used:

1) Both controllers can be proportional only, which would eliminate the problem.
2) Many override selectors are available with anti-windup protection on inputs designed for use with controllers having the integral mode of control.

### How it works

The controlled variable of primary concern will be discharge pressure.

A setpoint value representing the desired pressure will be set on this controller (controller B).

The suction pressure controller (controller A) will be set to a minimum safe level of pressure.

Unless the system experiences a fault condition, such as a shallow running supply or restricted line on the compressor inlet, the suction pressure should be well above the setpoint value of controller A. This variable is allowed to deviate from its setpoint, as long as the offset is in the acceptable direction.

The system will be normally selecting the output of controller B. Since this controller is reverse acting, its output will decrease to close the valve if pressure B moves above the setpoint.

Conversely, with the pressure dropping below the setpoint, the controller output increases to open the valve.

The increasing and decreasing output of this controller must remain below the output of controller A. This ensures that it will be selected.

If the compressor supply runs shallow, controller B will open the valve in an attempt to maintain the discharge pressure at its setpoint. As the valve is opened to control the discharge pressure, the pump suction increases. This reduction in inlet pressure reduces the output of controller A because A is a direct acting controller.

If the pressure at A reaches a dangerously low level, the override selector will select the low level output from controller A and send it to the valve. If the supply should begin running more shallow, note that the decreased pressure will cause controller A to *close* the valve. This action will decrease suction and maintain the inlet pressure at the minimum safe level.

Once the supply has been replenished, the compressor suction will decrease naturally, driving the output of controller A up, and the override selector will select controller B for “normal” control.

# Chapter 7 – Auxiliaries

## 7.1 Overview

**What's in this chapter?**

This chapter contains the following information:

**Introduction**

The topic table lists the Auxiliaries resident in the microprocessor memory of most controllers. The selection of an auxiliary is part of the configuration process of the controller.

# 7.2 Integrators

**Introduction**

In applications involving flow measurement, the primary element will usually indicate rate of flow. There are flow meters that indicate total flow (positive displacement devices), but the more common methods will produce a signal that represents an *instantaneous* value. For example, if a flow meter was used to detect the rate of flow of a fluid, the output signal could be compared to taking a “snap-shot” of the amount of flow for only an instant. Therefore, the flow rate which is indicated represents one instant in time, and the signal is a *continuous* measurement of the rate of flow of the process variable.

**The need for integration**

In many processes, an application may make it necessary to produce a history of the flow value over a period of time. For instance, a municipal water treatment plant must know the rate of influent sewage for controlling purposes. Along with controlling the purification of water, they must also report to the community the amount of water being treated each day. Such information can be obtained by integrating (totalizing) the flow signal over the one day period of time.

**Manual integration**

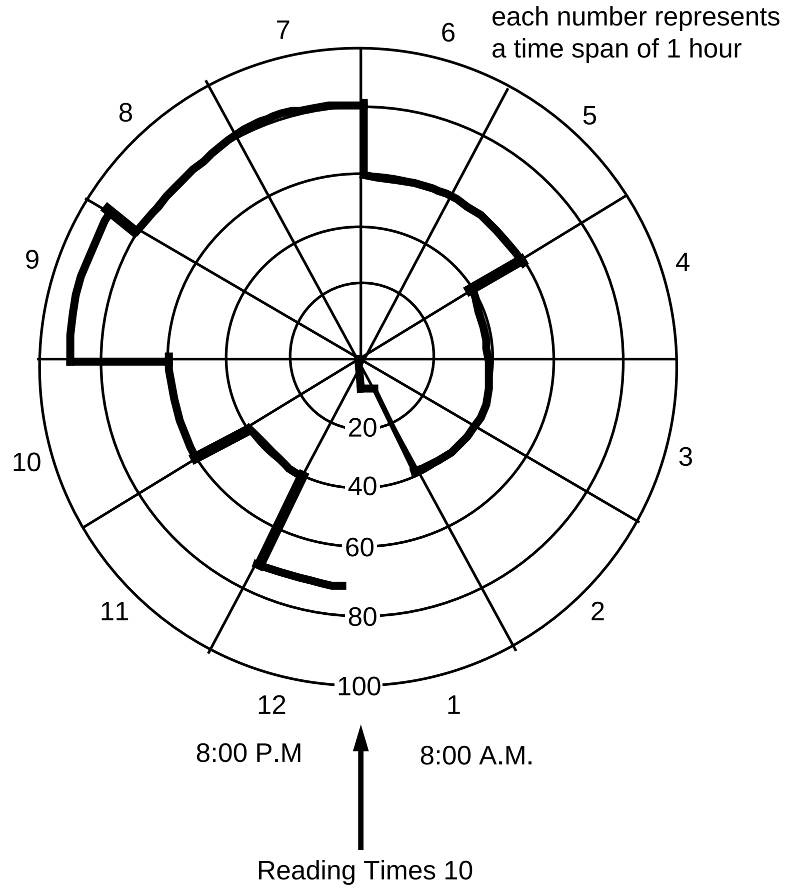
Integration, were it to be accomplished manually, could be rather involved and time consuming if the flow rate signal displayed on a chart is irregular (as it usually is). In an example where the flow is constant, a 50% rate of flow value on a 0-100,000 gallon/day chart, would yield a total daily flow of 50,000 gallons. In this case integration is simple.

*Continued on next page*

**Manual integration, continued**

The chart in Figure 7-1 shows a record of the rate of flow occurring in an application where the range of operation is from zero to one thousand gallons per hour. The chart is a twelve hour history of the changes that occurred. To totalize the flow signal on the chart, a human operator or an electronic device must calculate the area that exists underneath the curve drawn by the recorder pen.

Figure 7-1 Record of Rate of Flow



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**Manual integration, continued**

In order to manually totalize the flow in Figure 7-1, it is necessary to add the twelve one-hour flow rate values in order to yield the total flow between the hours of 8:00 A.M. and 8:00 P.M. Table 7-1 depicts this manual calculation and yields a total flow of 6,700 gallons.

Table 7-1 Manual Calculation of Total Flow

| Chart Selection | Time Span | Flow | Total Flow per Time Span |
|---|---|---|---|
| **#1** | 1 hour | 100 gal | 100 gal |
| **#2,#3, and #4** | 3 hours | 400 gal | 1200 gal |
| **#5 and #6** | 2 hours | 600 gal | 1200 gal |
| **#7 and #8** | 2 hours | 800 gal | 1600 gal |
| **#9** | 1 hour | 900 gal | 900 gal |
| **#10** | 1 hour | 600 gal | 600 gal |
| **#11** | 1 hour | 400 gal | 400 gal |
| **#12** | 1 hour | 700 gal | 700 gal |
| **Total** | 12 hours | | 6700 gal |

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**Auxiliary electronic integration**

Since most flow records will not be as "clear-cut" and easy to calculate manually as that in Figure 7-1, an electronic auxiliary accomplishes integration.

This calculation is achieved by producing a calibrated pulse train to a counter that continuously "counts" the total flow. As the flow rate decreases, so does the frequency of the output pulses. An electronic integrator might operate with a pulse rate output range from 0 to 50 ph to 0 to 50,000 cph. This means that a single unit will cover the desired span of most applications without a multiplication constant.

**Determining the integrator range**

To calculate the amount of counts that an integrator should produce with a constant input, the range must be known. The integrator range is determined by dividing the maximum flow by the period of time involved.

EXAMPLE: An integrator must be calibrated to indicate the total flow of water through a linear flow transmitter. Assume that the maximum amount of flow in the vessel was 20,000 liters per day. The desired period of time to which to calibrate the device is one hour. The relevant question becomes: *How many counts should occur in 1 hour?*

$$\text{Maximum Count} = \frac{\text{maximum flow}}{\text{unit number in flow period}}$$

$$\text{Maximum Count} = \frac{\text{20000 liters per day}}{\text{24 hours per day}}$$

$$\text{Maximum Count} = \text{833.33 counts per hour}$$

In one hour, with a 100% input signal, the integrator should count from zero to 833.3.

Since this device is a linear integrator, in 15 minutes, the counter should reach 1/4 of this value, or 208.33.

The range should be set so that with a 4 mA input, the count rate is zero, and with 20 mA input, the count rate should be 833.3/hour. No multiplication need be used for this application.

## 7.3 Square Root Extractors

### Introduction

The square root extractor is an auxiliary whose primary function is in the linearization of a differential pressure signal in the calculation of flow. When a fluid passes through a restriction in a flow vessel, there will be a change in the differential pressure across the restriction. If impulse taps were placed both upstream and downstream of the restriction, and the difference in pressures of both taps was measured, the measurement would show that the relationship of flow rate to differential pressure would be exponential. The formula describing this relationship is as follows:

Q = K ••P

*Where:*

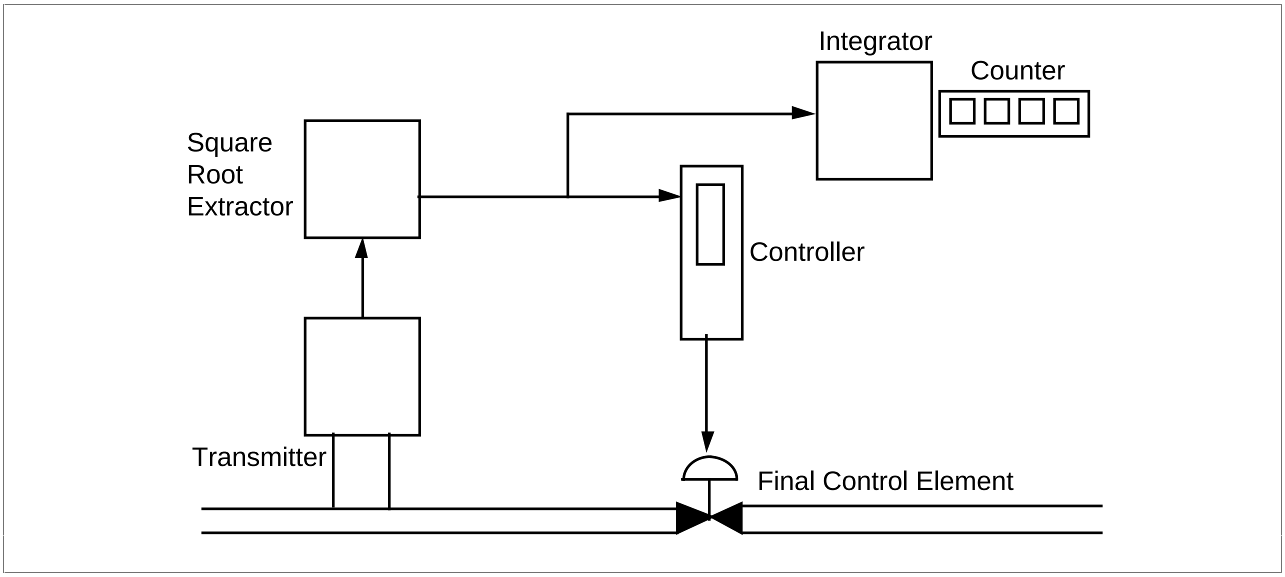
Q = The quantity of flow
K = A calibration constant that depends on the size of the restriction when compared to the inner pipe diameter, the maximum flow rate, and other non-changing parameters
•P = The differential pressure between the high pressure upstream side and the low pressure downstream side of the restriction.

