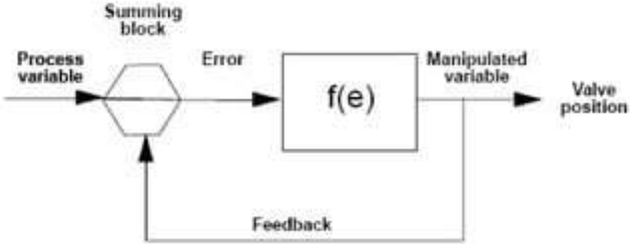
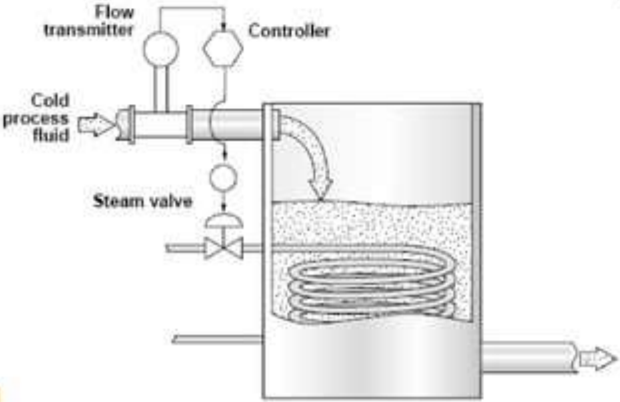
Chapter 5

PROCESS CONTROL





INTRODUCTION

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

- The following five sections are included in this module:

  1. The importance of process control
  2. Control theory basics
  3. Components of Control Loops
  4. Controller algorithms and tuning
  5. Process control systems

1) THE IMPORTANCE OF PROCESS CONTROL

The basic objectives of any process control system are:

1. Closely monitor the condition of the process
2. Maintain the process in a safe and stable condition
3. Compensate for changes in the process conditions and maintain production to a given specification
4. Increase profitability

LEARNING OBJECTIVES

After completing this section, you will be able to:

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

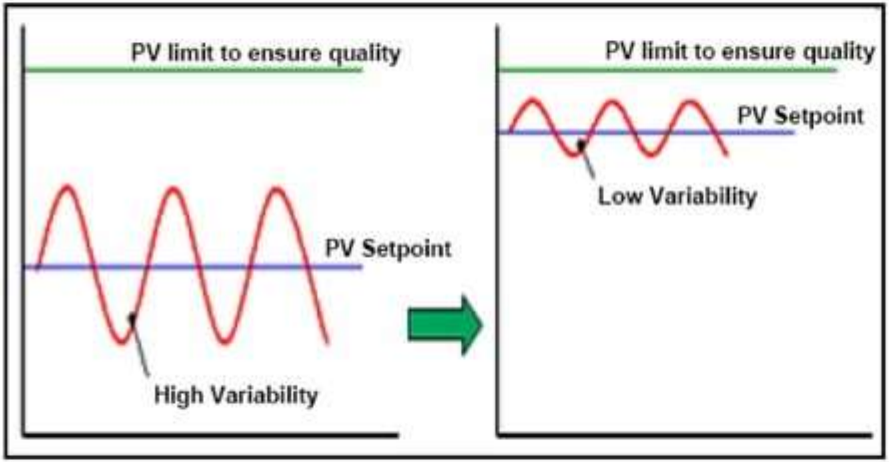
- ***Process*** as used in the terms *process control* and *process industry*, refers to the methods of changing or refining raw materials to create end products. The raw materials, which either pass through or remain in a liquid, gaseous, or slurry (a mix of solids and liquids) state during the process, are transferred, measured, mixed, heated or cooled, filtered, stored, or handled in some other way to produce the end product.
- Process industries include the chemical industry, the oil and gas industry, the food and beverage industry, the pharmaceutical industry, the water treatment industry, and the power industry.
- ***Process control*** refers to the methods that are used to control process variables when manufacturing a product. For example, factors such as the proportion of one ingredient to another, the temperature of the materials, how well the ingredients are mixed, and the pressure under which the materials are held can significantly impact the quality of an end product.

- **Manufacturers control the production process for three reasons:**

  1. **Reduce variability,**
  2. **Increase efficiency,**
  3. **Ensure safety**

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

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



Increase Efficiency

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

Ensure Safety

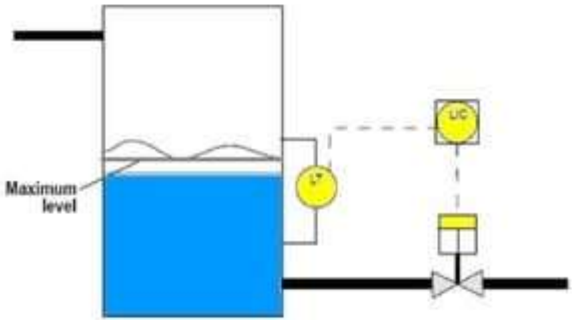
- A run-away process, such as an out-of-control nuclear or chemical reaction, may result if manufacturers do not maintain precise control of all of the processing variables. The consequences of a run-away process can be catastrophic.
- Precise process control may also be required to ensure safety. For example, maintaining proper boiler pressure by controlling the inflow of air used in combustion and the outflow of exhaust gases is crucial in preventing boiler implosions that can clearly threaten the safety of workers.

2) CONTROL THEORY BASICS

- This section presents some of the basic concepts of control and provides a foundation from which to understand more complex control processes and algorithms later described in this module. Common terms and concepts relating to process control are defined in this section.
- **Learning Objectives**
- **After completing this section, you will be able to:**
- Define control loop
- Describe the three tasks necessary for process control to occur:
  - Measure
  - Compare
  - Adjust
- Define the following terms:
  - Process variable
  - Setpoint
  - Manipulated variable
  - Measured variable
  - Error
  - Offset
  - Load disturbance
  - Control algorithm
- List at least five process variables that are commonly controlled in process measurement industries
- At a high level, differentiate the following types of control:
  - Manual versus automatic feedback control
  - Closed-loop versus open-loop control

The Control Loop

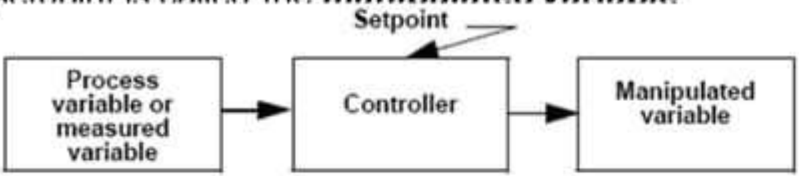
- Control loops in the process control industry work in the same way, requiring three tasks to occur:
  - Measurement
  - Comparison
  - Adjustment
- In the figure, a level transmitter (LT) measures the level in the tank and transmits a signal associated with the level reading to a controller (LIC). The controller compares the reading to a predetermined value, in this case, the maximum tank level established by the plant operator, and finds that the values are equal. The controller then sends a signal to the device that can bring the tank level back to a lower level—a valve at the bottom of the tank. The valve opens to let some liquid out of the tank.



Summary of Control Terminology

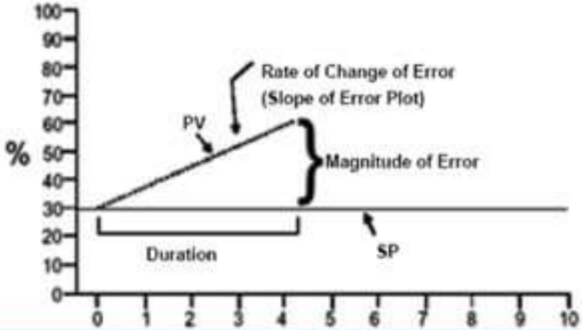
Set point	The value set on the scale of the control system in order to obtain the required condition. If the controller was set at 60°C for a particular application: 60°C would be termed as the 'set point'.
Desired value	The required value that should be sustained under ideal conditions.
Control value	The value of the control condition actually maintained under steady state conditions.
Deviation	The difference between the set point and the control value.
Offset	Sustained deviation.
Sensor	The element that responds directly to the magnitude of the controlled condition.
Controlled medium	The medium being controlled by the system.
Controlled condition	The physical condition of the controlled medium.
Controller	A device which accepts the signal from the sensor and sends a corrective (or controlling) signal to the actuator.
Actuator	The element that adjusts the controlled device in response to a signal from the controller.
Controlled device	The final controlling element in a control system, such as a control valve or a variable speed pump.

- **Process Variable:** is a condition of the process fluid (a liquid or gas) that can change the manufacturing process in some way.
- **Setpoint:** is a value for a process variable that is desired to be maintained. For example, if a process temperature needs to kept within 5°C of 100°C, then the setpoint is 100°C. A temperature sensor can be used to help maintain the temperature at setpoint.
- ***Measured variable*** is the condition of the process fluid that must be kept at the designated setpoint. Sometimes the measured variable is not the same as the process variable. For example, a manufacturer may measure flow into and out of a storage tank to determine tank level. In this scenario, flow is the measured variable, and the process fluid level is the ***process variable***. The factor that is changed to keep the measured variable at setpoint is called the ***manipulated variable***



Types of thermocouples

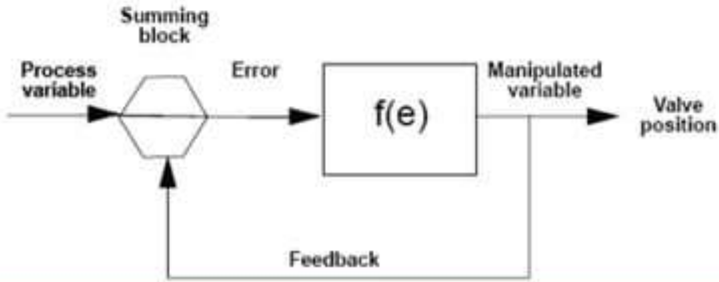
- ***Error*** **is the difference between the measured variable and the setpoint and can be either positive or negative.** The objective of any control scheme is to minimize or eliminate error. Therefore, it is imperative that error be well understood.
- ***Magnitude*** of the error is simply the deviation between the values of the setpoint and the process variable. The magnitude of error at any point in time compared to the previous error provides the basis for determining the change in error. The change in error is also an important value.
- ***Duration*** refers to the length of time that an error condition has existed.
- ***Rate of Change*** is shown by the slope of the error plot.



