MODULE I- PROCESS CONTROL STRATEGIES

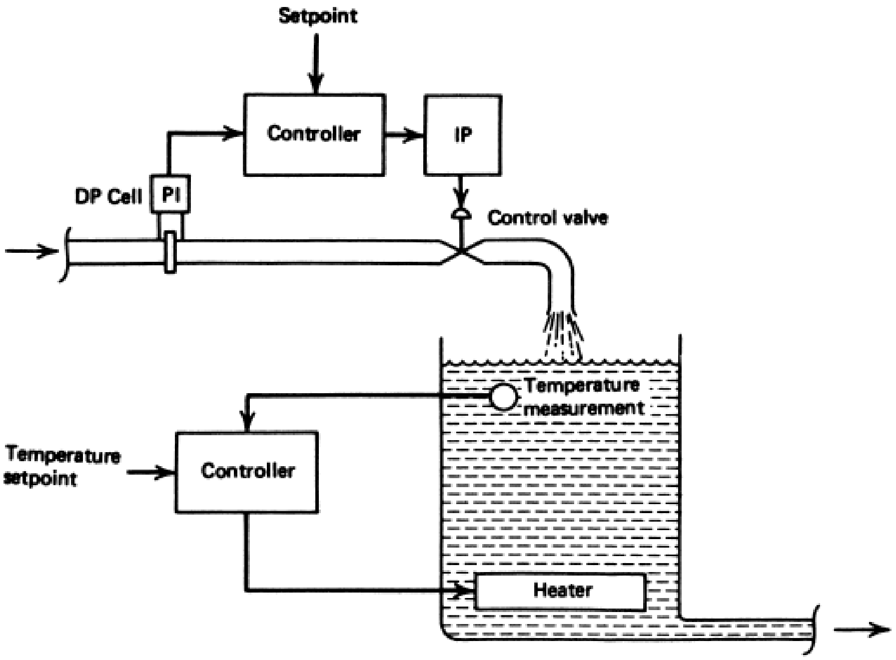
BASIC PROCESS CONTROL STRATEGIES

The purpose of a process control system is to maintain the controlled variable at the setpoint. The complexity of the system will depend upon the process under control. There are different types of variables involved in process control and are discussed here.

DIFFERENT VARIABLES IN PROCESS CONTROL

Single variable process control

It is the basic process control strategy. There is only a single variable that is under control. The variable is measured directly and is kept at the set point, regardless of other process variables. Is the simplest and the cheapest process control strategy.



In the example, there is a process control tank. Water is fed to the tank through the inlet tube. The flow control loop maintains the flow at a desired set point. This is one single variable loop. A second single-variable control loop, as in the figure, regulates the temperature of liquid in the tank by adjustment of heat input. This also is a single-variable loop that maintains the liquid temperature at the desired setpoint value.

Independent variable process control

In certain process control applications, it is desirable to keep the process variable at the setpoint, regardless (independent) of the change is other process variables. The control of this type is known as independent variable process control.

In the previous example, when there is a load change in flow, the controller adjusts the control valve to bring the flow to the desired setpoint. This is not dependent on the temperature control loop in the process tank. Thus, in the example, control of flow is independent variable process control.