The restriction can be any one of many primary elements. Depending on the application, the element could be an orifice plate, flow nozzle, venture tube, dall tube, or flow tube.

### Example of square root extraction

In applications that involve the totalizing of flow signals, it is mandatory that the signals be linearized before the calculation is made. Linearization is also necessary when it is desirable to use linear scales and charts instead of square root indications in system receivers. Figure 7-2 shows a typical loop using a square root extractor and a linear integrator.

Figure 7-2 Typical Loop using a Square Root Extractor and Linear Integrator;



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# 7.3 Square Root Extractors, Continued

**Input/Output percent values**

The chart shown in Table 7-1 depicts the input and output percent values for a correctly calibrated square root extractor.

Table 7-1

| % Input | % Out | % Input | % Out | % Input | % Out | % Input | % Out |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 25 | 50 | 50 | 70.7 | 75 | 86.6 |
| 1 | 10 | 26 | 50.9 | 51 | 71.4 | 76 | 87.1 |
| 2 | 14.1 | 27 | 51.9 | 52 | 72.1 | 77 | 87.1 |
| 3 | 17.3 | 28 | 52.9 | 53 | 72.8 | 78 | 88.3 |
| 4 | 20 | 29 | 53.8 | 54 | 73.5 | 79 | 88.9 |
| 5 | 22.4 | 30 | 54.8 | 55 | 74.2 | 80 | 89.4 |
| 6 | 24.5 | 31 | 55.7 | 56 | 74.8 | 81 | 90 |
| 7 | 26.4 | 32 | 56.6 | 57 | 75.5 | 82 | 90.5 |
| 8 | 28.2 | 33 | 57.4 | 58 | 76.1 | 83 | 91.1 |
| 9 | 30 | 34 | 58.3 | 59 | 76.8 | 84 | 91.6 |
| 10 | 31.6 | 35 | 59.2 | 60 | 77.4 | 85 | 92.2 |
| 11 | 33.2 | 36 | 60 | 61 | 78.1 | 86 | 92.7 |
| 12 | 34.6 | 37 | 60.8 | 62 | 78.7 | 87 | 93.3 |
| 13 | 36.1 | 38 | 61.6 | 63 | 79.4 | 88 | 93.8 |
| 14 | 37.4 | 39 | 62.4 | 64 | 80 | 89 | 94.3 |
| 15 | 38.7 | 40 | 63.2 | 65 | 80.6 | 90 | 94.9 |
| 16 | 40 | 41 | 64 | 66 | 81.3 | 91 | 95.4 |
| 17 | 41.2 | 42 | 64.8 | 67 | 81.9 | 92 | 95.9 |
| 18 | 42.4 | 43 | 65.6 | 68 | 82.5 | 93 | 96.4 |
| 19 | 43.6 | 44 | 66.3 | 69 | 83.1 | 94 | 96.9 |
| 20 | 44.7 | 45 | 67.1 | 70 | 83.7 | 95 | 97.5 |
| 21 | 45.8 | 46 | 67.8 | 71 | 84.3 | 96 | 97.9 |
| 22 | 46.9 | 47 | 68.6 | 72 | 84.9 | 97 | 98.5 |
| 23 | 47.9 | 48 | 69.3 | 73 | 85.4 | 98 | 98.9 |
| 24 | 48.9 | 49 | 70 | 74 | 86.0 | 99 | 99.5 |
|  |  |  |  |  |  | 100 | 100 |

# 7.4 Multiplier/Dividers

---

**Introduction**

A multiplier/divider is an analog computational auxiliary unit capable of performing one of seven mathematical operations. Each unit would typically be able to accept two or three 1-5 Vdc input signals and would compute a 1-5 Vdc output signal as a function of the program.

One of the most common applications of a multiplier/divider is in mass flow calculations. Mass flow is a type of flow measurement that is not only concerned with the differential pressure across a primary element, but also the **temperature** and **static pressure** of the fluid. By including pressure and temperature in the flow calculations the result will be a highly accurate measurement of flow.

---

**Conditions affecting static pressure**

If a gas is put into a confined area at a temperature and pressure equal to atmospheric conditions, the static pressure of the gas with reference to gauge pressure will be *zero*.

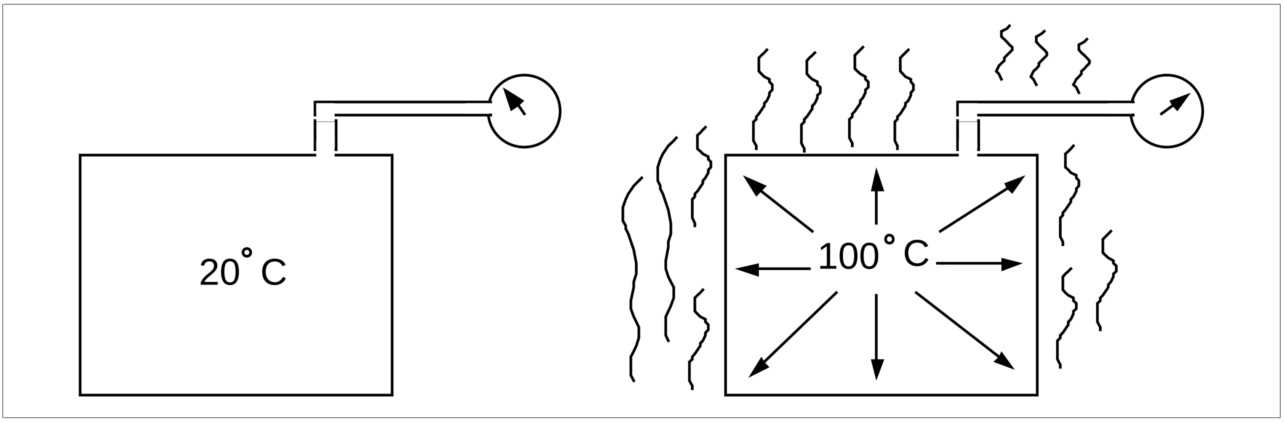
The two conditions that could affect the static pressure of the gas would be **change in temperature**, and a **change in the volume of the container**.

---

**Change in temperature**

Increasing the temperature will cause the molecules of the gas to move more rapidly. As the molecular motion increases, so does the tendency for the moving molecules to bombard the inner walls of the container. This bombardment will result in a higher static pressure. Likewise, colder temperatures result in lower pressures. This effect is shown in Figure 7-3.

Figure 7-3 The Effect of Temperature on Pressure;



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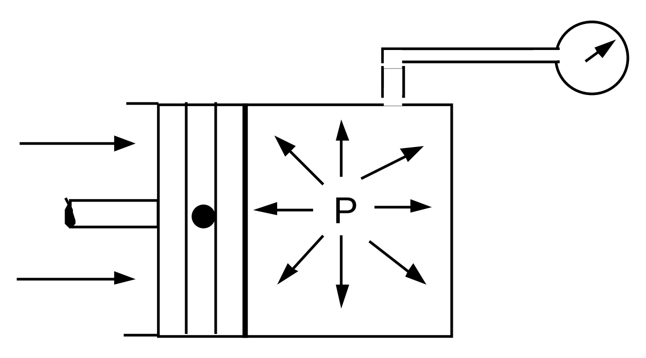
**Change in volume**

If the volume of the container is decreased, there will be a compression of the molecules of the gas. The compression of the molecules will also increase the static pressure. This effect is shown in Figure 7-4.

Figure 7-4 Change in Volume



In mass flow measurement, the temperature and pressure of the flowing fluid can affect the flow by changing the volume of the medium.

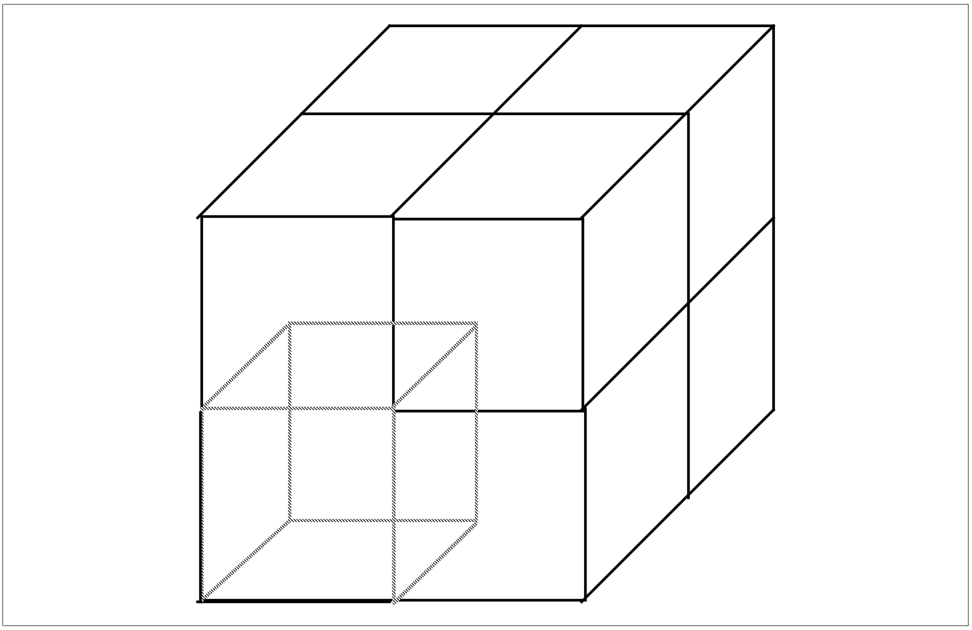
*Continued on next page*

**Increase in static pressure**

In Figure 7-5, the dotted area of the drawing represents one cubic foot of a methane gas. This volume of gas has the ability to do a specific amount of work. It can be assumed that it has the amount of energy equal to 1,000 BTUs. (The British Thermal Unit, or BTU, is the amount of energy required to raise the temperature of one pound of water, one degree Fahrenheit.)