- ***Offset*** is a sustained deviation of the process variable from the setpoint. In the temperature control loop example, if the control system held the process fluid at 100.5°C consistently, even though the setpoint is 100°C, then an offset of 0.5°C exists.
- **Load Disturbance:** is an undesired change in one of the factors that can affect the process variable. In the temperature control loop example, adding cold process fluid to the vessel would be a load disturbance because it would lower the temperature of the process fluid.
- **Control Algorithm:** is a mathematical expression of a control function. Using the temperature control loop example, **V** in the equation below is the fuel valve position, and **e** is the error. The relationship in a control algorithm can be expressed as:

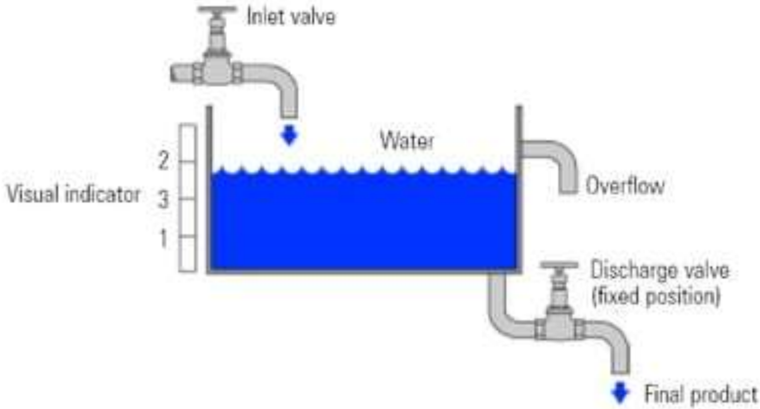
$$V = f(\pm e)$$

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

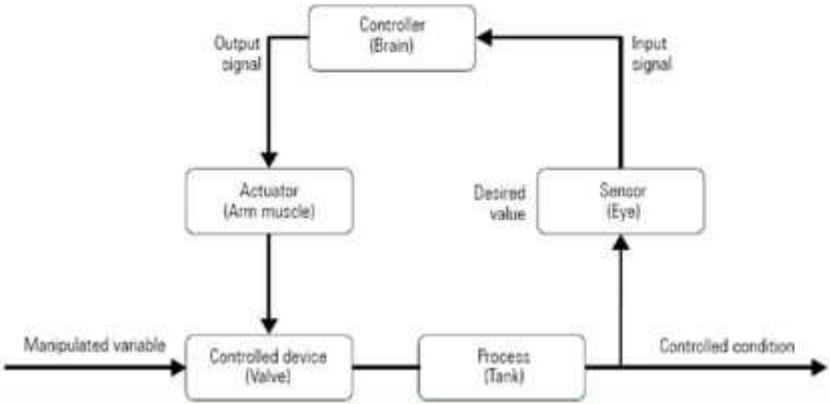


Manual and Automatic Control

- Before process automation, people, rather than machines, performed many of the process control tasks. For example, a human operator might have watched a level gauge and closed a valve when the level reached the setpoint. Control operations that involve human action to make an adjustment are called ***manual control* systems**.

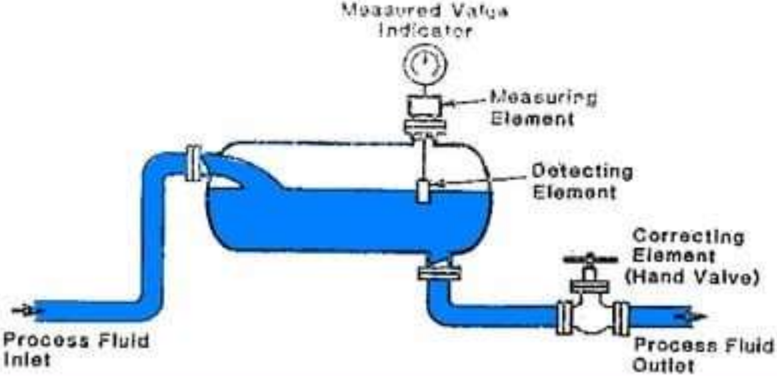


- Conversely, control operations in which no human intervention is required, such as an automatic valve actuator that responds to a level controller, are called ***automatic control systems***.
- Automatic control systems produce:
  - A more consistent product
  - Release skilled operators for other productive work
  - Reduce the physical effort required, lessening fatigue and boredom
  - Decrease the physical workload on an operator
  - Improve safety and working conditions
- Once an automatic control system has been installed and commissioned, it should be able to maintain a pre-set operating condition over an extended period of time without any operator involvement.

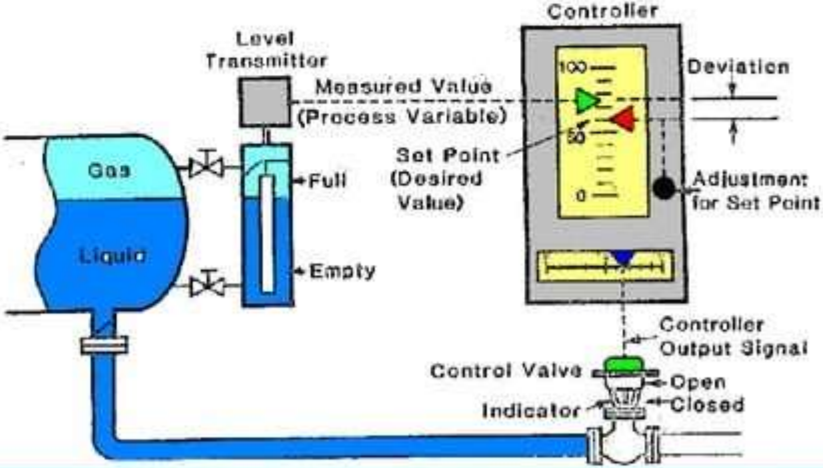


Open and Closed Control Loops

- An ***open control loop*** exists where the process variable is not compared, and action is taken not in response to feedback on the condition of the process variable, but is instead taken without regard to process variable conditions.
- Open loop control has no information or feedback about the measured value.
- The position of the correcting element is fixed.
- It is unable to compensate for any disturbances in the process.



- A ***closed control loop*** exists where a process variable is measured, compared to a setpoint, and action is taken to correct any deviation from setpoint.
- In a closed loop control system the output of the measuring element is fed into the loop controller where it is compared with the set point. An error signal is generated when the measured value is not equal to the set point. Subsequently, the controller adjusts the position of the control valve until the measured value fed into the controller is equal to the set point.
- Closed loop control has information and feedback about the measured value.
- The position of the correcting element is variable.
- It is able to compensate for any disturbances in the process.

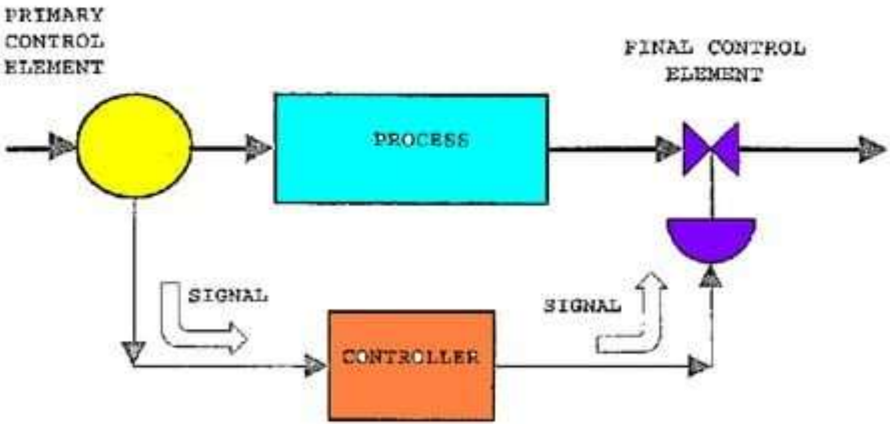


3) COMPONENTS OF CONTROL LOOPS

- This section describes the instruments, technologies, and equipment used to develop and maintain process control loops.

Control Loop Equipment and Technology

- The basic elements of control as measurement, comparison, and adjustment. In practice, there are instruments and strategies to accomplish each of these essential tasks.