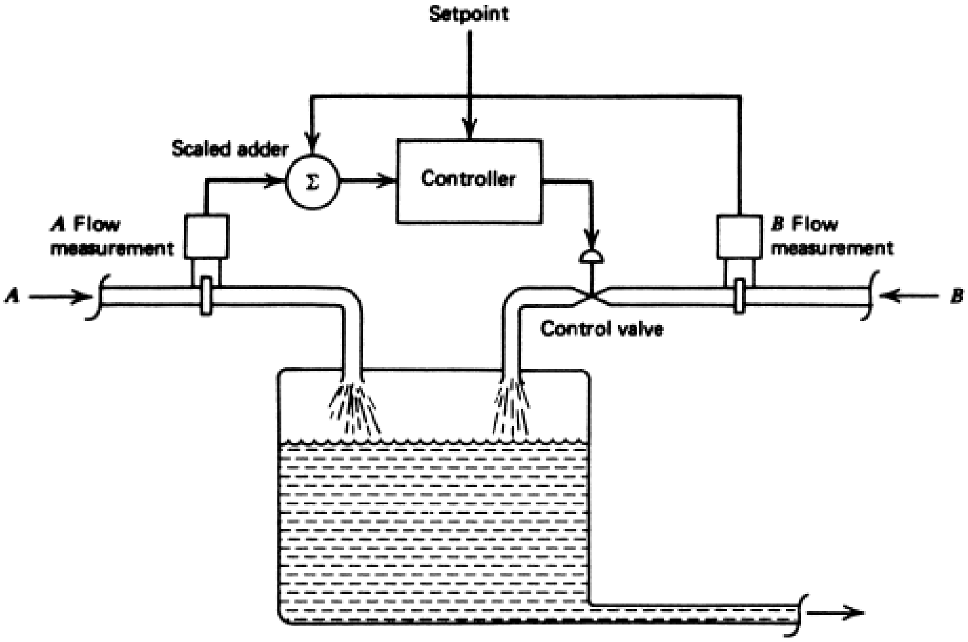
Interactive variable process control

In certain processes, there can be more than one control loop. The action of one control loop may affect the action of other. The loops can interact. In such processes, the control of one of the variables will depend upon the change in other variable.

In the previous example, when flow is held constant (under nominal conditions), the temperature is driven towards setpoint using the temperature control loop. Both flow and temperature are held constant. But when the flow changes, it will appear as a load change for the temperature control system, because, the change in inlet flow will vary the temperature of the fluid in the tank. That is, the variable temperature is interacting with the variable flow and hence the temperature control is interactive variable process control.

Compound variable process control

In some process control applications, a single loop is used to provide control of the relationship between two or more variables. This is termed as compound variable process control. This is done by applying measurements from two sensors as input to the controller. Sometimes a signal conditioning system is used to scale the measurements from two sensors. The analysis of such systems are generally complicated.

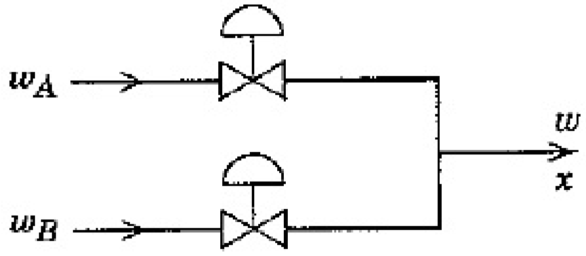


A common example is the control of chemical reaction. In a chemical reaction, it is desirable to keep the ratio of two reactants as a constant. In this example, flow rates of both the reactants and measured, scaled and added and is given as input to the controller. The controller compares it with the set point (set point will be scaled sum of two desired flow rates) and adjusts the control valve accordingly. It is to be noted that, the flow rate of only one of the reactants (reactant B) is controlled, and not both the flow rates.

Multivariable process control

In several practical control applications there are several variables to be controlled and this is done by adjusting several manipulated variables. Such systems involving several independent or interacting controlled/manipulated variables are known as multivariable systems. An important characteristic of multivariable systems is process interaction. That is, each manipulated variable can affect all the controlled variables. In-line blending system and distillation column are two examples of multi variable systems.