If the pressure of the gas decreases, or its temperature should increase enough to cause the volume of the gas to be eight times larger than the original cubic foot, the potential energy on *one* cubic foot will be much less than 1,000 BTUs. This condition has changed the total mass of one cubic foot of methane.

Figure 7-5 BTU’s;



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## 7.4 Multiplier/Dividers, Continued

### Definition of flow

The definition of flow is the movement of a quantity of fluid past a given point in a particular interval of time. Examples of some units of flow could be gallons per hour, cubic feet per minute, or liters per hour. Using the same volumetric unit of measurement that was discussed previously, assume a fuel flow of 200 cubic feet per minute into a furnace. If one cubic foot of fuel has the potential energy of 1,000 BTUs, than a fuel flow of 200 cubic feet per minute will contain a specific amount of energy. The amount of energy being delivered to the furnace in any instant of time, depends on two variables: the rate of fuel flow and the mass of one cubic foot of fuel.

### Standard flow measurement

In standard flow measurement, a controller can correct for changes in the fuel flow that the furnace will receive by correctly manipulating a control valve, but without knowing the mass, the amount of energy can fluctuate. If the temperature of the fuel increases, the mass of one cubic foot will decrease. A decrease in the *amount* of fuel in a cubic foot will decrease the BTU content. Maintaining a constant flow will not always assure a constant temperature. This is why mass flow calculation is necessary—especially in applications involving high consumption of steam or fuel. Mass flow measurement is a much more accurate means of measuring flow than simple rate of flow measuring devices.

### Formula for mass flow calculation

The formula for mass flow calculation by differential pressure means is as follows:

$$\text{Flow} = \bullet\frac{(\bullet P)\,(P)}{T}$$

*Where:*

**•P** = The differential pressure measured across the primary element

**P** = The static pressure of the fluid in pounds per square inch absolute (psia)

**T** = The fluid temperature in degrees Rankine

**ATTENTION**

1) The temperature in degrees Rankine is equal to degrees Fahrenheit plus 460° (°R = °F + 460)

EXAMPLE: 120°F = (460° + 120°)R, so 120°F = 580°R

2) All variables must be zero based absolute. For example:

•P could be 0 to 100 in$H_2O$

P could be 0 to 30 psia

T could be 0 to 660°R

By using **scaling and biasing factors**, each variable will be altered to create zero based ranges.

# 7.5 Calculation of Scaling and Bias Constants

### Introduction

As an example, assume that the following PV ranges exist:

**•P** = 0 to 20 in$H_2O$
**P** = 0 to 30 psig
**T** = 0 to 150°F

On **differential pressure** measurement of flow, the low end of the range is always zero for a “no flow” condition.

With this transmitter calibrated from zero to twenty inches of water, the multiplication scale factor (SCALE) will be 1 and the biasing will be zero. There is no need to condition the differential pressure signal.

SCALE = 1
BIAS = 0

### Convert to absolute pressure

In pressure measurement, the 0 to 50 psig must first be converted to absolute pressure.

- Use the approximate value of 14.7 psi as atmospheric pressure,
- Add 14.7 to the high and low range values of the gage pressure readings (pressures in psia are approximately equal to the value in psig plus 14.7)

So 0 to 50 psig = 14.7 to 64.7 PSIA. Now the pressure value is in PSIA.

Next, the measurement must be zero based (14.7 to 64.7 PSIA must become 0 to 64.7 PSIA).

### Formula for choosing the scaling factor

The formula for choosing the scaling factor is the span of the transmitter divided by the zero based span.

Notice that the calibration of the transmitter will be 14.7 to 64.7 PSIA (a span of 50), and the scaling and biasing constants will cause the auxiliary to see 0 to 64.7 PSIA.

$$K_{scale} = \frac{\text{Transmitter Span}}{\text{Zero Based Span}}$$

Using this formula: $K_{scale}$ equals:

$$\frac{\text{Transmitter Span}}{\text{Zero Based Span}} = \frac{(14.7 \text{ to } 64.7)}{(0 \text{ to } 64.7)}$$

or

$$\frac{50}{64.7} \text{ which equals .773}$$

*Continued on next page*

**Formula for bias voltage**

The Bias Voltage can be calculated by the following formula:

$$K_{bias} = \left[\frac{LRV}{URV}\right] \text{ x 4 volts}$$

*Where:* LRV is the lower range value of the transmitter range in PSIA.

URV is the upper range value of the transmitter range in PSIA.

The transmitter range is 14.7 to 64.7 PSIA, so the LRV equals 14.7 and the URV equals 64.7.

This formula produces a ratio times the 4 Volt span (1-5 Vdc):

$$K_{bias} = \left[\frac{14.7}{64.7}\right] \text{ x 4 volts or .91 Volts}$$

Therefore, the pressure scaling and biasing values are as follows:

SCALE = .773
BIAS = .91

**Temperature measurement**

In temperature measurement, the transmitter span is 0 to 150°F.

First the Fahrenheit temperature must be converted to the Rankine scale: °Rankine = 460 + °Fahrenheit.

Using this formula, 0 to 150°F is equal to 460 to 610°R (a span of 150°). Making this value zero based yields 0 to 610°R.

To compute $K_{scale}$ and $K_{bias}$, use the same formulas that were introduced for pressure. In this example,

$$K_{scale} = \frac{\text{Transmitter Span}}{\text{Zero Based Span}} = \frac{150}{610} \quad \begin{matrix}\text{(460 to 610)}\\ \text{(0 to 610)}\end{matrix}$$

$$K_{scale} = .246$$

$$K_{bias} = \left[\frac{LRV}{URV}\right] \text{ x 4}$$

$$K_{bias} = \left[\frac{460}{610}\right] \text{ x 4}$$

$$K_{bias} = \text{3.02 Volts}$$

Therefore, the temperature scaling and biasing factors are as follows:

SCALE = .246
BIAS = 3.02

## 7.6 Verification of the Scaling and Bias Constants

---

**introduction**

The range of the transmitter is 0 to 50 psig. The function of the input conditioner of the multiplier/divider is to modify the transmitter signal so that it appears to be operating over a range of 0 to 64.7 PSIA.

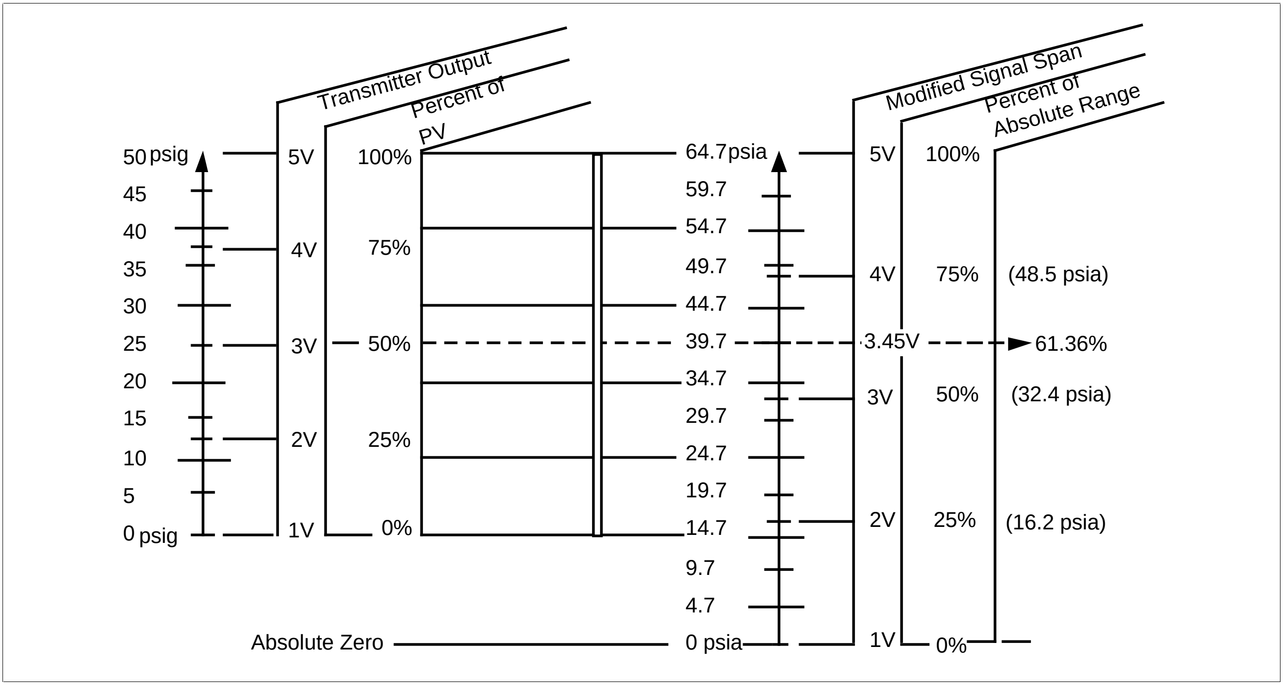
The calculated constants were:
SCALE = .773
BIAS = .91

If the actual range of operation (0 to 50 psig) was graphically placed beside the desired zero based range (0 to 64.7 psia), the result would appear as shown in Figure 7-6.

The zero percent end of the transmitter is 0 psig. The 50% and 100% values are 25 psig and 50 psig respectively.

What the input signal conditioner must do is modify the voltage equivalent of this range (1 to 5 Volts) so that it linearly represents the 14.7 to 64.7 psia span of the zero based range (0 to 64.7 psia).

Figure 7-6 Actual Range of Operation versus Zero-Based Range



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## 7.6 Verification of the Scaling and Bias Constants, Continued

**An example**

Assume that the pressure existing is 25 psig. By adding 14.7 psi to the gauge pressure value, the approximate equivalent on the absolute scale will be obtained.

25.0 psig + 14.7 psi = 39.7 psia—approximate atmospheric pressure measured by the transmitter.

The transmitter is measuring 39.7 psia.

If it is calibrated correctly, its output will be 50% of 1 to 5 Volts, or 3.0 Vdc. The measured value of 39.7 psia does not represent 50% of the zero-based range.

**Calculate the actual percent of span**

To calculate the actual percent of span that 39.7 psia represents, the measured value must be divided by the full scale span:

$$\frac{39.7 \text{ psia measured}}{64.7 \text{ psia scale span}} = 61.36\%$$

The measurement of 25 psig (39.7 psia), which is 50% of the transmitter range, must be modified to become 61.36% of the zero-based range.