- ***Primary elements*** are devices that cause some change in their property with changes in process fluid conditions that can then be measured.
- ***Transducer*** is a device that translates a mechanical signal into an electrical signal. For example, inside a capacitance pressure device, a transducer converts changes in pressure into a proportional change in capacitance.
- ***Converter*** is a device that converts one type of signal into another type of signal.
- ***Transmitter*** is a device that converts a reading from a sensor or transducer into a standard signal and transmits that signal to a monitor or controller
- **Signals:** There are three kinds of signals that exist for the process industry to transmit the process variable measurement from the instrument to a centralized control system.
  1. **Pneumatic signal**: are signals produced by changing the air pressure in a signal pipe in proportion to the measured change in a process variable. The common industry standard pneumatic signal range is 3–15 psig.
  2. **Analog signal**: The most common standard electrical signal is the 4–20 mA current signal. With this signal, a transmitter sends a small current through a set of wires.
  3. **Digital signal**: are discrete levels or values that are combined in specific ways to represent process variables and also carry other information, such as diagnostic information. The methodology used to combine the digital signals is referred to as protocol.

- ***Indicator*** is a human-readable device that displays information about the process.
- ***Recorder*** is a device that records the output of a measurement devices.
- ***Chart recorders:*** Recorders that create charts or graphs.
- ***Controller*** is a device that receives data from a measurement instrument, compares that data to a programmed setpoint, and, if necessary, signals a control element to take corrective action.
  - ***controllers*** are usually one of the three types: pneumatic, electronic or programmable. Controllers also commonly reside in a digital control system.
- ***Correcting* or *final control element*** is the part of the control system that acts to physically change the manipulated variable.
- ***Actuator*** is the part of a final control device that causes a physical change in the final control device when signalled to do so.

4) CONTROLLER ALGORITHMS AND TUNING

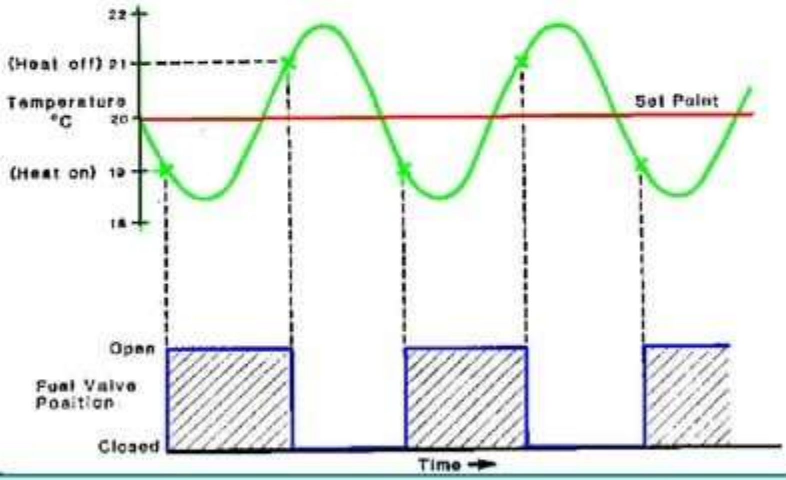
After completing this section, you will be able to:

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

Controller Algorithms

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

- ***Discrete controllers*** are controllers that have only two modes or positions: on and off (two-step). This type of control doesn't actually hold the variable at setpoint, but keeps the variable within proximity of setpoint in what is known as a *dead zone*.
- Two-step is the simplest of all the control modes. The output from the controller is either on or off with the controller's output changing from one extreme to the other regardlessof the size of the error.

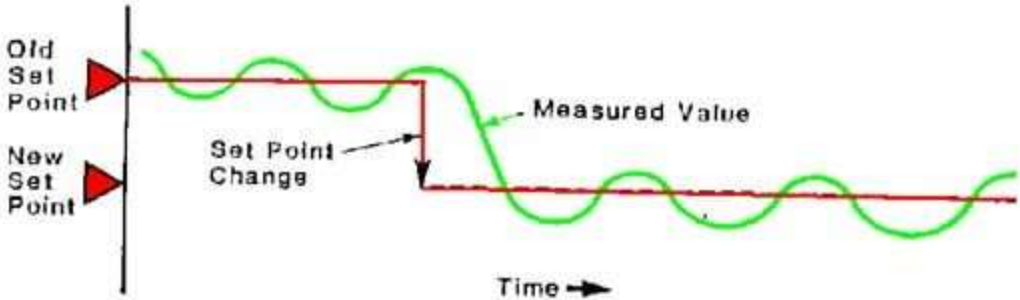


Advantages of ON-OFF Control:

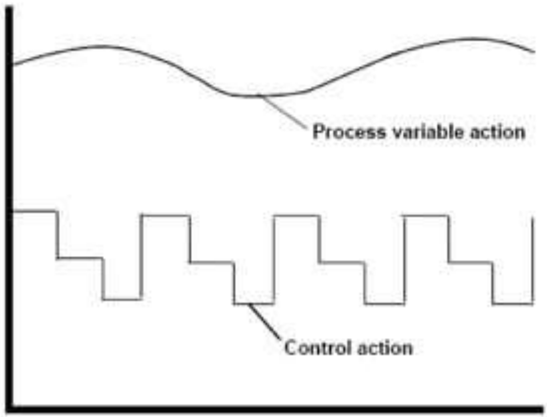
- On/Off control makes "trouble shooting" very easy and requires only basic types of instruments.

Disadvantages of ON-OFF Control:

- The process oscillates.
- The final control element (usually a control valve) is always opening and closing. This causes excessive wear.
- There is no fixed operating point.

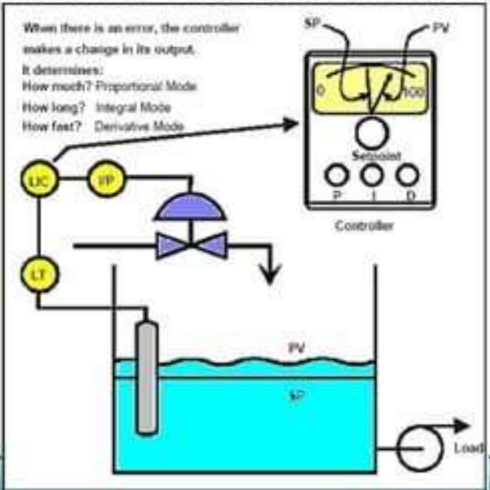


- ***Multistep controllers*** are controllers that have at least one other possible position in addition to on and off. Multistep controllers operate similarly to discrete controllers, but as setpoint is approached, the multistep controller takes intermediate steps. Therefore, the oscillation around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



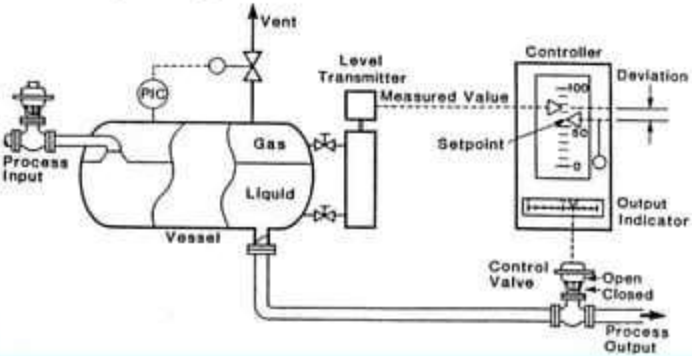
Continuous Controllers

- **Controllers** automatically compare the value of the PV to the SP to determine if an error exists. If there is an error, the controller adjusts its output according to the parameters that have been set in the controller. The tuning parameters essentially determine:
  - » *How much* correction should be made? The *magnitude* of the correction (change in controller output) is determined by the proportional mode of the controller.
  - » *How long* the correction should be applied? The *duration* of the adjustment to the controller output is determined by the integral mode of the controller
  - » *How fast* should the correction be applied? The *speed* at which a correction is made is determined by the derivative mode of the controller.

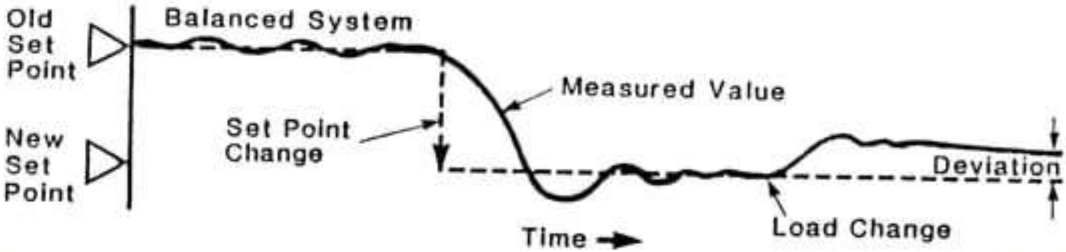


Proportional Action

- With proportional control action, the correcting element is adjusted In proportion to the change in the measured value from the set point. The largest movement is made to the correcting element when the deviation between measured value and set point is greatest. Usually, the set point and measured value are equal when the output is midway of the controller output signal range.
- In the accompanying diagram, the set point is shown at 60%, the measured value at 75% and the output at 65%. If the measured value were to drop to 60%, that is, equal to the SP, the output would stabilise at the designed 50%. By repositioning the set point to 50% the measured value falls to 50%, the output would again be 50%.
- Assuming that the level transmitter, controller and control valve are all operating correctly and have been recently calibrated, when set point and measured value are equal and the system is in stable condition, the valve will be 50% open. The valve would have been sized during design to maintain the stable condition under a set of known conditions.



