Controller Principles

UNIT-3

Introduction

- The controller inputs the result of a measurement of the controlled variable and determines an appropriate output to the final control element.
- The input signal maybe an analog or digital, pneumatic or electronic solves certain equations to calculate the proper output.
- The nature of the process and the particular controlled variable determine which mode or modes of control are to be used.

PROCESS CHARACTERISTICS

- The selection of what controller modes to use in a process is a function of the characteristics of the process.
- Few properties of processes that are important for selecting the proper modes.

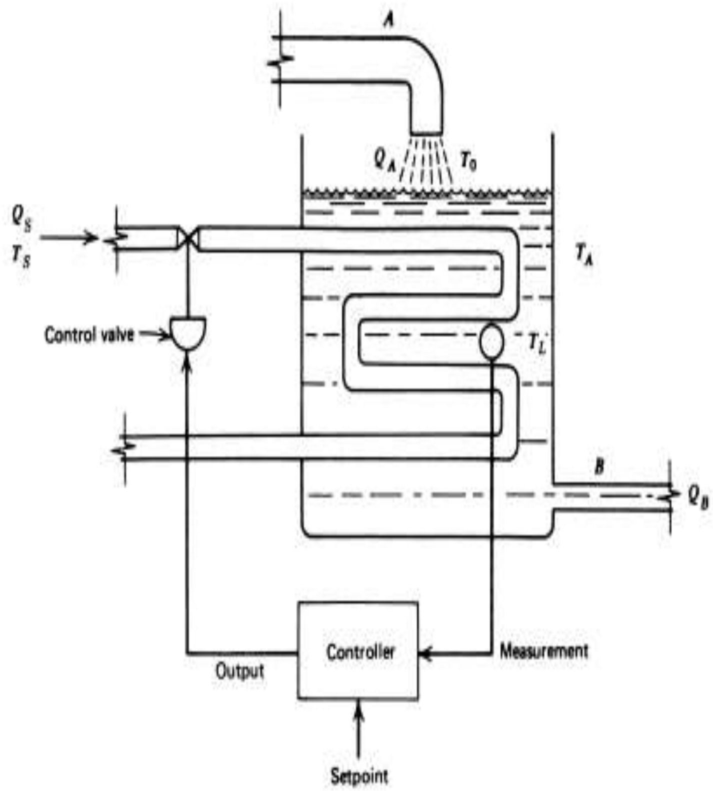
➢ Process Equation

➢ Process Load

➢ Process Lag

➢ Self-Regulation

Process Equation



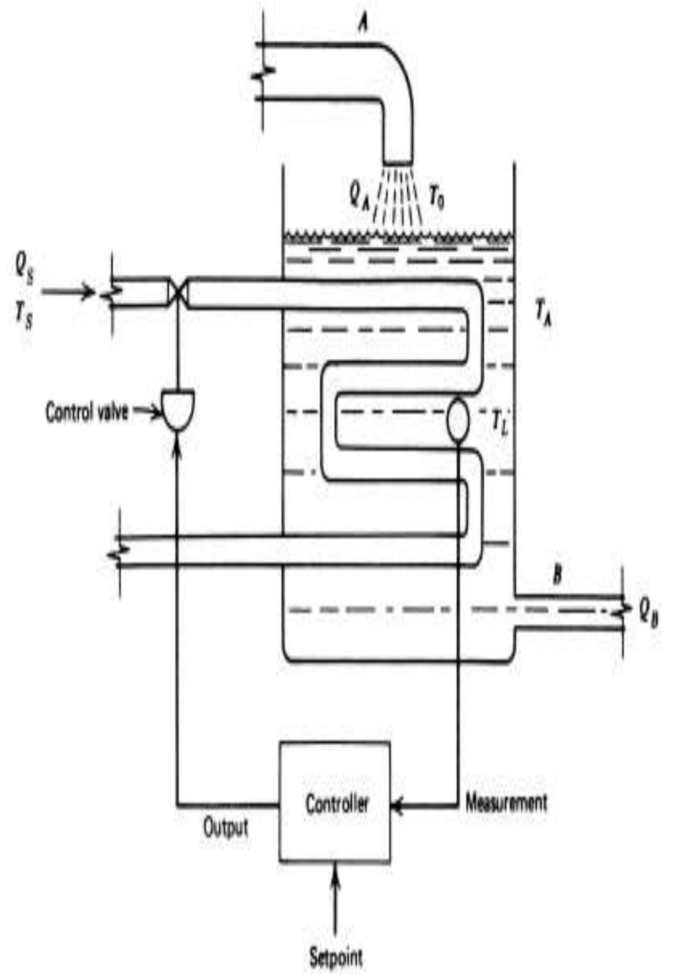
$$T_L = F(Q_A, Q_B, Q_S, T_A, T_S, T_0)$$

where Q_A, Q_B = flow rates in pipes A and B
Q_S = steam flow rate
T_A = ambient temperature
T_0 = inlet fluid temperature
T_S = steam temperature