**Check the operation of the input signal conditioner constants**

To check the operation of the input signal conditioner constants calculated earlier, calculate the desired voltage that should be obtained.

With an input voltage of 3.0 Vdc (50%), the output from the input signal conditioner of the multiplier/divider must be 61.36% of 1 to 5 Volts.

Removing the "LIVE" zero of 1.0 Volt, 61.36% of the full scale span of 4.0 Volts is 2.45 Volts. After the percent of span figure has been calculated, adding the "LIVE" zero of 1.0 Volt yields 3.45 Volts. This is the 25 psig equivalent signal on the zero based absolute scale.

Using the calculated constants of: ...

SCALE = .773
BIAS = .91

... the 3.0 Volt signal is the first zero stripped. In this way it becomes 2.0 Vdc. The zero stripped signal is multiplied by the input scanner of .773 to yield 1.546 Volts. Adding the input bias value of .91 Volt yields 2.456 Volts.

**Check the validity**

To check the validity of the signal conditioner, the +1 Volt "LIVE" zero must be summed with 2.456 Volts. The result is 3.456 Volts.

This operation has modified the 50% (3.0 Vdc) transmission signal, representing 25 psig or 39.7 psia, to appear as its equivalent in an absolute pressure range from 0 to 64.7 psia . . . or 63.36% (3.45 Volts).

*Continued on next page*

## 7.6 Verification of the Scaling and Bias Constants, Continued

**Conclusion**

This exercise has proved both constants to be valid ones. Note that the actual PV will not fall below approximately 23% of the modified signal span. This is the rough equivalent of a zero psig signal from the transmitter. This should not be viewed as a problem since the transmitter has been calibrated for a 0 to 50 psig range; so the actual PV should never fall into the vacuum range during normal operation.

**Graphical example**

Using the previous example for scaling and bias constants, assume that the A, B, and C Inputs are •P, Pressure, and Temperature respectively. See Figure 7-7. In this case, the multiplier/divider will be programmed for:

$$\frac{A\ B}{C}$$

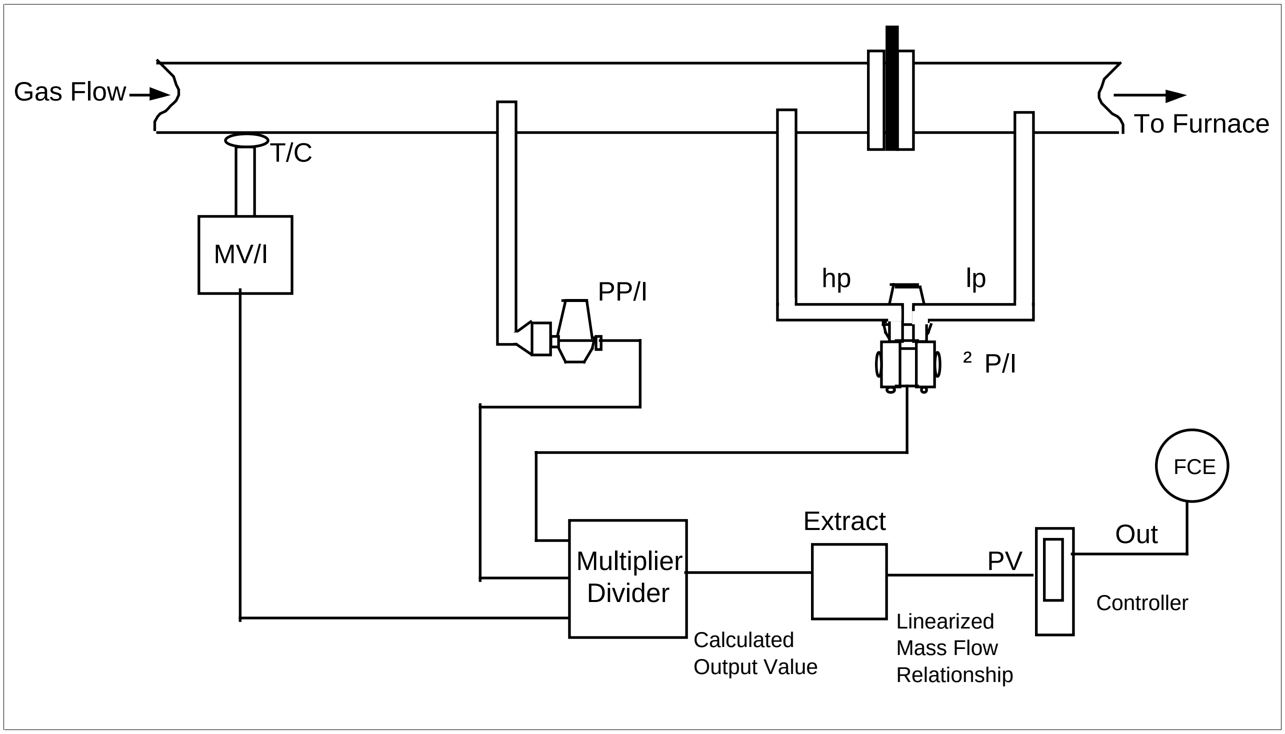
After the calculation has been made, the square root extractor will linearize the signal.

For Input A:
$K_{scale} = 1$ and $K_{bias} = 0$

For Input B:
$K_{scale} = .773$ and $K_{bias} = .91$

For Input C:
$K_{scale} = .246$ and $K_{bias} = .302$

Figure 7-7 Graphical Example



# 7.7 Adder/Subtractor

**Introduction**

The Adder/Subtractor is an analog computational device capable of accepting up to four 1 to 5 Vdc input signals. The output is a 1 to 5 Vdc signal which is a function of the program.

**A common application**

One common application for the Adder/Subtractor is the addition of fuel flows to furnaces. One such application is shown in Figure 7-8.

The furnaces are labeled A, B, and C.

The process variable in each control loop is the temperature of the raw material being treated. This application requires a need for the total instantaneous fuel consumption. Knowing the total flow during periods of peak usage will prove to be a valuable economical aid in plant operation.

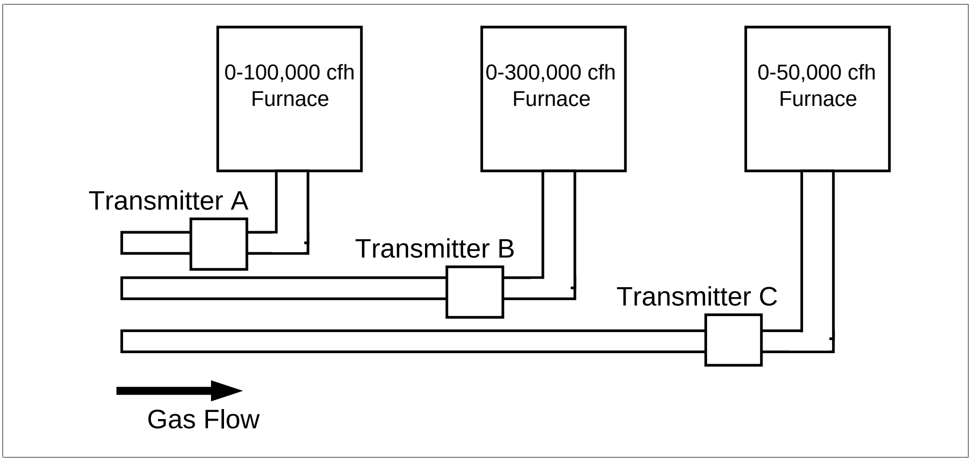
Furnace “A” -
operates in a range of 0 to 100,000 cubic feet of fuel per hour.

Furnace “B” -
Operates from 0 to 300,000 cfh, and

Furnace “C” -
operates from 0 to 50,000 cfh

All transmitters are 4 to 20 Millamp units.

Figure 7-8 Adder/Subtractor Application



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**The role of Adder/Subtractor in the loop**

Figure 7-9 shows the role of the Adder/Subtractor in the loop.

To add the three •P/I differential pressure signals, they must first be linearized with respect to a linearly changing flow.

The square root extractors accomplish this task by changing the exponential input change to a linear Output. The linearized flow signals enter their respective controllers, where the final control elements regulate the amount of energy delivered to each furnace.

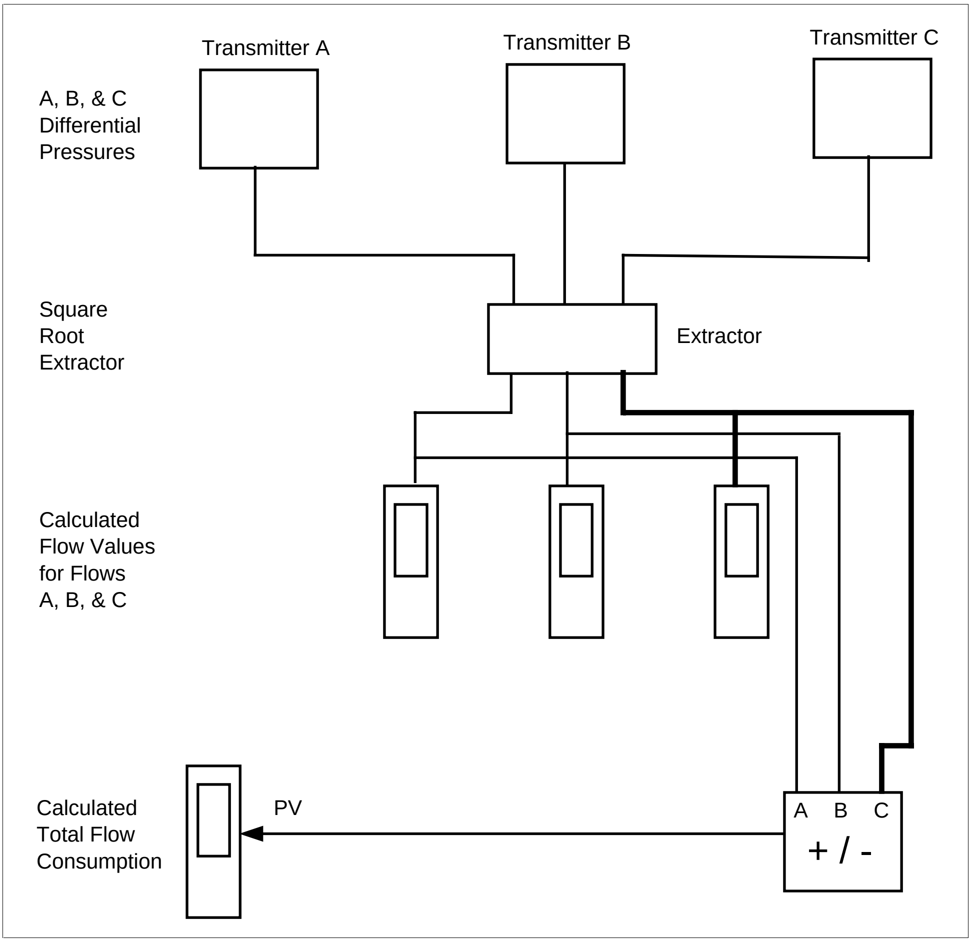
Each 1 to 5 Volt PV flow signal will enter the adder/subtractor which will add the three signals. Notice that a 100% output signal from each will represent different flow values.