- The process throughput, the fluid condition, the vessel, operating pressure and the back-pressure from the downstream process can all affect the throughput of the control valve. From .the diagram, it can be seen that the process input is equal to the process output and steady state conditions have been achieved with a level stabilised at 75%, but with a SP of 60%.
- Under these conditions, the control valve would need to be 65% open; the magnitude of deviation is used to reposition the valve from its normal 50% open position. Deviation from other changes in operating conditions, particularly load changes, would also open or close the valve to achieve the new stable level.



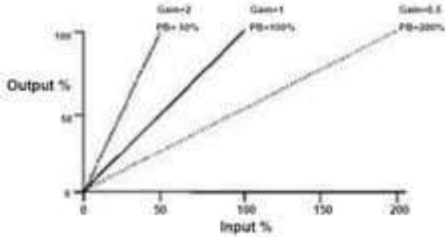
- The process load can be changed in the following ways to remove the deviation:
  - » Reduce the process input to the vessel allowing the level to drop so that a stable level is achieved at 60%'when the valve is 50% open.
  - » Increase the operating pressure of the vessel. This creates a higher differential pressure across the control valve, causing the fluid to flow from the vessel at an increased rate. This allows the level to' fall so that» a stable level is achieved at 60% when the valve is 50% open.
  - » Reduce the back pressure from the downstream process, creating a higher differential pressure across the control valve. This also causes the fluid to flow from the vessel at an increased rate.
  - » Increase the capacity of the control valve to allow more process fluid to flow through the valve so that at 50% open a 60% level in the vessel is achieved.
  - » Any combination of the above conditions will also remove the deviation. Over compensation may cause the measured value to move below the set point, causing a deviation in the opposite direction.

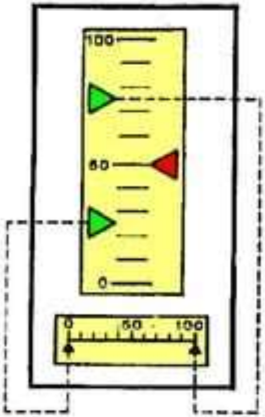
Proportional Mode:

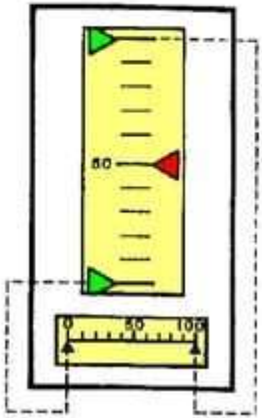
- The simplest and most common form of control action to be found on a controller is proportional. With this form of control the output from the controller is directly proportional to the input error signal, i.e. the larger the input error the larger the output response from the controller.
- The actual size of the output depends on another factor, the controller's proportional band or gain. (The controller's sensitivity)
- The setting for the proportional mode may be expressed as either:
  - » Proportional Band (PB) is another way of representing the same information and answers this question: *"What percentage of change of the controller input span will cause a 100% change in controller output?"* PB = Δ Input (% Span) For 100% Δ Output.
  - » Proportional Gain (Kc) answers the question: *"What is the percentage change of the controller output relative to the percentage change in controller input?"* Proportional Gain is expressed as: Gain, (Kc) = Δ Output% / Δ Input %

Converting Between PB and Gain

- Gain is just the inverse of PB multiplied by 100 or gain = 100/PB
- **PB = 100/Gain**
- Also recall that: **Gain = 100% / PB**
- Proportional Gain, (Kc) = Δ Output% / Δ Input %
- PB= Δ Input (%Span) For 100% Δ Output





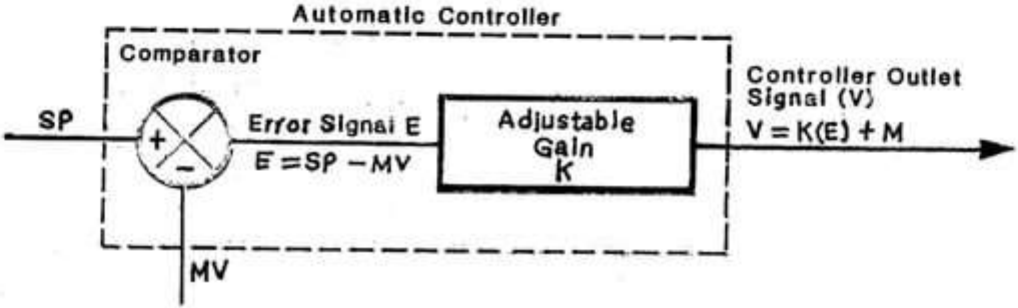


- The proportional mode of control can be described mathematically as:
  V = K (E) + M

Where

  - » V = controller output signal to correcting unit,
  - » K = adjustable gain,
  - » E = magnitude of error signal,
  - » M = constant which is the position of the valve when there is no deviation, that is, SP = MV and E = 0.

- This can be shown diagrammatically as in the following diagram and gain settings can be shown graphically as in the following diagram.

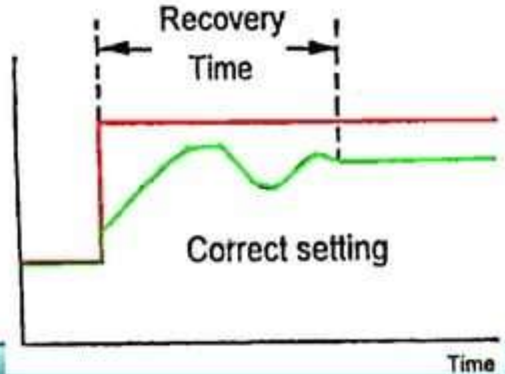


Summary of Proportional control

With Proportional Control:

- Δ Controller Output = (Change in Error)(Gain)
- Proportional Mode Responds only to a change in error
- Proportional mode alone will not return the PV to SP.
- Stable control
- Suffers from offset due to load changes.

- **Narrow PB%**
  - Fast to respond,
  - Large overshoot,
  - Long settling time,
  - Small offset
- **Wide PB%**
  - Slow to respond,
  - Quick to settle'
  - Large offset
- Proportional control used in process where load changes are small and the offset can be tolerated.
- Tuning - reduce PB (increase gain) until the process cycles following a disturbance, then double the PB (reduce gain by 50%).
- **With Optimum Setting of P Control**

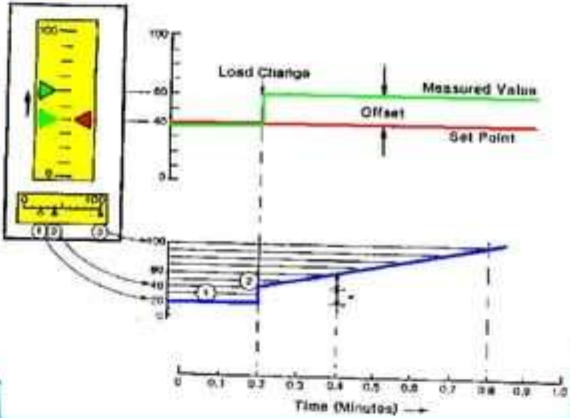


Integral Mode

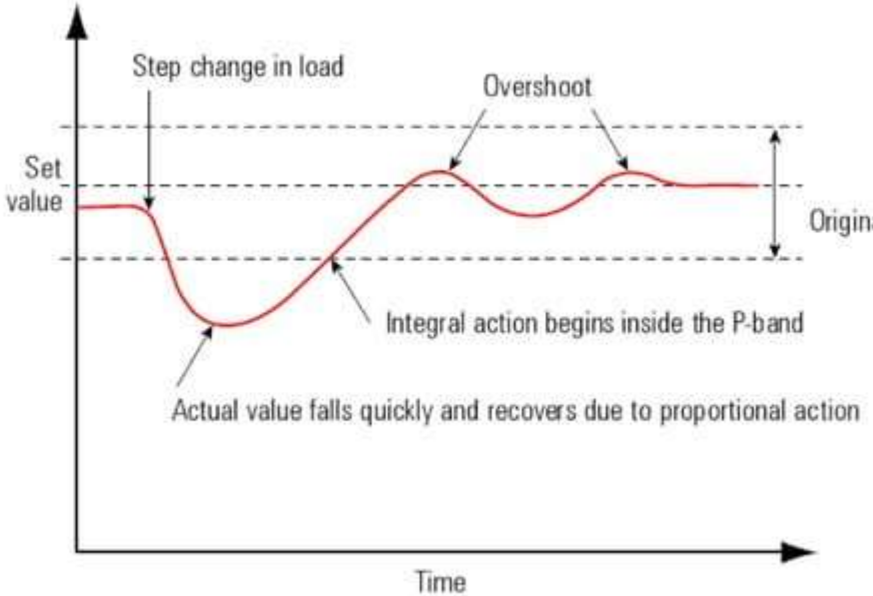
Integral Action

- Another component of error is the ***duration*** of the error, i.e., how long has the error existed?. The controller output from the integral or reset mode is a function of the duration of the error.
- Integral action is used in conjunction with proportional action to eliminate offset problem resulting from P control.
- This is accomplished by repeating the action of the proportional mode as long as an error exists.