- A process-control loop regulates some dynamic variable in a process.
- This controlled variable, a process parameter, may depend on many other parameters (in the process).
- If a measurement of the controlled variable shows a deviation from the setpoint, then the controlling parameter is changed, which in turn changes the controlled variable.
- As an example:
- The control of liquid temperature in a tank, as shown in Figure 1.
- The controlled variable is the liquid temperature.
- This temperature depends on many parameters in the process—for example, the input flow rate via pipe A, the output flow rate via pipe B, the ambient temperature, , the steam temperature, inlet temperature, and the steam flow rate.
- In this case, the steam flow rate is the controlling parameter chosen to provide control over the variable (liquid temperature).
- If one of the other parameters changes, a change in temperature results.
- To bring the temperature back to the setpoint value, we change only the steam flow rate—that is, heat input to the process.
- This process could be described by a process equation where liquid temperature is a function as

Process Load

- From the process equation, or knowledge of and experience with the process, it is possible to identify a set of values for the process parameters that results in the controlled variable having the setpoint value. This set of parameters is called the nominal set.
- The term process load refers to this set of all parameters, excluding the controlled variable. When all parameters have their nominal values, we speak of the nominal load on the system.
- The required controlling variable value under these conditions is the nominal value of that parameter.
- If the setpoint is changed, the control parameter is altered to cause the variable to adopt this new operating point.
- The load is still nominal, however, because the other parameters are assumed to be unchanged.
- Suppose one of the parameters changes from nominal, causing a corresponding shift in the controlled variable. We then say that a process load change has occurred.



•The controlling variable is adjusted to compensate for this load change and its effect on the dynamic variable to bring it back to the setpoint.
•In the example of Figure 1, a process load change is caused by a change in any of the five parameters affecting liquid temperature.

Process Lag

- At some point in time, a process-load change or transient causes a change in the controlled variable.
- The process-control loop responds to ensure that, after sometime the variable returns to the setpoint value.
- Part of this time is consumed by the process itself and is called the process lag.
- Thus, referring to Figure 1, assume the inlet flow is suddenly doubled.
- Such a large process-load change radically changes (reduces) the liquid temperature.
- The control loop responds by opening the steam inlet valve to allow more steam and heat input to bring the liquid temperature back to the setpoint.
- The loop itself reacts faster than the process.
- In fact, the physical opening of the control valve is the slowest part of the loop.
- Once steam is flowing at the new rate, however, the body of liquid must be heated by the steam before the setpoint value is reached again.
- This time delay or process lag in heating is a function of the process, not the control system.
- Clearly, there is no advantage in designing control systems many times faster than the process lag.

Self-Regulation

- A significant characteristic of some processes is the tendency to adopt a specific value of the controlled variable for nominal load with no control operations.
- The control operations may be significantly affected by such self-regulation.
- The process of Figure 1 has self-regulation.

(1) Suppose we fix the steam valve at 50% and open the control loop so that no changes in valve position are possible.

(2) The liquid heats up until the energy carried away by the liquid equals that input energy from the steam flow.

(3) If the load changes, a new temperature is adopted (because the system temperature is not controlled).

(4) The process is self-regulating, however, because the temperature will not “run away,” but stabilizes at some value under given conditions.

- An example of a process without self-regulation is a tank from which liquid is pumped at a fixed rate.
- Assume that the influx just matches the outlet rate.
- Then the liquid in the tank is fixed at some nominal level.
- If the influx increases slightly, however, the level rises until the tank overflows. No self-regulation of the level is provided.

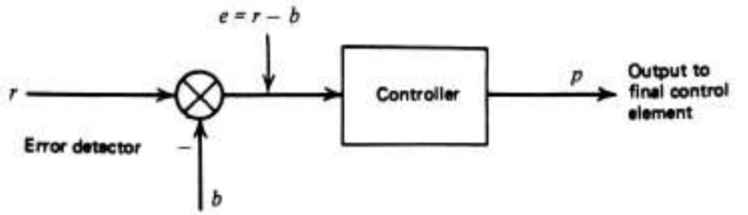
CONTROL SYSTEM PARAMETERS

- The basic characteristics of the process that are related to control.