In transmitter “A”, 5 Volts will represent 100,000 cubic feet per minute.

In transmitters “B” and “C”, 100% output will represent 300,000 and 50,000 cfh respectively.

Totalizing the three 100% signals without input scaling and/or biasing would be like adding apples and oranges. The three signals must be placed on an equal basis. To do this, the adder/subtractor provides a scaling factor from 0 to 2.0 Vdc and a Bias value of 0 to 8.0 Vdc.

Figure 7-9 The Role of the Adder/Subtractor in the Loop



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**Adder/Subtractor calibration coefficients**

The formula necessary for performing flow totalization in the previous example is as follows:

$$\text{Scale} = \frac{\text{Individual Max Flow}}{\text{Flow Total}}$$

Using the information provided on the previous page:

FLOW A = 100,000 Cubic Feet per Hour
FLOW B = 300,000 Cubic Feet per Hour
FLOW C = 50,000 Cubic Feet per Hour

In a 100% condition, the TOTAL FLOW will be
FLOW A = 100,000
FLOW B = 300,000
\+ FLOW C = 50,000
Total Flow = 450,000

Using the flow signals for each input will yield the necessary scaling constants.

**Scale for A**

$$= \frac{\text{Max Flow A}}{\text{Flow Total}} = \frac{100{,}000}{450{,}000} = .22$$

**Scale for B**

$$= \frac{\text{Max Flow B}}{\text{Flow Total}} = \frac{300{,}000}{450{,}000} = .67$$

**Scale for C**

$$= \frac{\text{Max Flow C}}{\text{Flow Total}} = \frac{50{,}000}{450{,}000} = .11$$

# Chapter 8 – How to Apply Digital Instrumentation in Severe Electrical Noise Environments

## 8.1 Overview

**Guideline overview**

Products that incorporate digital technology provide recognized performance advantages over conventional analog instrumentation used for process control. These advantages can result in better product uniformity and greater overall efficiency when used correctly.

There are, however, certain guidelines regarding installation and wiring which must be carefully followed in order to achieve this performance. In addition to the traditional precaution of the separation of signal and power wiring in separate conduits, other measures must be taken to minimize the effects of electromagnetic interference (EMI) and radio frequency interference (RFI) on the operation of the equipment. Otherwise, if high level, short duration, noise spikes are permitted to enter the digital equipment, the noise can be transferred into the system's logic networks and can be misinterpreted as signal data, resulting in erroneous system operation and other unpredictable responses.

**What's in this chapter?**

This chapter contains the following information:

## 8.2 Potential Noise Sources

**Overview**

Noise can enter electronic equipment via three methods of coupling, namely:

- Capacitive (or electrostatic)
- Inductive (or magnetic)
- Impedance.

**Capacitive and inductive coupling**

Capacitive and inductive coupling have the same essential effect — they couple current or voltage, without any actual connection of the two circuits. Impedance coupling requires a connection between the two circuits. Typical noise-generating sources that could affect electronic equipment through capacitive and inductive coupling include:

- Relay coils
- Solenoids
- AC power wires — particularly at or above 100 Vac
- Current carrying cables
- Thyristor field exciters
- Radio frequency transmissions.

**Impedance-coupled noise**

Impedance-coupled noise may enter by way of the lines used to power the digital equipment or by way of improper grounding. Most power lines, at typical industrial locations, are far from noise-free. The noise on them can be generated in many ways, but are nearly always associated with switching circuits of some nature.

These include:

- Large relays
- Contactors
- Motor starters
- Business and industrial machines
- Power tools
- HID (high intensity discharge) lights
- Silicon controlled rectifiers (SCRs) that are phase-angled fired.

## 8.3 Prevention Methods

**Introduction**

There are three ways to prevent electrical noise from interfering with the operation of the electronic digital equipment.

- Built-in noise rejection
- Separation of signal and power lines
- Noise suppression at source

**Built-in noise rejection**

The first method is to design the digital equipment with a high degree of noise rejection built in. This includes housing the equipment in a case that will provide shielding, liberal use of noise rejection filters and opto-isolators, and the use of noise suppressors on potential noise sources within the equipment itself. This, of course, is the responsibility of the manufacturer who usually performs extensive laboratory and field testing of newly designed digital equipment to insure the adequacy of its immunity to noise. As a minimum requirement, the equipment should be able to pass the tests outlined in the IEEE Standard 472-1974 *(Surge Withstand Capacity Tests).*

**Signal and power line separation**

The second method is to prevent noise from getting on the signal and power lines that are connected to the equipment. This is achieved by proper separation and shielding of those lines. In some cases, separate power lines or special power line regulation or filtering may be required for satisfactory electronic digital equipment operation. It is the responsibility of the installer to follow good wiring practices.

**Suppression at the source**

The third prevention method is to suppress the noise at its source. This is the most effective but also the most difficult because it is not easy to identify all of the potential noise sources in a typical industrial installation. Therefore, "suppression" is usually a last resort for those extreme situations where the other methods are insufficient by themselves. See *Noise Suppression at Source* which follows.

## 8.4 Recommended Wiring Practices

**General rules**

- All wiring must conform to local codes and practices.
- Wires carrying similar types of signals (Table 8-1) may be bundled together, but bundles with different types of signals must be kept separate to prevent inductive or capacitive coupling.

**Wire bundling**

Table 8-1 shows what wiring should be bundled together to prevent inductive or capacitive coupling.

Table 8-1 External Wiring

| Wire Function | | Bundle No. | Are Shielded Twisted Wires Recommended? |
|---|---|---|---|
| **No.** | **Type** | | |
| | HIGH VOLTAGE | 1 | NO |
| **1** | Line Power | | |
| **2** | Earth Ground | | |
| **3** | Line Voltage<br>Digital I/O | | |
| | ANALOG I/O | 2 | YES |
| **4** | Process Variable<br>RTD<br>Thermocouple<br>dc Millivolts | | |
| **5** | Low Level (<100V)<br>4-20 mA dc<br>1-5 Vdc | | |
| | DIGITAL I/O | 3 | YES |
| **6** | Low Voltage (<100V) | | |
| **7** | Computer Interface | | |

*Continued on next page*

**Additional rules**

Please observe these additional rules for wire bundling:

- For distances over five (5) feet, and when shielding is recommended, use a separate metal tray or conduit for each bundle. Where conduits or trays are not practical, use twisted wires with a metal overbraid and provide physical separation of at least one foot.

- Tray covers must be in continuous contact with the side rails of the trays.

- When unlike signal levels must cross, either in trays or conduits, they should cross at a 90-degree angle and at a maximum spacing. Where it is not possible to provide spacing, a grounded steel barrier or grid should be placed between the unlike levels at the crossover points.

- Trays containing low level wiring should have solid bottoms and sides. Tray covers must be used for complete shielding. Tray cover contact with side rails must be positive and continuous to avoid high reluctance air gaps, which impair shielding. Trays for low level cables should be metal and solidly grounded.

- Wires containing low level signals should not be routed near any of the following:
  - Contactors,
  - Motors,
  - Generators,
  - Radio transmitters, and
  - Wires carrying high current that is being switched on and off.

- Use a 12-gage (or heavier) insulated stranded wire for the ground connection. Attach it firmly to a proven good earth ground such as a metal stake driven into the ground.

- All shields should be grounded at one end only — preferably the instrument end.

# 8.5 Power Source Considerations

**Operate within limits**

The AC power for the digital electronic equipment must be within the voltage and frequency limits specified for that equipment. Attempts to operate outside the specified limits will result in no performance. For those installations where the supply voltage will not stay within the specified limits, a ferroresonant transformer, for voltage resolution, should be used.

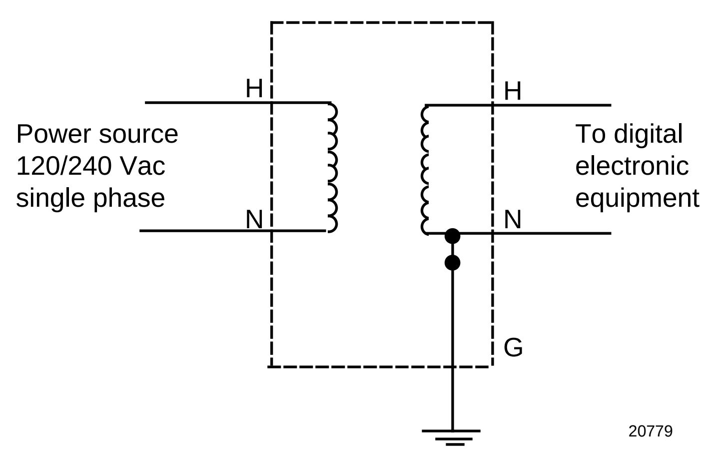
**Independent AC source**

For protection against noise, the AC source for the digital electronic equipment should be independent of all other loads especially when switching loads are involved. For example, it should not provide power for air-conditioning, convenience outlets, lighting, motors, or similar noise- generating devices. To obtain electrical isolation (see Figure 8-1) a separate transformer is required to supply power to the digital equipment. For additional noise and transient rejection, shielded primary and secondary windings may be required. And, if necessary, power line filters may be added to attenuate noise signals that have a higher frequency than the power line frequency.

**Transformer for digital equipment**

Figure 8-1 is an illustration of a separate transformer required to supply power to digital equipment.

Figure 8-1 Transformer for Digital Equipment



## 8.6 Noise Suppression at the Source

**Introduction**

Generally speaking, when good wiring practices are used with well-designed digital electronic equipment, no further noise protection is necessary. However, in some severe electrical environments, the magnitude of the electrical noise is so great that it must be suppressed at the source. In most control cabinets, the main sources of noise are motor starters, contactors, relays, and switching gear. For this reason, many manufacturers of these devices supply ”surge suppressors” which mount directly on the noise source (for example, on the coil of a control relay or motor starter).