- An example of integral action in P + I controller is shown in the following diagram, here if the process is operating under steady state conditions at a set point of, say, 40% at time T = 0 minutes, the output of the controller is at 20%. In a proportional only controller the output would be 50% when the measured value is equal to set point, but this is not necessarily the case In a proportional plus reset controller.
- At the time T = 0.2 minutes a sudden load change occurs which causes the measured value to rise 20% above set point to 60%. Proportional action increases the output 20% to 40%, which indicates a PB of 100% or a gain of 1.
- If the offset is maintained after this output change because the increased output cannot cause the measured variable to drop, the controller output will begin to increase in a ramp fashion.
- The time it takes to ramp the controller output up to a value equal to the effect of the initial proportional action is called the integral action time. So the initial proportional action is a 20% increase in output. This action is repeated by integral action in 0.4 - 0.2 = 0.2 minutes to move the output from 40% to 60%, so for this example, integral action time = 0.2 minutes per repeat = 5 repeats/min.

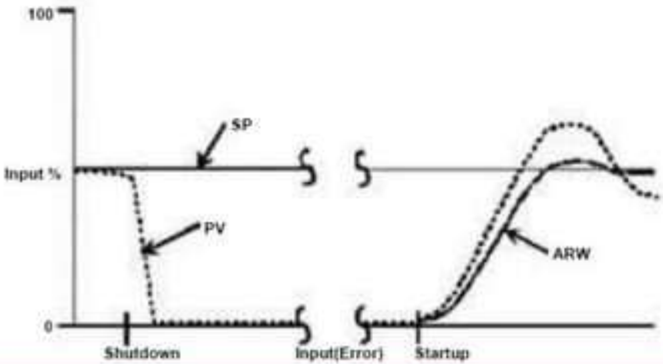


- Integral Action Effect



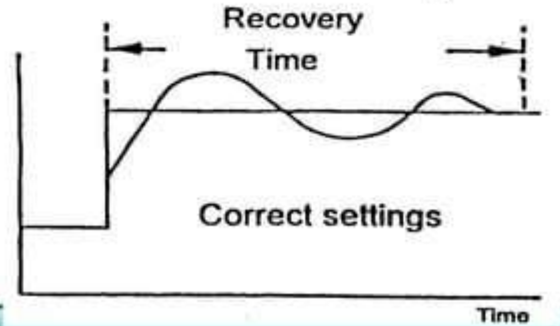
Integral Saturation or Reset Wind-up

- A common problem caused by integral action is called integral saturation or wind-up. During the time a process is shut down the integral action will keep trying to move the valve to correct for the error between its set point and the actual process value. When the process is started up it will take time for the process controller to gain control of the valve again. This time delay could result in damage to the plant or shutdown due to the plant safety devices cutting in. Normally a process such as this would be brought up on manual control and then switched over to automatic.
- To prevent saturation from occurring controllers are fitted with integral de-saturation or anti wind-up devices. De-saturation relays prevent the controller's output from falling below 3 psi and rising above 1 psi.



Summary of integral action (Reset)

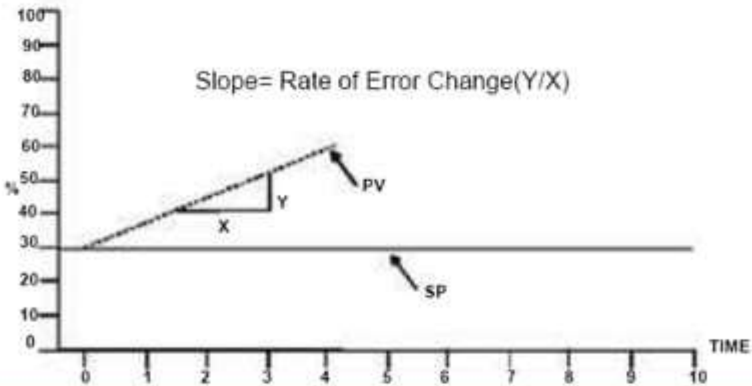
- Integral (Reset) Summary - Output is a repeat of the proportional action as long as error exists. The units are in terms of repeats per minute or minutes per repeat.
- **Advantages -** Eliminates error
- **Disadvantages:** Makes the process less stable and take longer to settle down.
- Can suffer from integral saturation or wind-up on batch processes.
- **Fast Reset** (Large Repeats/Min., Small Min./Repeat)
  - High Gain
  - Fast Return To Setpoint
  - Possible Cycling
- **Slow Reset** (Small Repeats/Min., Large Min./Repeats)
  - Low Gain
  - Slow Return To Setpoint
  - Stable Loop
- P + I controller is used when offset must be eliminated automatically and integral saturation due to a sustained offset is not a problem.
- **Trailing and Error Tuning -** Increase repeats per minute until the PV cycles following a disturbance, then slow the reset action to a value that is 1/3 of the initial setting.



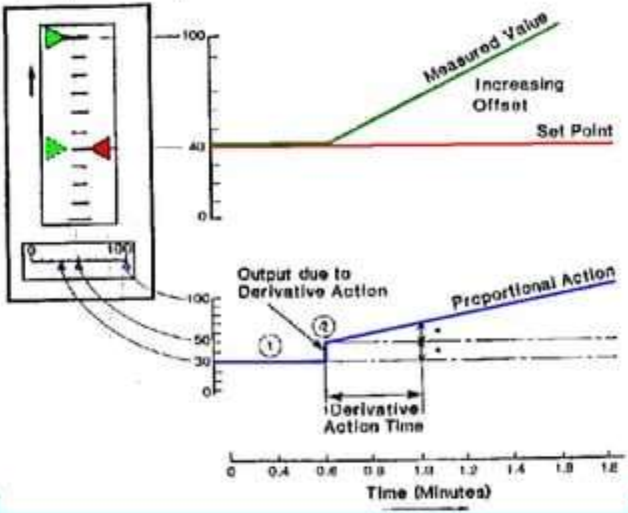
Derivative Mode

Why Derivative Mode?

- Some large and/or slow process do not respond well to small changes in controller output. For example, a large liquid level process or a large thermal process (a heat exchanger) may react very slowly to a small change in controller output. To improve response, a large initial change in controller output may be applied. This action is the role of the derivative mode.
- The derivative action is initiated whenever there is a ***change in the rate of change of the error*** (the slope of the PV). The magnitude of the derivative action is determined by the setting of the derivative.
- In operation, the controller first compares the current PV with the last value of the PV. If there is a change in the slope of the PV, the controller determines what its output would be at a future point in time (the future point in time is determined by the value of the derivative setting, in minutes). The derivative mode *immediately* increases the output by that amount.

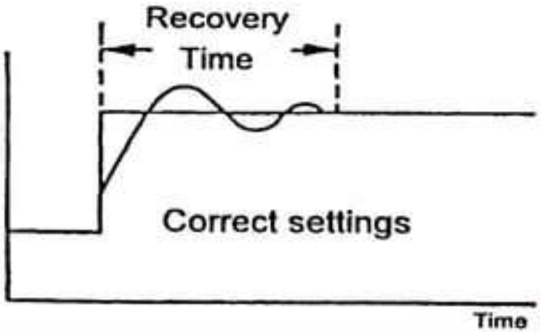


- **Derivative Action:**
- The following illustration shows the effect of derivative action when a constant rate of change of offset is considered [the derivative time is 0.4 minutes (1 - 0.6)]. When the set point is equal to the measured value the output remains constant.
- Once the rate at which the measured value is increasing from the set point is determined, then derivative action acts to increase the controller output, in this case, from 30% to 50%. The output then increases due to proportional action.
- The additional correction exists only while the error is changing, it disappears when the error stops changing even-though there may still be a large value of error signal.
- Derivative action has no effect on the offset in a proportional only controller and therefore it is unusual to find a proportional plus derivative controller.



Summary of Derivative action (Rate)

- Rate action is a function of the *speed of change* of the error. The units are *minutes*. The action is to apply an immediate response that is equal to the proportional plus reset action that would have occurred some number of minutes I the future.
- **Advantages -** Rapid output reduces the time that is required to return PV to SP in slow process.
- **Disadvantage -** Has no effect on offset. Dramatically amplifies noisy signals; can cause cycling in fast processes.
- **Large (Minutes):**
  - » High Gain
  - » Large Output Change
  - » Possible Cycling
- **Small (Minutes):**
  - » Low Gain
  - » Small Output Change
  - » Stable Loop
- **Trial-and-Error Tuning**
  - » Increase the rate setting until the process cycles following a disturbance, then reduce the rate setting to one-third of the initial value.

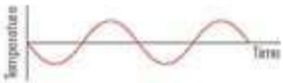
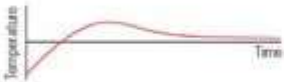


Proportional, PI, and PID Control

- By using all three control algorithms together, process operators can:
  - Achieve rapid response to major disturbances with derivative control
  - Hold the process near setpoint without major fluctuations with proportional control
  - Eliminate offset with integral control
- Not every process requires a full PID control strategy. If a small offset has no impact on the process, then proportional control alone may be sufficient.
- PI control is used where no offset can be tolerated, where *noise* (temporary error readings that do not reflect the true process variable condition) may be present, and where excessive *dead time* (time after a disturbance before control action takes place) is not a problem.
- In processes where no offset can be tolerated, no noise is present, and where dead time is an issue, customers can use full PID control.