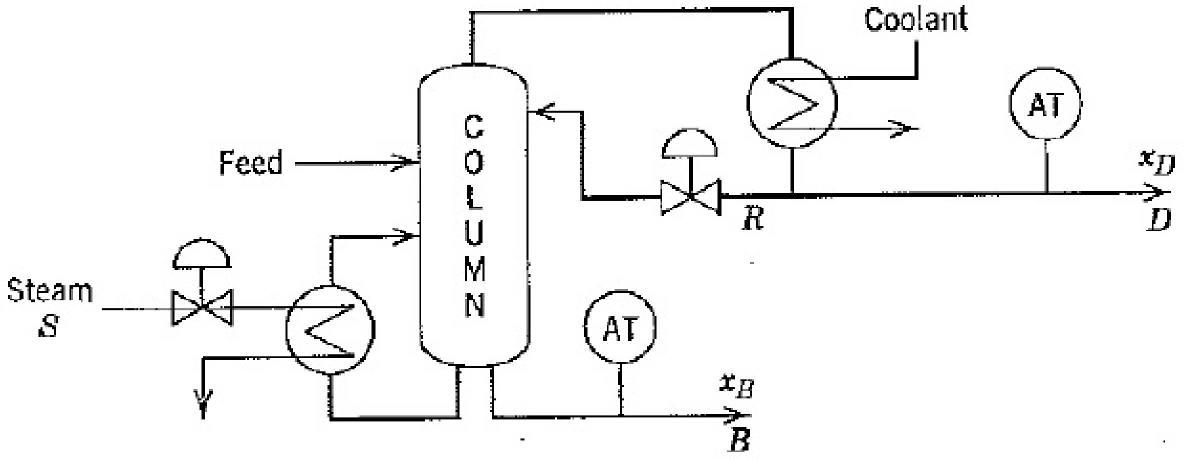
a) In-line blending system



In-line blending system

Two streams A and B are blended (mixed) to produce a product stream. W_A and W_B denote the mass flow rates of A and B respectively. At the product side, w and x represents mass flow rate and composition respectively of the product stream. Varying either W_A or W_B affects both w and x. Hence this is a multivariable system with process interaction.

b) Distillation column

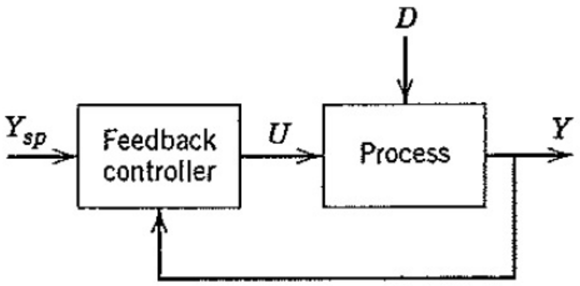


Distillation column

A distillation column is used to separate the components in a mixture, based on the difference in their volatilities. The feed indicates the mixture which is supplied to the column. Steam (S) is passed through the bottom of the column to heat the mixture. Components having high volatility rises up the column and is collected at the output as the distillate product. x_D denotes the composition of distillate product. Those components having less volatility will remain at the bottom of the distillation column and is collected as the bottom product. x_B denotes the composition of bottom product. A portion of the distillate product known as Reflux R is condensed and supplied back to the top of the column, which again undergoes the process and gets separated to either distillate product or bottom product. Here the two main input variables are reflux R and Steam S and output variables of the process are distillate composition x_D and bottom composition x_B. Varying either S or R will vary both x_D and x_B. Hence this is another multivariable process with significant process interaction.

IMPORTANT CONTROL STRATEGIES FOR A PROCESS

Feedback control



In feedback control system, the controlled variable is measured using sensors or transducers. The measured value of controlled variable is compared with the setpoint. Based on the deviation of controlled variable from the setpoint, the controller changes the action of final control element, on the process. It has the following **advantages:**

1. Corrective action takes place as soon as the controlled variable deviates from the setpoint, regardless of the type of disturbance.
2. Development of a process model is not required for feedback control.
3. The most common form of feedback controller is a PID controller. It is simple, less complex mathematically and robust. It gives satisfactory control for almost all systems.

A feedback controller has the following **disadvantages:**

1. Corrective action is taken only when the controlled variable deviates from the setpoint. Even if the deviation is known in advance, no action can be performed until it actually occurs.
2. There is no predictive control in the presence of disturbances.

3. It is not suitable for slow processes, that is for process with dead time or cycling.
4. Feedback control requires measurement of the controlled variable on-line. It may not be possible if the process environments are dangerous.