For those devices that do not have accessory ”surge suppressors,” resistance-capacitance (RC) circuits and/or voltage limiters such as metal varistors may be added when and where needed. This can be broken down into two categories, namely inductive loads (for example, a relay switch in series with a relay coil) and contacts.

**Inductive coils**

Metal Oxide Varistors (MOVs) are recommended for transient suppression in inductive coils. An MOV is connected in parallel with the coil and is as close as physically possible to the coil (see Figure 8-2). MOV devices (listed in Table 8-2) are recommended for general purpose applications.

Table 8-2 lists part numbers for recommended MOV devices.

Table 8-2 MOV Devices

| Part Number | 30732481-501 | 30732481-502 |
|---|---|---|
| Maximum AC | 130V | 275V |
| Energy Pulse Rating | 10 Joules | 15 Joules |
| Supplier (General Electric) | V130LA10A | V275LA15A |

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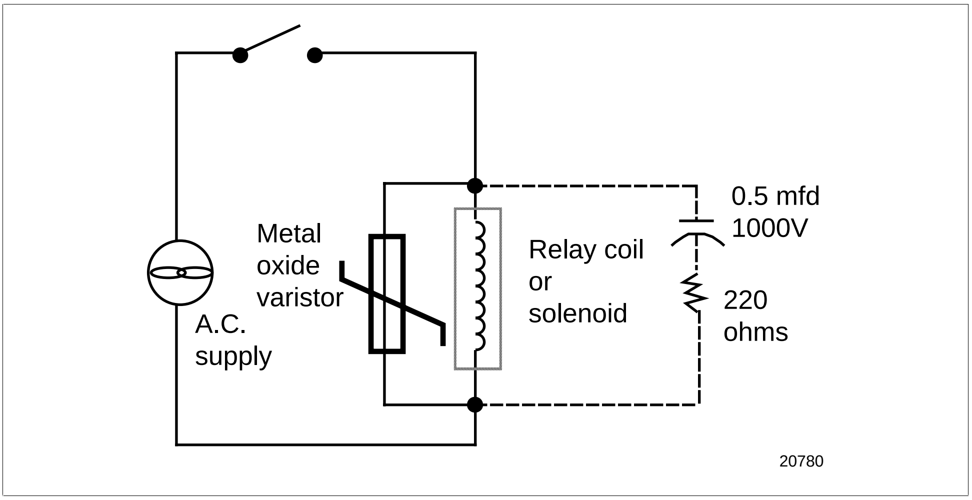
**Inductive coils, continued**

Figure 8-2 is an illustration of transient suppression in inductive coils.

Figure 8-2 Transient Suppression in Inductive Coils



Additional protection may be provided by adding an RC circuit in parallel with the MOV. This consists of a 220-ohm resistor in series with a 0.5 microfarad, 1000V capacitor. The power rating of the resistor will depend on the voltage rating of the coil (see Table 8-3).

Table 8-3 Coil Voltage vs Resistor Voltage Rating

| Coil Voltage | Resistor Voltage Rating |
|---|---|
| 115V | 1/4 Watt |
| 230V | 1 Watt |
| 460V | 3 Watt |
| 550V | 5 Watt |

*Continued on next page*

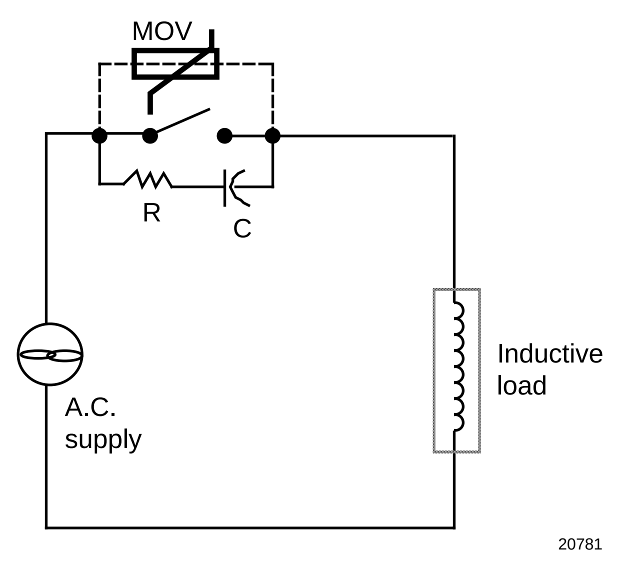
**Contacts**

When a contact interrupts an inductive load, a certain amount of energy is stored in the load. An MOV or RC circuit in parallel with the load provides a place where this energy may be dissipated. However, if there is no MOV or RC circuit, the energy may create a visible electrical arc across the open contacts. This, in turn, results in electrical noise as well as damage to the contacts.

One way to eliminate this arc is to connect a resistor and capacitor across the contacts (see Figure 8-3). A combination of 47 ohms and 0.1 microfarads (1000 Vdc) is recommended for circuits up to 3 amps and 300 Vac. For voltages above 2000 Vac, an MOV across the contact may be added for extra protection.

Figure 8-3 is an illustration of a resistor and capacitor connected across a contact to eliminate electrical noise.

Figure 8-3 Contact Noise Suppression



For large load currents, a rule of thumb is to size the capacitor so that the number of microfarads equals the number of amperes in the load current, and the resistor has the same resistance value as the load. The objective is to eliminate the visible arc.

Either discrete resistors and capacitors or packaged RC networks may be used. An RC network (47 ohms and 0.1 microfarad) is available from Honeywell as part number 30371852-001. Similar RC networks are available from Electrocube Inc. (part number RG1782-3) and from Industrial Condensor Corporation.

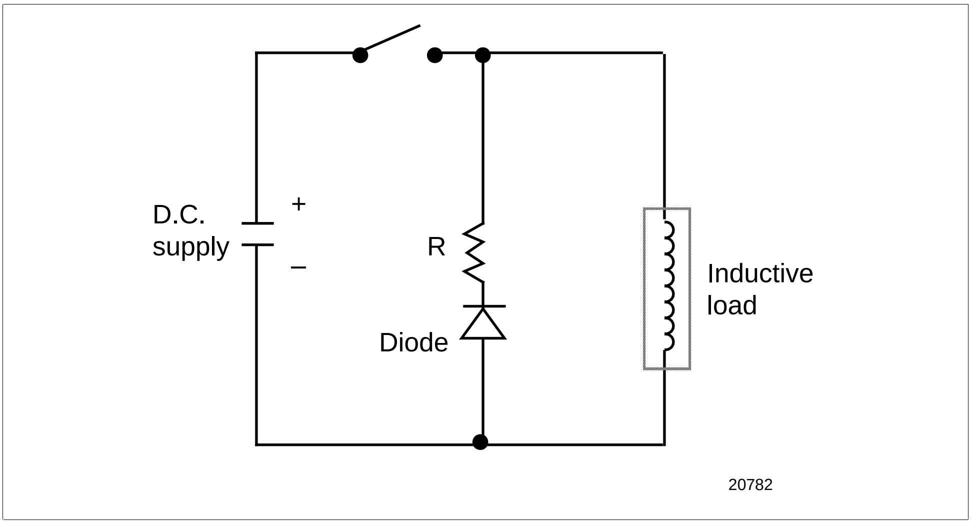
*Continued on next page*

**Contacts, continued**

In DC circuits, the power dissipation under steady state condition can be eliminated by placing a diode (in series with a resistor) in parallel with the load (see Figure 8-4). The value of R should be less than or equal to the DC resistance of the inductive load.

Figure 8-4 is an illustration of DC load noise suppression.

Figure 8-4 DC Load Noise Suppression



# GLOSSARY

## a

**Absolute Pressure** – the sum of gauge pressure plus atmospheric pressure. Absolute pressure can be zero only in a perfect vacuum.

**Accuracy** – the degree of conformity of an indicated value to a recognized accepted standard value or ideal value.

**Accutune** – continually (or On-demand) adjusts the Gain or Proportional Band (P), Rate (I), and Reset Time (D) tuning constants in response to setpoint changes and/or Process Variable disturbances.

**Actuation Signal** – the setpoint minus the controlled variable at a given instant.

**Actuator** – a controlled motor, relay, or solenoid in which the electric energy is converted into a rotary, linear, or switching action. An actuator can effect a change in the controlled variable by operating the final control elements a number of times. Valves and dampers are examples of mechanisms which can be controlled by actuators. *Also see Proportional, Spring Return, and Two-Position Actuators.*

**Adaptive Tune** – changes control parameters according to current process conditions. It identifies process gains and time that can be used to improve the response of a control loop.

**Alarm** – an audible device or visible signal indicating a malfunction or off-normal condition.

**Alarm Circuit** – an electrical circuit that includes a bell, horn, or similar device to signal an unsafe condition.

**Algorithm** – a prescribed set of well defined rules or processes for the solution of a problem in a finite number of steps.

**Ambient Temperature** – the temperature of the air surrounding the equipment.

**Amplifier** – a device used to increase the magnitude of a small input signal to proportions sufficient to perform some desirable function.

**Amplitude Ratio** – the size-relationship between two quantities obtained by dividing one size by another; specifically, the ratio of peak height of an output signal to the peak height of a related signal.

**Analog Input** – a continuous variable input.

**Atmospheric Pressure Compensation** – the value of the atmospheric pressure of the process when using the Relative Humidity algorithm.

**Auto Bias** – is used for bumpless transfer when transferring from local setpoint to remote setpoint. Auto Bias calculates and adds a bias to remote Setpoint input each time a transfer is mode.

**Automatic Control** – a system that reacts to a change or unbalance in one of its variables by adjusting the other variables to restore the system to the desired balance.

**Automatic Control Valve** – an electrically operated valve which combines a valve body and a valve actuator or motor. A signal from some remote point can energize the actuator or motor to open or close the valve, or to proportion the rate of flow through the valve.

**Automatic Mode** – the controller will operate from the local *or* remote setpoint and automatically adjust the output to maintain the setpoint at the desired value.

**Autotune** – automatically calculates Gain (PB), Rate (Derivative), and Reset (Integral) Time tuning constants on demand. These tuning constants are calculated at the end of the Autotune procedure based on the output step introduced onto the process.

# GLOSSARY

**Auxiliary Output** – generally a millivolt or voltage out that can be configured to represent a controller parameter (such as PV, an Input, setpoint, deviation or the control output). The range of the auxiliary output can be easily scaled by the operator.