(1) Inputs to the controller are a measured indication of both the controlled variable and a setpoint representing the desired value of the variable, expressed in the same as the measurement

(2) The controller output is a signal representing action to be taken when the measured value of the controlled variable deviates from the setpoint.

- b- measured variable, r-reference/setpoint, e-error detection



Error

- The deviation or error of the controlled variable from the setpoint is given by

$$e = r - b$$

where e = error
b = measured indication of variable
r = setpoint of variable (reference)

- Equation expresses error in an absolute sense, or in units of the measured analog of the control signal.

Span of actual measured variable

- Error as percent of the measured variable range is span.
- The measured value of a variable can be expressed as percent of span over a range of measurement by the equation

$$c_p = \frac{c - c_{min}}{c_{max} - c_{min}} \times 100$$

where
c_p = measured value as percent of measurement range
c = actual measured value
c_{max} = maximum of measured value
c_{min} = minimum of measured value

Span of measured indication

- Equation can be expressed in terms of the measured indication, *b*.
- *It is necessary only to translate the* measured minimum and maximum to b_{max} and b_{min}.
- To express error as percent of span, it is necessary only to write both the setpoint and measurement in terms of percent of span and take the difference according to Equation.
- The result is

$$e_p = \frac{r - b}{b_{\max} - b_{\min}} \times 100$$

where e_p = error expressed as percent of span

- A positive error indicates a measurement below the setpoint, and a negative error indicates a measurement above the setpoint.

Variable Range

- Generally, the variable under control has a range of values within which control is to be maintained.
- This range can be expressed as the minimum and maximum value of the variable or the nominal value plus and minus the spread about this nominal value.
- If a standard 4- to 20-mA signal transmission is employed, then 4 mA represents the minimum value of the variable and 20 mA the maximum.
- When a computer-based control system is used, the dynamic variable is converted to an *n-bit digital signal*.
- *Often, the transformation is made so that all **0's are the minimum*** value of the variable and all **1's are the maximum value.**

Control Parameter Range

- The final control element has some minimum and maximum effect on the process.
- The controller output range is the translation of output to the range of possible values of the final control element.
- Generally, all **0's are the minimum output and all 1's the maximum.**
- **These numbers** do not necessarily represent the minimum and maximum of the final control element, however. We may wish a valve never to be fully closed, for example; therefore, all **0's might** represent some percentage of full open.
- Often, the output is expressed as a percentage where 0% is the minimum controller output and 100% the maximum (obviously).
- The valve in the fully open position corresponds to a 100% controller signal output.
- Often, however, the minimum does *not correspond to zero effect.*
- *For example, it may be that the steam flow* should never be less than that flow which results with the valve half open.
- In this case, a 0% minimum controller corresponds to the flow rate with a half-open valve.
- The controller output as a percent of full scale when the output varies between specified limits is given by

$$p = \frac{u - u_{\min}}{u_{\max} - u_{\min}} \times 100$$

where p = controller output as percent of full scale
u = value of the output
$u_{\max}$ = maximum value of controlling parameter
$u_{\min}$ = minimum value of controlling parameter

Control Lag

- The control system also has a lag associated with its operation that must be compared to the process lag.
- When a controlled variable experiences a sudden change, the process-control loop reacts by outputting a command to the final control element to adopt a new value to compensate for the detected change.
- *Control lag refers to the time for* the process-control loop to make necessary adjustments to the final control element.
- Thus, in Figure 1, if a sudden change in liquid temperature occurs, it requires some finite time for the control system to physically actuate the steam control valve.

Dead Time

- Another time variable associated with process control is a function of both the process control system and the process.
- This is the elapsed time between the instant a deviation (error) occurs and when the corrective action first occurs.
- An example of *dead time occurs in the control* of a chemical reaction by varying reactant flow rate through a long pipe.
- When a deviation is detected, a control system quickly changes a valve setting to adjust flow rate.
- But if the pipe is particularly long, there is a period of time during which no effect is felt in the reaction vessel.
- This is the time required for the new flow rate to move down the length of the pipe.
- Such dead times can have a profound effect on the performance of control operations on a process.