Feedback control of liquid level in a boiler drum

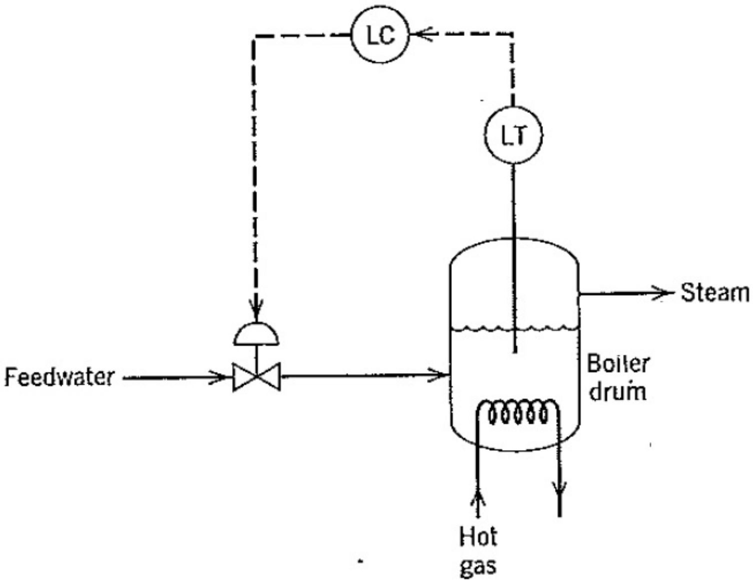
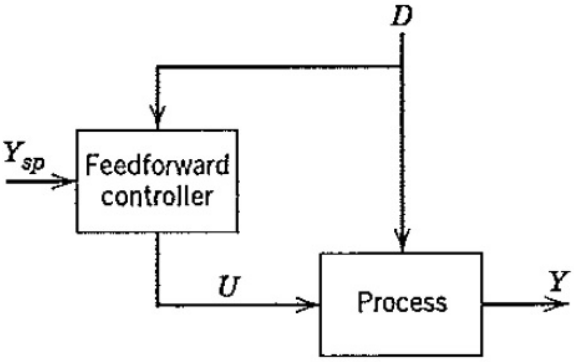


Figure represents feedback control of liquid level in a boiler drum. Level is measured using a Level Transmitter (LT) and is compared with the setpoint at the Level Control (LC). Based on the deviation of Level from the setpoint, the control valve is adjusted accordingly. The use of feedback control for controlling level in boiler drum has two disadvantages. One is that, steam is continuously withdrawn from the boiler drum dur to requirements downstream the process. Hence, the level fluctuates very often. Second disadvantage is that, it is difficult to measure the level of boiling liquid. The steam output act as a disturbance in this system. Hence, feedforward control is preferred for controlling the level in a boiler drum.

Feedforward control



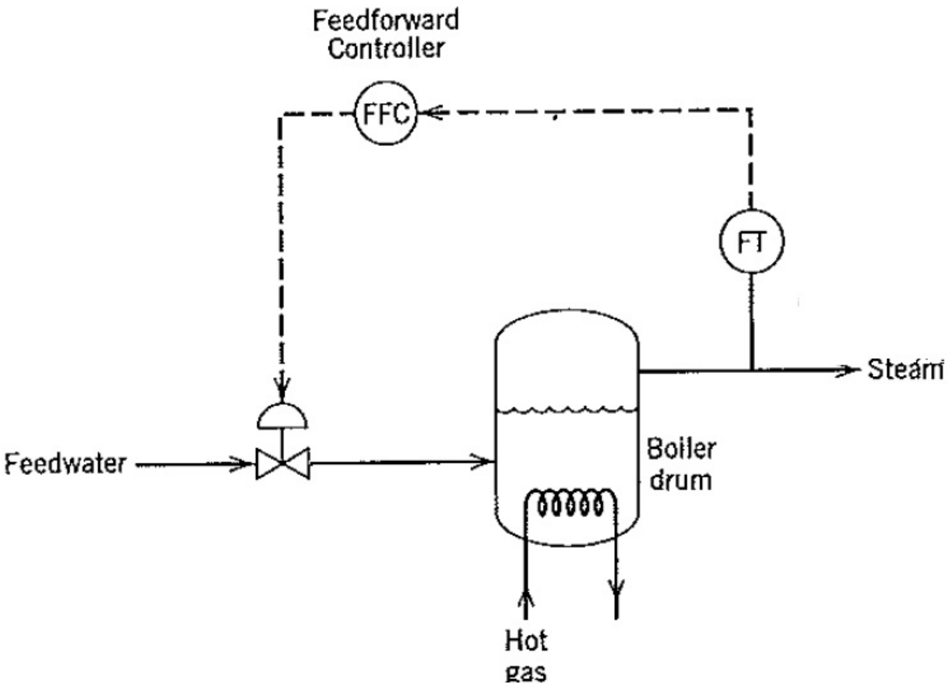
In feedforward control, instead of measuring the controlled variable, disturbances affecting the process is measured. Using a proper process model, the effect of disturbance in the variation of controlled variable is calculated. The measured value of disturbance is applied to the feedforward controller. The feedforward controller evaluates the effect of disturbance on controlled variable and based on the setpoint, generates a control signal U, which is used to control the process. It has the following **advantages:**