## b

**Bargraph** – a vertical or horizontal display of discrete bars that represent the Setpoint, Output, or Deviation.

**Baud** – transmission speed in bits per second.

**Bias** – is used to compensate the input for drift of an input value due to deterioration of a sensor, or some other cause.

**Bumpless Transfer** – change from manual mode to automatic mode of control, or vice versa, without change in control signal to the process.

**Burnout (Sensor Break Protection)** – if the input fails, the indicated PV signal will increase (Upscale) or decrease (Downscale) with some indication on the operator interface.

## c

**Calibrate** – the procedure used to adjust the instrument for proper response (for example: Zero, Span, Alarm, and Range).

**Capacitance** – the change in energy or material required to make a unit change in a measured variable.

**Capacitive Load** – a leading load; a load that is predominantly capacitive, so that the alternating current leads the alternating voltage, i.e., the voltage does not change direction until after the corresponding current does.

**Cascade Control** – control action where the output of one controller is the setpoint of another controller. It can be used in a controller using two loops of control.

**Chassis** – a sheetmetal box, frame, or single plate on which the components of a device are mounted; the assembled frame and parts.

**Closed Loop** – the complete signal path in a control system; represented as a group of units connected to a process in such a manner that a signal started at any point follows a closed path and comes back to that point. The signal path includes a forward path, a feedback signal, and a summary point.

**Communications Address** – a number that is assigned to an instrument that will be its address in a communications message exchange.

**Configuration** – a dedicated operation where you use straightforward keystroke sequences to select and establish pertinent control data best suited for your application.

**Control Action** – the nature of the change of the output effected by the input. The output may be a signal or the value of a manipulated variable. The input may be an actuating error signal, the output of another controller, or the control loop feedback signal when the setpoint is constant.

**Control Element** – a component of a control system that reacts to manipulate a process attribute when stimulated by an actuating signal.

**Controlled Medium** – the substance (usually air, water, or steam) whose characteristics (such as temperature, pressure, flow rate, volume, level, or concentration) are being controlled.

**Controlled System** – the system made up of all equipment in which the controlled variable exists, but which does not include the automatic control equipment.

# GLOSSARY

**Controlled Variable** – that quantity or condition of a controlled medium which is measured and controlled. For example, temperature, pressure, flow rate, volume, level, or concentration.

**Controller** – a device which senses and measures changes in the controlled variable and *indirectly* acts to maintain the controlled variable within present limits.

**Control Mode** – designates the mode in which the controller will operate (such as Manual. Automatic with Local Setpoint, Automatic with Remote Setpoint, Manual-Cascade, Automatic-Cascade)

**Control Point** – the value of the controlled variable which the controller operates to maintain. *Also see Setpoint.*

**CSA Approval** – Canadian Standards Association approval.

**Current Duplex** – similar to current proportional but provides a second current output (split range) or a second current output via the auxiliary output for heat cool zones.

**Current Simplex** – supplies proportional direct current output for the final control element which require a 4 to 20 mA signal.

**Current/Time (Relay) Duplex** – a variation of duplex with current active for 50% output and relay active for 50% output.

**Cycle Time** – the length of one time proportional output relay cycle.

## d

**Damping** – the progressive reduction or suppression of oscillation in a device or system. It is built into electrical circuits and mechanical systems to prevent rapid or excessive corrections which may lead to instability or oscillatory conditions.

**Deadband** – is an adjustable gap between the operating ranges of output 1 and output 2 in which neither output operates (positive value) or both outputs operate (negative value).

**Derivative Action** – a type of control-system action in which a predetermined relation exists between the position of the final control element and the derivative of the controlled variable with respect to time.

**Deviation** – the difference between the setpoint and the value of the controlled variable at any instant.

**Differential** – the smallest range through which the controller variable must pass in order to move the final control element from one to the other of its two possible positions, such as from ON to OFF.

**Differential Gap** – the smallest increment of change in a controlled variable required to cause the final control element in a two-position control system to move from one position to its alternative position.

**Digital Control Programmer** – executes program control (setpoint programming) of process temperature, pressure, flow, rotation speed, and other variables.

**Digital Filter** – an algorithm which reduces undesirable frequencies in the signal.

**Digital Input** – information or data in digital form transferred or to be transferred from an external device into a computer or individual device.

# GLOSSARY

**Direct Acting Control** –in this control action, the controller's output increases as the process variable increases.

**Disturbance** – an undesired change in a variable applied to a system which tends to affect adversely the value of a controlled variable.

**DMCS Communications** – a communication link between Honeywell devices and a Honeywell supplied interface device capable of communicating via RS232 communications protocol with a host computer.

**Dropoff Value**– output value that below which the controller output will dropoff to the low output limit value that was configured.

**Duplex Control** – a control in which two independent control elements share a common input signal for the operation of separate final control elements both of which influence the value of the controlled condition.

## e

**Eight Segment Characterizer** – provides an 8-segment piecewise linear function generator which can approximate almost any curve shape (i.e., linearizing a process variable, characterizing a remote setpoint, or changing the opening characteristics of an installed control valve).

**EMI (Electromagnetic Interference)** – any spurious effect produced in the circuits or element of a device by external electromagnetic fields.

**Emissivity** – for radiamatic inputs. A radiamatic pyrometer converts radiant energy emitted by a target into electrical energy. Emissivity is a correction factor applied to the radiamatic input signal that is the ratio of the actual energy emitted from the target to the energy which would be emitted if the target were a perfect radiator.

## f

**Failsafe Output** – the output value to which the device will go to protect against the effects of failure of the equipment, such as, fuel shut-off in the event of loss of flame in a furnace or a sensor break.

**Feedback Control –** an error driven control system in which the control signal to the actuators is proportional to the difference between a command signal and a feedback signal from the process variable being controlled. *Also see Control.*

**Feedforward Control** – a method of control that compensates for a disturbance before its effect is felt in the output. It is based on a model that relates the output to the input where the disturbance occurs. In distillation the disturbances are usually feed rate and feed compositions. Steady-state feedforward models are usually combined with dynamic compensation functions to set the manipulative variables and combined with feedback adjustment (trim) to correct for control model-accuracy constraints. *Also see Control.*

**Feedforward Multiplier –** a feedforward algorithm that calculates a new output signal by multiplying the computed PID output value the the feedfoward signal (Input A) [i.e., **Output Signal = PID Output x (Input A x Ratio A + Bias A)**]. It then sends the resultant value to the final control element.

**Feedforward Summer –** uses Input A, following a Ratio and Bias calculation as a value summed directly with the PID computed output value [i.e., **Controller Output = PID Output + (Input A x Ratio A + Bias A)**]. The result is sent as an output value to the final control element. Applies to Loop 1 only. This algorithm will only function in the automatic mode.

**Fieldbus –** a bus that interconnects process control sensors, actuators, and control devices.

# GLOSSARY

**Field Wiring –** wiring that must be done at the installation site (in addition to factory wiring) in order to complete an installation.

**Final Control Element –** the device that directly controls the manipulated variable of a control loop.

**First-Order Lag –** a term used to describe the signal-delaying and signal-size-changing effects of a part of the control loop. The name comes from the form of the equation which represents the relation between output and input. The effects are evaluated by a "Time Constant."

**FM Approval –** Factory Mutual Association approval.

**Frequency –** the number of recurrences of a periodic phenomenon in a unit of time, usually expressed in hertz (Hz).

**Frequency Response –** the response of a component, instrument, or control system to input signals at varying frequencies.

## g

**Gain –** the ratio of the change in output to the change in input which caused the change. The reciprocal of Proportional Band.

**Gain Scheduling –** predefined separate GAIN tuning values automatically applied to predefined process variable regions.

**Guaranteed Soak –** guarantees that a setpoint programming segment's process variable is within ± deviation for the configured soak time. Whenever the ± deviation is exceeded, soak timing is frozen.

## h

**Hertz (Hz) –** a unit of frequency equal to one cycle per second.

**High Limit –** a controller which shuts down the system if a condition exceeds its maximum value for safe operation. *See Limit.*

**High Output Limit –** the highest value of output beyond which you do not want the controller automatic output to exceed.

**High Reset Limit –** the highest value of output beyond which you want no reset to occur.

**Hysteresis –** an adjustable overlap of the ON/OFF states of each control output or alarm.

## i

**Inductive Load –** a lagging load; a load that is predominantly inductive, so that the alternating current lags behind the alternating voltage; i.e., the current does not change direction until after the voltage does.

**Input –** signals taken in by an input interface as indicators of the condition of the process being controlled.

**Input High Selector –** algorithm that specifies the PV or SP as the higher of two separate inputs.

**Input Low Selector –** algorithm that specifies the PV or SP as the lower of two separate inputs.

**Integral Action –** a type of controller function where the output (control) signal or action is a time integral of the input signal.

# GLOSSARY

**Integrator –** a device whose output is proportional to the integral of the input variable with respect to time.

**Interference, electromagnetic –** any spurious effect produced in the circuits or elements of a device by external electromagnetic fields. *Also see RFI.*

**Internal Cascade –** a control system composed of two loops where the SP of one loop (inner loop) is the output of the other loop (outer loop).

**Intrinsic Safety –** a method to provide safe operation of electric process control instrumentation where hazardous atmospheres exist.

**ISA –** Instrument Society of America

**Isolated Circuit –** a circuit in which the current, with the equipment at reference-test conditions, to any other circuit or conductive part does not exceed the limit for leakage current.

## j

**Jumper –** a short length of wire used to compete a circuit temporarily or to bypass part of a circuit. Also, the action of using a jumper.

## k

**Knockout –** a removable portion in the side of a box or cabinet. During installation, it can be readily taken out with a hammer, screwdriver, or pliers so wires, cables, or fittings can be attached.

## l

**Lag –** a relative measure of time delay between two events, states, or mechanisms.

**Latching Relay –** real device or program element that retains a changed state without power.

**Limit –** a controller which continuously monitors a condition (such as temperature, pressure, or liquid level) in a controlled medium and responds immediately to shut down the system if a dangerous, predetermined condition occurs. It is normally set beyond the operating range of the controlled equipment.

**Limit Control –** a sensing device that shuts down an operation or terminates a process step when a prescribed limiting condition is reached.

**Linearity –** closeness of a calibration curve to a specified straight line. Linearity is expressed as the maximum deviation of any calibration point on a specified straight line, during any one calibration cycle. It is expressed as “within ±__ percent of full scale output.”