Cycling

- We frequently refer to the behavior of the dynamic variable error under various modes of control.
- One of the most important modes is an oscillation of the error about zero. This means the variable is *cycling above and below the setpoint value.*
- In case of *steady-state cycling* both the peak amplitude of the error and the period of the oscillation.
- If the cycling amplitude decays to zero, however, we have a *cyclic transient error.*
- Here we consider the initial error, the period of the cyclic oscillation, and decay time for the error to reach zero.

Controller Modes

- Controller modes refer to the methods to generate different types of control signals to final control element to control the process variable.
- Broad classifications of different controller modes used in process control are as follows:

(1) Discontinuous Controller Modes

- ➢ Two-position (ON/OFF) Mode
- ➢ Multiposition Mode
- ➢ Floating Control Mode: Single Speed and Multiple Speed

(2) Continuous Controller Modes

- ➢ Proportional Control Mode
- ➢ Integral Control Mode
- ➢ Derivative Control Mode

(3) Composite Controller Modes

- ➢ Proportional-Integral Control (PI Mode)
- ➢ Proportional-Derivative Control (PD Mode)
- ➢ Proportional-Integral-Derivative Control (PID or Three Mode Control)

Controller Modes contd..

- Based on the controller action on the control element, there are two modes:

(1) ***Direct Action****: If the controller output increases with increase in controlled* variable then it is called direct action.

(2) ***Reverse Action****: If the controller output decreases with increase in controlled* variable then it is called reverse action.

Discontinuous Controller Modes

- In these controller modes the controller output will be discontinuous with respect to controlled variable error.

➢ Two-position (ON/OFF) Mode

➢ Multiposition Mode

➢ Floating Control Mode: Single Speed and Multiple Speed

Two-Position Mode

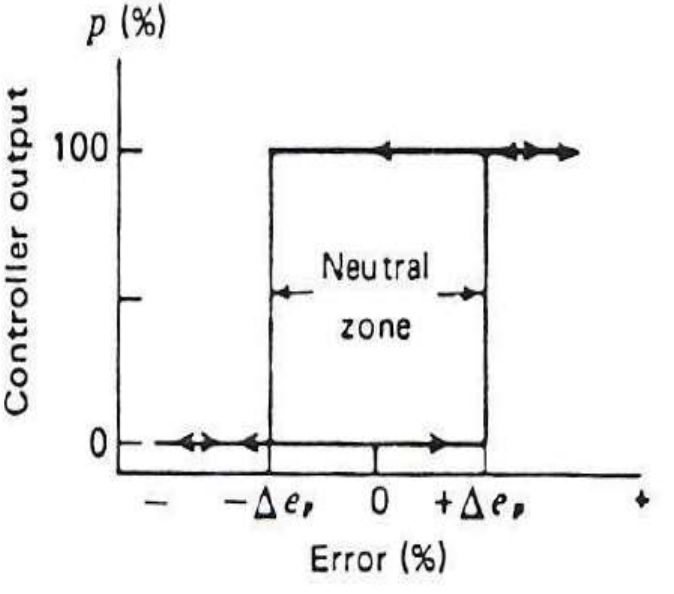
- The most elementary controller mode is the two-position or ON/OFF controller mode.
- It is the simplest, cheapest, and suffices when its disadvantages are tolerable. The most general form can be given by

$$P = \begin{cases} 0\,\% & e_p < 0 \\ 100\,\% & e_p > 0 \end{cases}$$

- The relation shows that when the measured value is less than the setpoint (i.e. *ep > 0)*, *the* controller output will be full (i.e. 100%), and
- when the measured value is more than the setpoint (i.e. *ep < 0), the controller output will be zero (i.e. 0%).*

Neutral Zone

- In practical implementation of the two-position controller, there is an overlap as *ep increases through zero or decreases through zero.*
- *In this span, no change in* the controller output occurs.
- It can be observed that, until
- an increasing error changes by Δe_p *above zero, the controller* output will not change state.
- In decreasing, it must fall Δe_p *below zero before the* controller changes to 0%.
- The range 2Δ*ep is referred to as neutral zone or differential gap.*
- *Two-position controllers are purposely designed with neutral zone to prevent* excessive cycling.
- The existence of such a neutral zone is an example of desirable hysteresis in a system.



Applications

- Generally the two-position control mode is best adapted to:
- Large-scale systems with relatively slow process rates.
  - ➢ Example: Room heating systems, air-conditioning systems.
- Systems in which large-scale changes are not common
  - ➢ Examples: Liquid bath temperature control, level control in large-volume tanks.