1. In feedforward control, disturbance is measured and the corrective action is taken before the controlled variable deviates from the setpoint.
2. It is suitable for slow processes.
3. The effect of disturbances is taken into consideration
4. It does not require the measurement of controlled variable online.

Feedforward control has the following **disadvantages:**

1. The disturbance variables are to be measured online. Sometimes it is not feasible.
2. Feedforward control needs a mathematical model for the process called the process model. Developing a mathematical model for an industrial process is a difficult task.
3. If there are unmeasurable disturbances, feedforward control is not effective.

Feedback control of liquid level in a boiler drum



The feedforward control scheme is better suited for the control of liquid level in a boiler drum. In this method, the controlled variable is the liquid level, but it is not measured. Steam flow output is a disturbance variable. It is measured and given to the feedforward controller. Based on the amount of steam, the flow of feedwater to the boiler drum is controlled. The liquid level is maintained at the setpoint, before any deviation or error occurs and without actually measuring it.

Ratio Control

Ratio control is special type of feedforward control. It has a lot of applications in process industries. Its aim is to maintain the ratio of two process variables at a constant specified value. The two variables are usually flow rates, a manipulated variable u and a disturbance variable d. Thus, the ratio R is maintained at the setpoint ratio, instead of controlling the individual variables.

$$R = \frac{u}{d}$$

Applications of ratio control include the following:

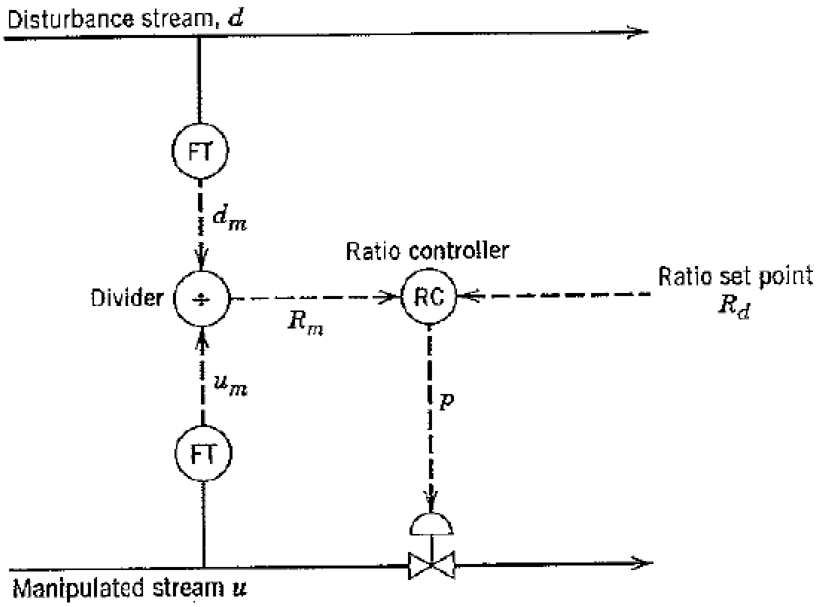
- Specifying the relative amount of components in blending operations.
- Maintaining the stoichiometric ratio of reactants in a reactor.
- Keeping specified reflux ratio in a distillation column.
- Maintaining air-fuel ratio for combustion in a furnace at an optimum value.