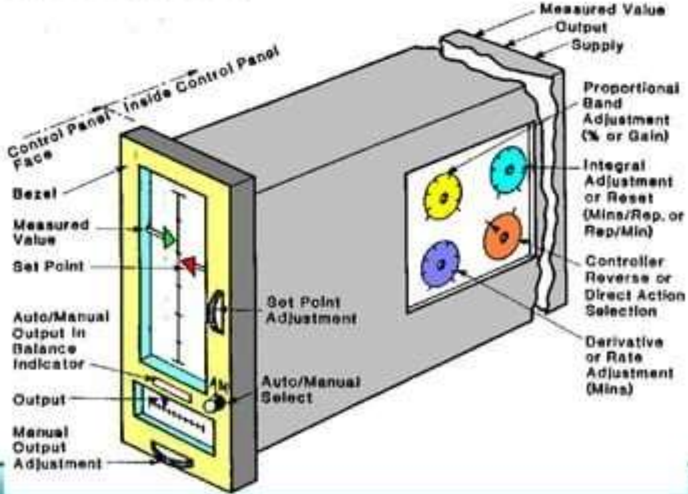
Controlled Variable	Proportional Control	PI Control	PID Control
Flow	Yes	Yes	No
Level	Yes	Yes	Rare
Temperature	Yes	Yes	Yes
Pressure	Yes	Yes	Rare
Analytical	Yes	Yes	Rare

• Summary of Control modes and responses

Control mode	Typical system responses	Advantages/disadvantages
On/off		• Inexpensive • Simple • Operating differential can be outside of process requirements
Proportional P		• Simple and stable • Fairly high initial deviation (unless a large P-band is chosen), then sustained offset • Easy to set up • Offset occurs
Proportional plus Integral P + I		• No sustained offset • Increase in proportional band usually required to overcome instability • Possible increased overshoot on start-up
Proportional plus Derivative P+D		• Stable • Some offset • Rapid response to changes
Proportional plus Integral plus Derivative P+I+D		• Will give best control, no offset and minimal overshoot • More complex to set up manually but most electronic controllers have an 'autotune' facility. • More expensive where pneumatic controllers are concerned

Automatic Controller Adjustments

- Set point adjustment, which allows the operator to select the required operating point for the process when the controller is in automatic mode.
- Auto/manual selector switch. When in the manual position the controller output becomes independent of the measured value and set point, that is, the controller 'operates in open loop.
- Output adjustment which allows the position of the final control element to be controlled by the operator when the controller is in manual mode so that the correcting element can be moved from fully closed to fully open and can be held at any position in between.



Bumpless Transfer

- When switching a controller from auto to manual or vice versa, care must be taken that the output signal does not move sharply when the auto/manual switch is operated. This may cause a severe disturbance in the process, which may result in damage or shutdown.
- **Switch Auto to Manual**
  - » Adjust manual output until the balance indicator shows that the manually adjusted output pressure is equal to the output pressure generated by the auto mechanism. The balance indicator mechanism varies according to the manufacturer of the controller, but all indicate by a flag or some similar device when the two output pressures are equal.
  - » Once the balance position has been found, It Is safe to switch from auto to manual without any process bump. The manual output adjustment now has control of the output to the final control element.
- **Switch Manual to Auto**
  - » When switching from manual to auto, the set point should Initially be moved towards the measured value to see if an output balance can be found. It is usual to find balance where there is an offset between set point and measured value. When the balance point has been found, it is then safe to switch to auto and slowly reposition the set point to the desired operating condition.

Controller Tuning

Why Controllers Need Tuning?

- Controllers are tuned in an effort to match the characteristics of the control equipment to the process so that two goals are achieved; is the foundation of process control measurement in that electricity:
  - The system responds quickly to errors.
  - The system remains stable (PV does not oscillate around the SP)
- Controller tuning is performed to adjust the manner in which a control valve (or other final control element) responds to a change in error.
- In particular, we are interested in adjusting the controller's modes (gain, Integral and derivative), such that a change in controller input will result in a change in controller output that will, in turn, cause sufficient change in valve position to eliminate error, but not so great a change as to cause instability or cycling.
- There are many trial and error methods of controller tuning which do not involve mathematical analysis and should be demonstrated by an experienced person, otherwise shutdowns may occur.
- The first adjustment, which would normally be made, would be to set forward or reverse action as required. A forward acting controller has increasing output in response to an increasing measured variable. A reverse acting controller has decreasing output in response to an increasing measured variable.

- # PB at Optimum Value

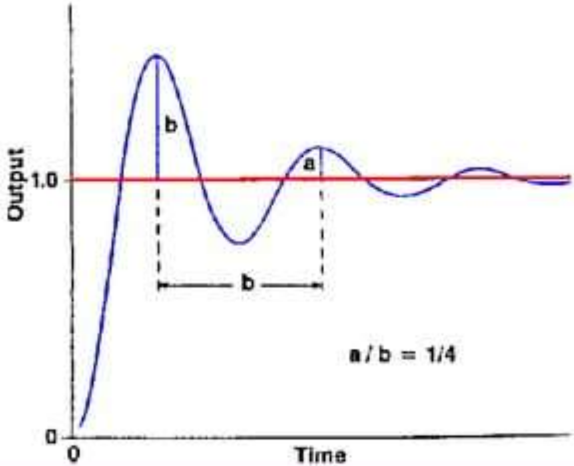
- Controller optimisations can then be carried out as follows. For any particular control system there is a value of the proportional band, which will produce the best controller performance:
  - » Increasing the proportional band above this value will result in greater deviations of the controlled condition from the desired value owing to disturbances in the process.
  - » Decreasing the Proportional band below the critical value will increase the tendency for the process to hunt, and disturbances will cause prolonged oscillation of the controlled condition about the control point. Indeed, if made too narrow, the system becomes unstable and instead of the oscillations dying out they will increase in amplitude.
- Trained observation of the chart record, following a plant disturbance, thus provides a method of initially adjusting a controller's settings to the process. Process disturbances are easily simulated by moving the set point away from the desired value and returning it to its original position.

Empirical Tuning Method

- **Proportional only controller**
  - » With transfer switch at manua1, set PB at maximum or at safe high value, usually 200% PB.
  - » Move transfer switch to auto and make changes in set point. The time required for the disturbance to settle may then be noted.
  - » Continue reducing band-width to half its previous value until the oscillation do not die away, But continue to be perceptible.
  - » Now increase the band-width to twice its value. This gives the required stability, that is, the minimum stabilising time and minimum offset.
- **Proportional plus integral action**
  - » Set the Integral Action Time (IAT) to maximum.
  - » Adjust the proportional band as for a proportional controller.
  - » Decrease the IAT in steps, each step being such that line IAT 1s halved at each adjustment. Below some critical value, depending upon the lag characteristics of the process, hunting will occur. This hunting Indicates that the IAT has been reduced too far.
  - » Now increase the time to approximately twice this value to restore the desired stability.


- **Proportional plus derivative action**
  - » Adjust the Derivative Action Time (DAT) to its minimum value.
  - » Adjust the proportional band as described for proportional controller, but do not increase the band when hunting occurs.
  - » Increase the DAT (that is, double each setting) so that; the hunting caused by the narrow band is eliminated.
  - » Continue to narrow the band and again increase the DAT until the hunting is eliminated.
  - » Repeat previous step until further increase of the derivative action time fails to eliminate the hunting introduced by the reduction of the proportional band, or tends to increase it. This establishes the optimum value of the DAT and the hunting should be eliminated by increasing the width of the proportional band slightly.
- **Proportional plus integral plus derivative action**
  - » Set IAT to a maximum.
  - » Set DAT to a minimum.
  - » Adjust the proportional band as for a P + D controller.
  - » Adjust derivative using same procedure as for above, P + D.
  - » Adjust integral to a related value of the final derivative setting.

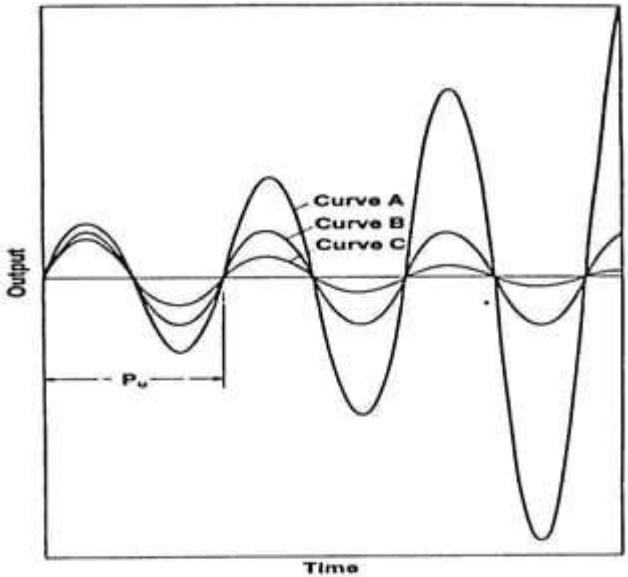
- In many cases, the setting procedure may be shortened by omitting settings, which are outside the probable range.
- The process should then respond to set point or load changes, where integral action removes offset and the second overshoot of set point is approximately 1/4 the amplitude of the first. This is commonly referred to as the 1/4 decay method and is generally agreed to be the optimum controller setting for a P + I controller.
- The above method is only used when no other controller setting data is available and must be practised with care.



Optimum Settings (Ultimate Method)

- The closed loop or ultimate method involves finding the point where the system becomes unstable and using this as a basis to calculate the optimum settings.
- The following steps may be used to determine ultimate PB and period:

1. Switch the controller to Manual and set the proportional band to high value.
2. Turn off all integral and derivative action.
3. Switch the controller to automatic and reduce the proportional band value to the point where the system becomes unstable and oscillates with constant amplitude. Sometimes a small step change is required to force the system into its unstable mode. The below figure showing typical response obtained when determining ultimate proportional band and ultimate period time.
4. The proportional band that required causing continuous oscillation is the ultimate value **Bu.**
5. The ultimate periodic time is **Pu**.
6. From these two values the optimum setting can be calculated as per the following procedures.