**Local Automatic Mode –** in this mode, the controller operates from the local setpoint and automatically adjusts the output to maintain the setpoint at the desired value.

**Local Setpoint –** setpoint determined by the controller or recorder.

**Lockout –** any condition which prevents any unauthorized configuration or calibration changes.

**Logic Gate –** used in solving math problems through a repeated use of simple functions which define basic concepts (i.e., AND, OR, NOR, etc.).

**Loopback –** tests communications hardware.

# GLOSSARY

**Loop Rate –** loop sampling rate for any input selectable from 3 to 12 conversions per second.

**Low Limit –** a controller which shuts down the system if a condition drops below its minimum value for safe operation. *See Limit.*

**Low Output Limit –** the lowest value of output below which you do not want the controller automatic output to exceed.

**Low Reset Limit –** the lowest value of output beyond which you want no reset to occur.

## m

**Manual Mode –** controller does not adjust the output for changes in SP or PV; output can be changed manually.

**Minutes Per Repeat –** the time between each repeat of the proportional action by reset.

## n

**NEMA Rating –** consensus standards for electrical equipment approved by the majority of the members of the National Electrical Manufacturers Association.

**Noise –** an unwanted component of a signal or variable which obscures the information content. *Also see Interference, electromagnetic.*

**Nonlinearity –** signifies that the relationship between the output and input is not representable by a single straight line.

## o

**Offset –** a sustained deviation between the actual control point and the setpoint under stable operating conditions.

**On/Off Control –** is the simplest control type. the output can be either ON(100%) or OFF(0%)

**Open Collector –** type of relay output.

**Open Loop –** a control system in which there is no self-correcting action for misses of the desired operational condition,as there is in a closed-loop system

## p

**Parity –** a binary digit added to a group of bits to make the sum of all the bits always odd (odd parity) or even (even parity)to verify data storage and transmission.

**PD with Manual Reset –** is used whenever integral action is not wanted for automatic control. The equation is computed with no integral contribution. The manual reset , which is operator adjustable, is then added to the present output to form the controller output.

**PID A Algorithm –** control algorithm normally used for three mode control. The output can be adjusted somewhere between 100% and 0%. It applies all three control actions- - Proportional, Integral, and derivative -- to the error signal

**PID B Algorithm –** control algorithm normally used for three mode control. The controller gives only an integral response to setpoint change, with no effect o, and it gives full response to PV changes.n the output due to the gain or rate action

# GLOSSARY

**Position Proportioning Control –** type of control that uses two SPDT relays and a motor which has a 100 to 1000 ohm feedback slidewire.

**Pot –** short for potentiometer.

**Potentiometer –** an electromechanical device consisting of a resistive element with a terminal at each end, and a third terminal connected to the wiper contact. As the wiper moves along the element, it changes the resistance in each leg (portion of the element between each end terminal and the wiper). Thus, the electrical input or output can be changed mechanically.

**Power Up Mode Recall –** determines which mode and setpoint the controller will use when the controller restarts after a power loss.

**Pressure Controller –** a controller which monitors the pressure of steam, air, gases, or liquids, and operates to keep the pressure within predetermined limits. It may operate as a pressure switch (ON-OFF), or it may be a proportioning controller.

**Process –** the manufacturing operations which use energy measurable by some quality such as temperature, pressure, or flow, to produce changes in quality or quantity of some material or energy.

**Process Variable –** any characteristic or measurable attribute whose value changes with changes in prevailing conditions.

**Proportional Band –** is the percent of the range of the measured variable for which a proportional controller will produce a 100% change in its output. The reciprocal of Gain.

**Proportional Control –** a control mode in which there is a continual linear relationship the deviation in the controller, the signal of the controller, and the position of the final control element.

## r

**Ramp Segment –** the time it takes to change the setpoint to the next setpoint value in the program.

**Ramp Time –** the time it takes for a setpoint ramp to reach the next or final setpoint.

**Range –** the region between the limits within which a quantity is measured , received, or transmitted, expressed by stating the lower and upper range values.

**Rate Action (Derivative Control) –** produces a corrective signal proportional to the rate at which the controlled variable is changing. It produces a corrective action faster than proportional action alone.

**Rate Time –** in the action of a proportional-plus rate or proportional-plus reset-plus-rate controller, the time by which the rate action advances the proportional action on the controlled device.

**Reference Junction –** a thermocouple junction which is at a known or reference temperature.

**Relative Humidity –** the ratio of the amount of water vapor contained in the air at a given temperature and pressure to the maximum amount it could contain at the same temperature and pressure under saturated conditions.

**Relay –** an electromechanical device with contacts that open and/or close when its coil is energized or de-energized in response to a change in the conditions of the electrical circuit. The operation of the contacts affect the operation of other devices in the same circuit or in other circuits.

**Relay Chatter –** noise due to the rapid opening and closing of relay contacts.

# GLOSSARY

**Remote Automatic Mode –** the controller will operate from a remote setpoint, usually other than input 1.

**Remote Setpoint –** a setpoint generated externally from the controller or recorder.

**Remote Switching (Digital Input) –** detects the state of external contacts but responds according to how the switching input is configured.

**Repeatability –** the ability of a controller or interlock to maintain a constant setpoint characteristic.

**Repeats Per Minute –** unit of Reset Rate.

**Reset Action –** adjusts the controller's output in accordance with both the size of the deviation (SP-PV) and the time it lasts.

**Reset Rate (Integral Action Rate) –** the number of repeats per minute or minutes per repeat that the proportional response of a two or three mode controller to a step input is repeated by the initial integral response.

**Resistance –** the opposition to the flow of electricity in an electric circuit measured in ohms.

**Resolution –** the minimum detectable change of some variable in a measurement system.

**Response –** the change in output in relation to the change of input.

**Reverse Acting Control –** control in which the value of the output signal decreases as the value of the input (measured variable or controlled variable) increases.

**RFI (Radio Frequency Interference) –** a type of electrical noise that can affect electronic circuits adversely.

**RS422/485 Communication –** a standard for serial data transmission.

**Run Period –** the period of time after ignition trials and before the operating setpoint is reached during which the main burner is firing. (In a flame safeguard programming control, the timer stops.)

## S

**Sensor Break Protection (Burnout) –** will make the indicated PV signal increase (upscale) or decrease (downscale) when a sensor fails.

**Setpoint Program –** individual Ramps and Soak Segments needed to generate the required setpoint versus time profile.

**Setpoint Ramp –** a ramp that can be configured to occur between the current local setpoint and a final local setpoint over a time interval.

**Setpoint Rate –** a specific rate of change for any local setpoint change.

**Setpoint Tracking –** the local setpoint will track either the PV or the remote setpoint and will use that value when transfer is made.

**Shed Mode –** determines the mode of local control that the units will go to when there is shed from communication.

**Shed Time –** this number represents the number of sample periods there will be before the instrument sheds from communications.

**Short –** a short circuit. Also, to intentionally bypass part of a circuit with a jumper.

**Short Circuit –** an abnormal connection of relatively low resistance between two points of a circuit, resulting in a flow of excess (often damaging) current between these two points.

**Signal –** a physical variable, one or more of which carry information about another variable (which the signal represents).

# GLOSSARY

**Single Setpoint Ramp –** occurs between the current local setpoint and a final setpoint over a time interval.

**Soak Segment –** a combination of a soak setpoint (value) and a soak duration (time) in Setpoint programming.

**Specific Gravity –** the ratio of the weight or mass of a given volume of a substance to that of the same volume of a standard (water for liquids and solids; air or hydrogen for gases) at the same temperature; abbreviated sp. gr., s.g., or G.

**Split Range Control –** action in which two or more signals are generated or two or more final control elements are actuated by an input signal.

**Stability –** the ability of an electronic device or circuit to maintain specified operating characteristics over extended periods of service.

**Static Pressure –** the steady state pressure applied to a device, in the case of a differential pressure device, the process pressure applied equally to both connections.

**Step Change –** the change from one value to another in a single increment in negligible time.

**Switch –** a mechanical or electrical device that makes or breaks contacts to either complete or open an electrical circuit; may be automatic or manual.

**System –** a set or arrangement of things so related or connected as to form a unity or organized whole; a collection of consecutive operations and procedures required to accomplish a specific objective.

## t

**Temperature Units –** medium of temperature indication or display (usually °F or °C).

**Thermocouple –** a device for measuring temperature consisting of two electrical conductors of dissimilar metals joined at a point, called the “hot” junction. When heat is applied to the “hot” junction, a voltage directly proportional to the temperature is developed across the output.

**Three Position Step Control –** an algorithm which is an extension of the ON/OFF Duplex control and includes internal feedback of the state of the relays. The effect of the control action is that the ON and OFF time of the output relay change in proportion to the error signal and the Gain and reset time settings.

**Time Constant –** time required for the output of a “First Order Lag” device to reach a percentage of its final value for a step change in input.

**Time/Current Duplex –** a variation of duplex with Current active for 50 to 100% output and Time active for 0 to 50% output.

**Time Proportioning Duplex –** an Output algorithm that uses two SPDT relays for Time Duplex Proportional Control. Its normally open (NO) or normally closed (NC) contacts are selected by positioning an internal jumper.

**Time Proportioning Simplex –** an Output algorithm that uses one SPDT relay for Time Proportional Control. Its normally open (NO) or normally closed (NC) contacts are selected by positioning an internal jumper.

**Totalizer –** calculates and displays the total flow volume as measured by the input or derived by an input algorithm.

**Transducer –** any device or component that converts an input signal of one form to an output signal of another form.

**Transmitter Characterization –** instructs the controller or recorder to characterize a linear input to represent a non-linear one.

# GLOSSARY

**Tuning –** The adjustment of control constants in algorithms or analog controllers to produce the desired control effect.

**Two Loop Control –** two independent loops of control or internal cascade control.

## u

**UL Approval –** approved by Underwriters Laboratories, an independent testing and certifying organization.

**Upload/Download –** Data or program transfer, usually from a computer to a controller or recorder and vice-versa.

## v

**Valve Positioner –** A position controller, which is mechanically connected to a moving part of a valve or its actuator, and automatically adjusts its output pressure to the actuator in order to maintain a desired position that bears a predetermined relationship to the input signal.

**Variable, Measured –** The process condition (such as temperature or pressure) selected to represent the state of material which is being made or processed.

## w

**Weighted Average –** the controller combines two inputs and computes a PV for the control algorithm.

## z

**Zero Shift –** A shift in the instrument calibrated span evidenced by a change in the zero value. Usually caused by temperature changes, overrange, or vibration of the instrument.

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Honeywell

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