Ratio control scheme can be implemented using two schemes.

Ratio Control – Method I

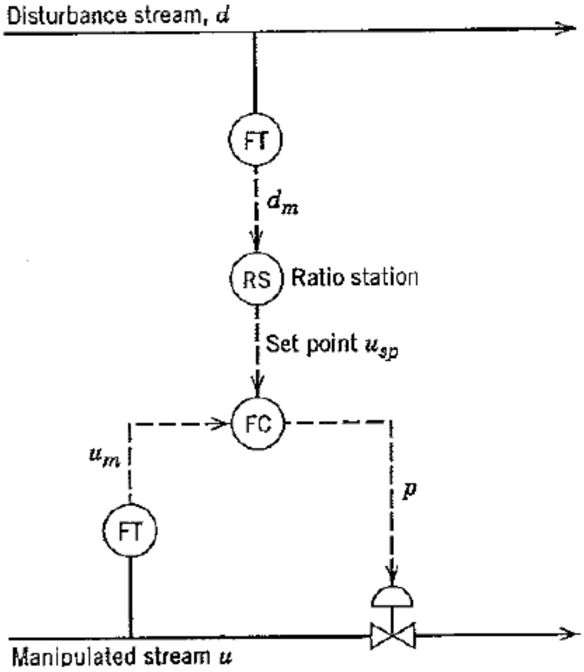
In this method, the flow rates of both the disturbance stream and manipulated stream are measured. The ratio of measured flow rates is then calculated.

$$R_m = \frac{u_m}{d_m}$$



The output of the divider element is sent to the ration controller (RC) and is compared with the desired ratio R_d of flow rates. If the desired ratio is not equal to the ratio of measured flow rates, the flow of manipulated stream is controlled accordingly. A PI controller is usually used as the ratio controller (RC). The advantage of this method is that the measured ratio R_m s calculated. The disadvantage is that it needs to include a divider element in the loop. In order to avoid this, the second ratio control method is usually preferred over the first one.

Ratio Control – Method II



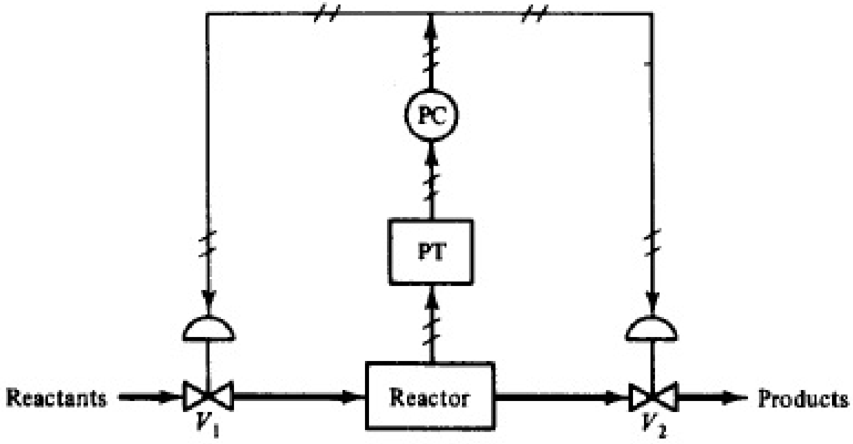
In this method, the flow rate of both disturbance stream and manipulated stream is measured. The measured value of disturbance flow rate is transmitted to the ratio station (RS). It is multiplied with the desired ratio of flow rates. The output signal from the Ratio Station is then used as the set point u_{sp} for the flow controller. The flow controller then adjusts the flow rate of manipulated stream accordingly. Both ratio control schemes are a type of feed forward control.

Split Range control

In split range control, there is only one measurement (controlled output) and more than one manipulated variable. The control signal is split into two parts. Each will affect one of the two manipulated variables. That is, a single process output is controlled by coordinating the action of several manipulated variables. Such systems are not common in industry. But, they increase safety of the system.