Curve A: unstable.
Curve B: continuous cycling.
Curve C: stable.

- Look for curve **B** that represents the continuous oscillation

Optimum setting calculation

- **For proportional action only**
  - » PB% = 2 Bu %
- **Proportional + Integral**
  - » PB% = 2.2 Bu %
  - » Integral action time = Pu / 1.2 minutes/repeat
- **Proportional + Integral + Derivative**
  - » PB%=1.67Bu
  - » Integral action time = Pu / 2 minutes/repeat
  - » Derivative action = Pu / 8 minutes

Typical Controller Settings

Process	Gain	PB(%)	Integral		Derivative
			T_i (sec)	min/rpt.	T_d (sec)
Flow	0.6-0.8	167-125	3.0-1.8	0.05-0.03	0.0
Pressure	5.0	20.0	120-60	2.0-1.0	0.0
Temp.	1.0-2.0	100-50	120-30	2.0-0.5	6.0-12
Level	0.8-1.2	125-83	600-300	10.0-5.0	0.6-1.2

5) PROCESS CONTROL LOOPS

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

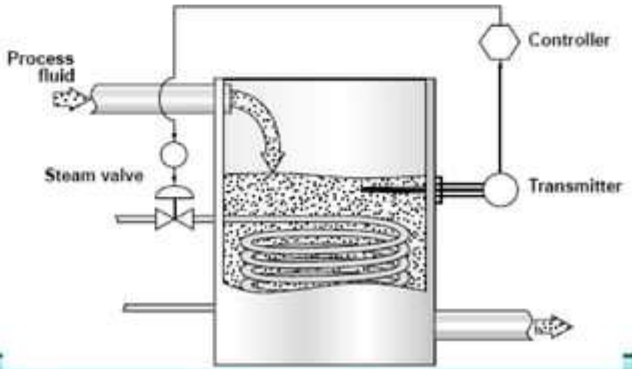
Learning Objectives:

After completing this section, you will be able to:

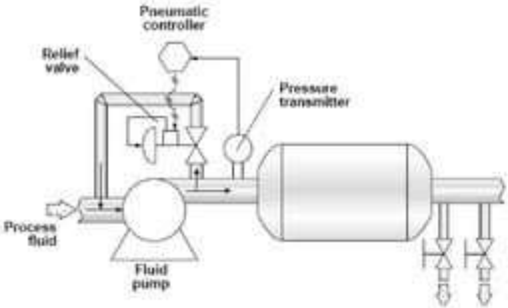
- Explain how a multivariable loop is different from a single loop.
- Differentiate feedback and feedforward control loops in terms of their operation, design, benefits, and limitations
- Perform the following functions for each type of standard process control loop (i.e., pressure, flow, level, and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

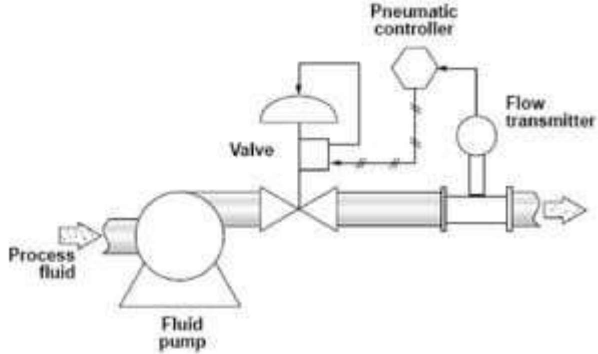
5.1) Single Control Loops

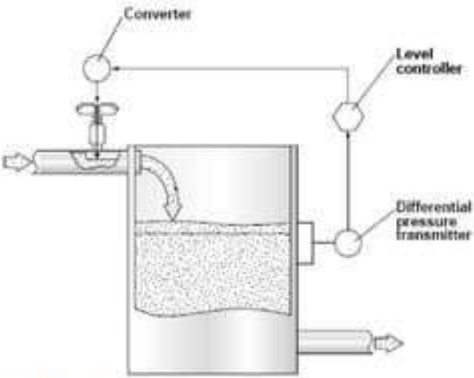
- **Feedback Control loop**: measures a process variable and sends the measurement to a controller for comparison to setpoint. If the process variable is not at setpoint, control action is taken to return the process variable to setpoint. In the figure, a feedback loop in which a transmitter measures the temperature of a fluid and, if necessary, opens or closes a hot steam valve to adjust the fluid's temperature.
- Feedback loops are commonly used in the process control industry. The advantage of a feedback loop is that it directly controls the desired process variable. The disadvantage to feedback loops is that the process variable must leave setpoint for action to be taken.

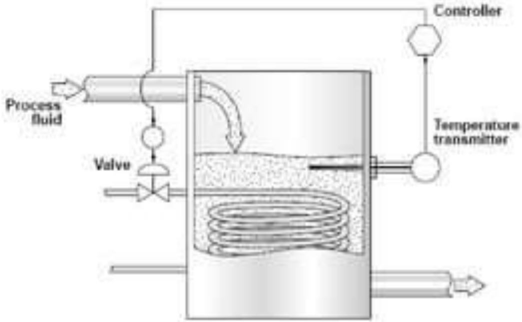


Examples of feedback Control Loops

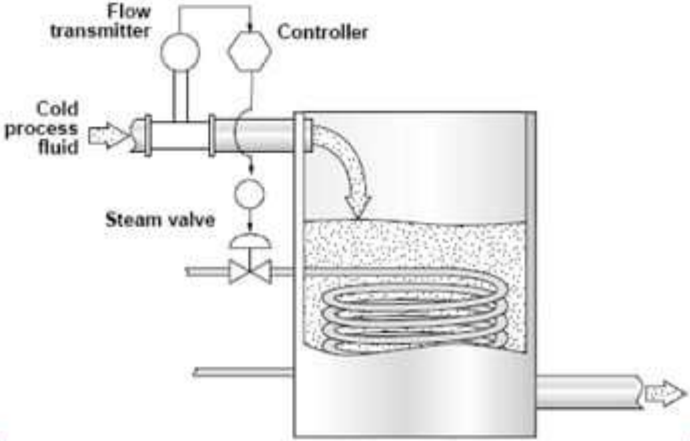








- ***Feedforward control*** is a control system that anticipates load disturbances and controls them before they can impact the process variable. For feedforward control to work, the user must have a mathematical understanding of how the manipulated variables will impact the process variable. In the figure the flow transmitter opens or closes a hot steam valve based on how much cold fluid passes through the flow sensor.
- An advantage of feedforward control is that error is prevented, rather than corrected. However, it is difficult to account for all possible load disturbances in a system through feedforward control. Factors such as outside temperature, buildup in pipes, consistency of raw materials, humidity, and moisture content can all become load disturbances and cannot always be effectively accounted for in a feedforward system.

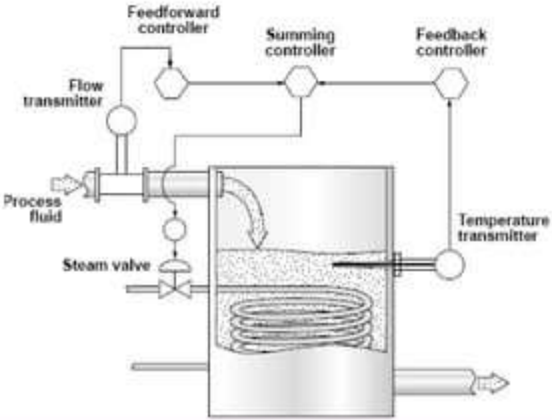


5.2) Multi-Variable / Advanced Control Loops

- ***Multivariable loops*** are control loops in which a primary controller controls one process variable by sending signals to a controller of a different loop that impacts the process variable of the primary loop.
- When tuning a control loop, it is important to take into account the presence of multivariable loops. The standard procedure is to tune the secondary loop before tuning the primary loop because adjustments to the secondary loop impact the primary loop. Tuning the primary loop will not impact the secondary loop tuning.

Feedforward Plus Feedback

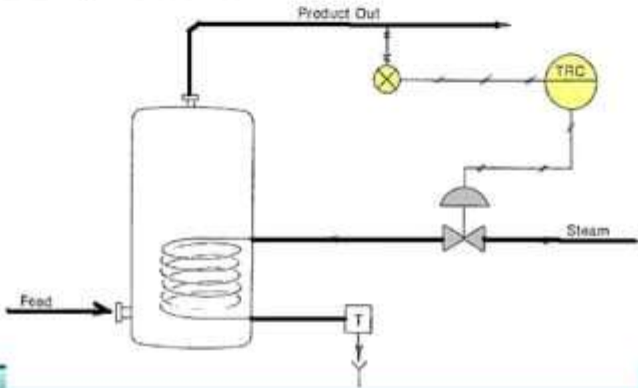
- Because of the difficulty of accounting for every possible load disturbance in a feedforward system, feedforward systems are often combined with feedback systems. Controllers with summing functions are used in these combined systems to total the input from both the feedforward loop and the feedback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



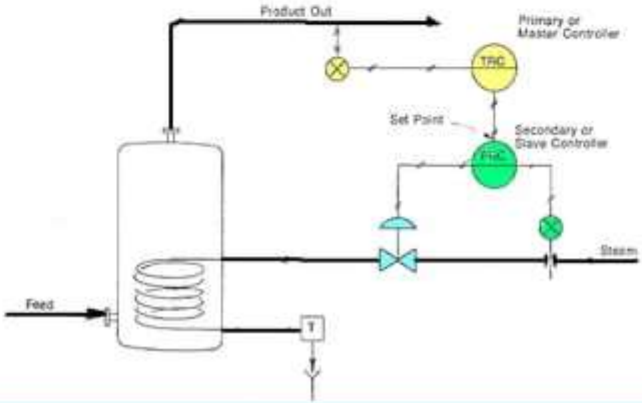
Cascade Control

- Cascade control is a technique that uses two *measuring and control* systems to manipulate a single final control element. Its purpose is to provide increased stability to particularly complex process control problems. The technique has been used for many years and is very effective in many applications.
- Cascade control accomplishes two important functions:
  - » it reduces the effect of load changes near their source, and
  - » it improves control by reducing the effect of time lags.

- The schematic shows how control is accomplished directly with the temperature controller regulating steam flow through the heating coil. This system works very well except when disturbances occur in the feed rate or when steam pressure variations change the amount of flow through the heating coil. Because of the fluid capacity in the vessel and because of the measurement lag time, the temperature controller does not immediately detect the disturbances. By the time detection is made, the disturbance may have receded to its normal operation. Cyclic action probably occurs.

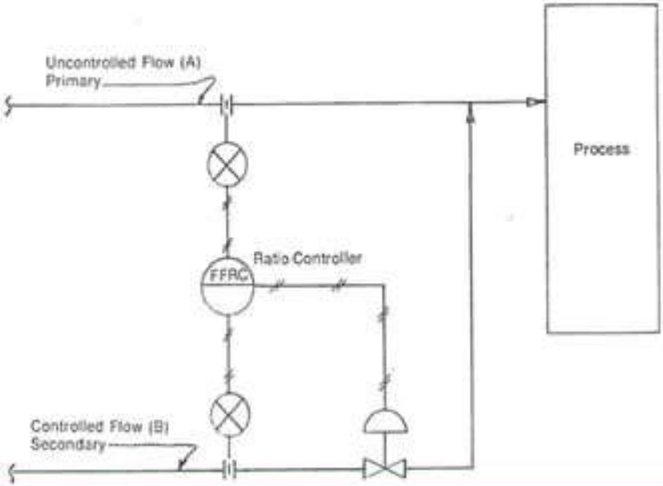


- IN this schematic, illustrates how the cascade system operates. The steam feed is placed on now control so that the desired steam now is maintained despite pressure fluctuations in the supply. The temperature controller is cascaded with the flow controller, however, so that long-range fluctuations such as feed rate, ambient temperature effects, etc., will be overcome, and the desired variable (temperature) is maintained as needed. It resets the flow control set point as necessary to maintain the correct temperature.
- Cascade systems can be overemphasized; they are not a panacea for every unstable process condition encountered or for all measurement lag problems. However, they do provide satisfactory solutions to many application problems.

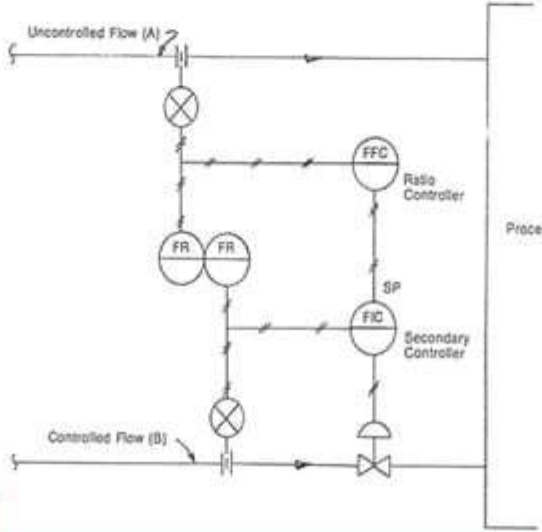


Ratio Control

- As the name implies, ratio control is maintaining a fixed ratio between two variables. The most common application for ratio control is maintaining a fixed relationship between two flows, such as air-fuel ratios in furnaces, feed and catalysts ratios in reactors and mixtures of two or more raw materials in blending operation.
- In this figure: The uncontrolled flow (A) is measured and an adjustable ratio linkage on the controller is used to control flow (B) to the desired ratio between A and B

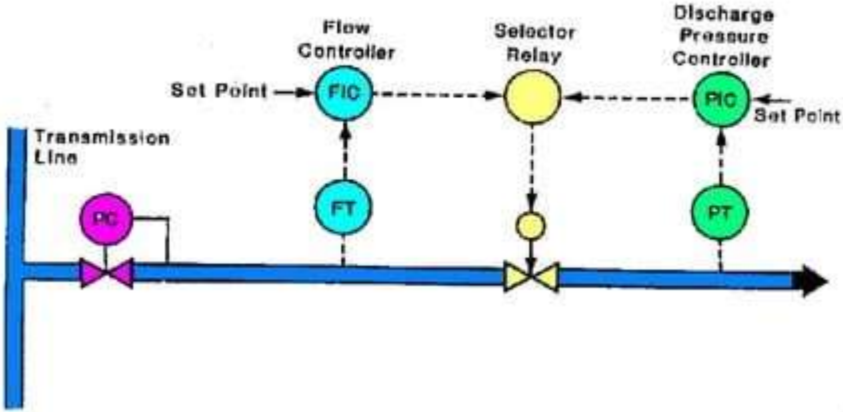


- A more common method of ratio control is using separate units to provide the ratio system. In this figure, the measurement of an uncontrolled flow transmitted to a ratio unit where it is multiplied by a ratio factor, and the output of the ratio unit becomes the set point of the secondary controller. The ratio unit normally has a manually adjusted scale to adjust the ratio between the two variables.



Override Control

- In process control systems it often becomes desirable to limit a process variable to some low or high value to avoid damage to process equipment or to the product. This is accomplished by override devices. As long as the variable is within the limits set by the override devices, normal functioning of the control system continues; when the set limits are exceeded, the override devices take predetermined actions.

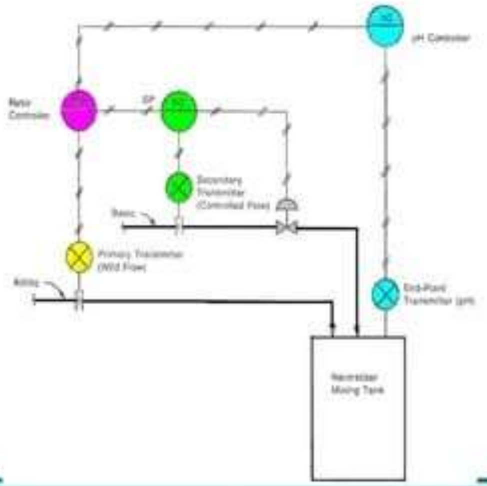


Time-Cycle Control

- Time-cycle control involves one or more circuits, usually electrical, which activate on-off valves and other control devices to perform repetitive operations in process operations.
- There are many process functions that require this type control for entire operational sequences. Some functions are simple, such as switching drying chambers in dessicant air dryers that have two dessicant beds used alternately in the drying and reactivation cycles.
- Other more complex systems include absorbent type drying systems such as molecular sieves for moisture removal or other liquid or component separation. Such systems as these involve switching, furnace operation and other on-off functions that are accomplished on a pure time cycle or a combination of time cycle and end-point control.

End-Point Control

- End-point control is a combination of control systems in which a primary variable automatically adjusts set points or ratios of controllers to achieve control of the primary variable.
- In the example a process must be neutral at the mixing tank to prevent unnecessary corrosion to process equipment downstream. A combination of cascade and ratio unit control systems is used for this purpose.
- End-point analysis is made by a pH detector, and its controller adjusts the ratio of the neutralizing agent (secondary flow) to the acid stream (primary flow) to achieve a neutralized (basic) mixture. As acidity changes in the primary stream, the pH controller detects the deviation from set point and adjusts the ratio setting automatically to keep the mixture under control.
- This technique can also be applied to controlling air-fuel ratio in furnaces by measuring the oxygen content of the exhaust gases.



Batch Control (Program Control)

- ***Batch processes*** are those processes that are taken from start to finish in batches. For example, mixing the ingredients for a juice drinks is often a batch process. Typically, a limited amount of one flavor (e.g., orange drink or apple drink) is mixed at a time. For these reasons, it is not practical to have a continuous process running. Batch processes often involve getting the correct proportion of ingredients into the batch. Level, flow, pressure, temperature, and often mass measurements are used at various stages of batch processes.
- A disadvantage of batch control is that the process must be frequently restarted. Start-up presents control problems because, typically, all measurements in the system are below setpoint at start-up. Another disadvantage is that as recipes change, control instruments may need to be recalibrated.

Fuzzy Control

- *Fuzzy control* is a form of adaptive control in which the controller uses fuzzy logic to make decisions about adjusting the process. *Fuzzy logic* is a form of computer logic where whether something is or is not included in a set is based on a grading scale in which multiple factors are accounted for and rated by the computer. The essential idea of fuzzy control is to create a kind of artificial intelligence that will account for numerous variables, formulate a theory of how to make improvements, adjust the process, and learn from the result.
- Fuzzy control is a relatively new technology. Because a machine makes process control changes without consulting humans, fuzzy control removes from operators some of the ability, but none of the responsibility, to control a process.