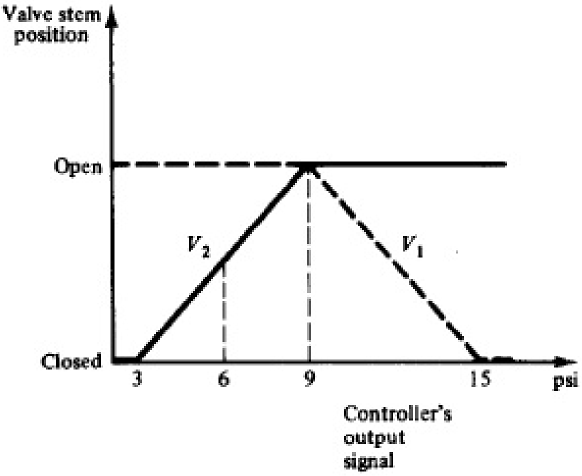
Split Range Control of chemical reactor

In the figure, split range control of a chemical reaction is demonstrated. The reactants are in gaseous phase. There is only one measurement, which is the pressure inside the reactor. Based on the variation of pressure, the flow rates of both the feed and the product streams are manipulated. That is, there are two manipulated variables. When the pressure in the reactor increases, the controller's output signal increases. It is split into two parts and affects the two valves simultaneously.



The following actions take place.

1. When the controller’s output signal is less that 3 psi, Valve V1 is completely open and Valve V2 is completely closed.
2. As pressure increases, when it range is between 3 psi-9 psi, valve V1 remains fully open. The Valve V2 will gradually begin to open.
3. At 9 psi, both the valves are fully open.
4. As pressure further increases (between 9 psi and 15 psi), valve V2 will remain fully open. On the other hand, valve V1 will begin to close.
5. When the pressure is large (>15 psi), Valve V1 is fully closed and valve V2 is fully open.

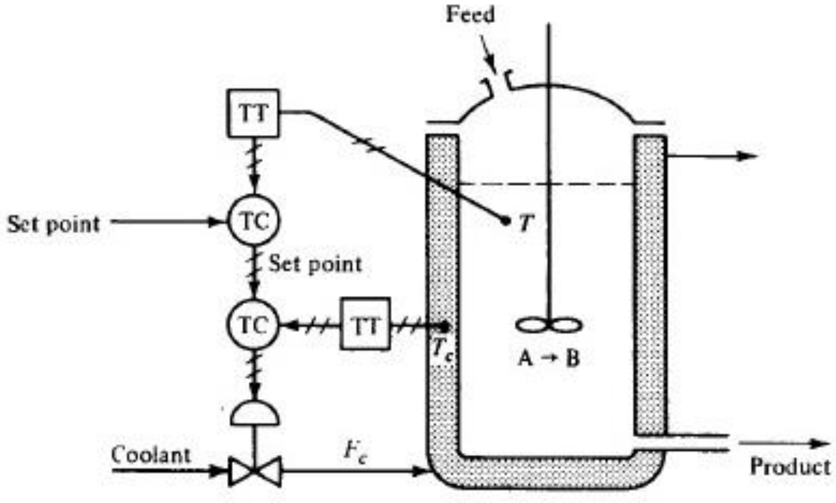


OUTPUT SIGNAL AND VALVE COORDINATION

Controller's output signal	Valve V_1 stem position	Valve V_2 stem position
3 psig	Open	Closed
9 psig	Open	Open
15 psig	Closed	Open

Cascade Control

In cascade control, there is only one manipulated variable and more than one measurement. That is, only one output can be controlled. Cascade control can be explained with the example of CSTR.



Consider the Continuous Stirred Tank Reactor shown in figure. The reaction is exothermic (Generates heat). The heat generated is removed by the coolant, which flows in a jacket around the tank. The control objective is to keep the temperature of the reacting mixture, T, at a constant desired temperature. The disturbances in this system are the feed temperature T_i and the coolant temperature T_c. The manipulates flow rate is the coolant flow rate F_c. That is, the temperature of the reactant mixture is kept at the desired value by controlling the flow of coolant through the jacket.

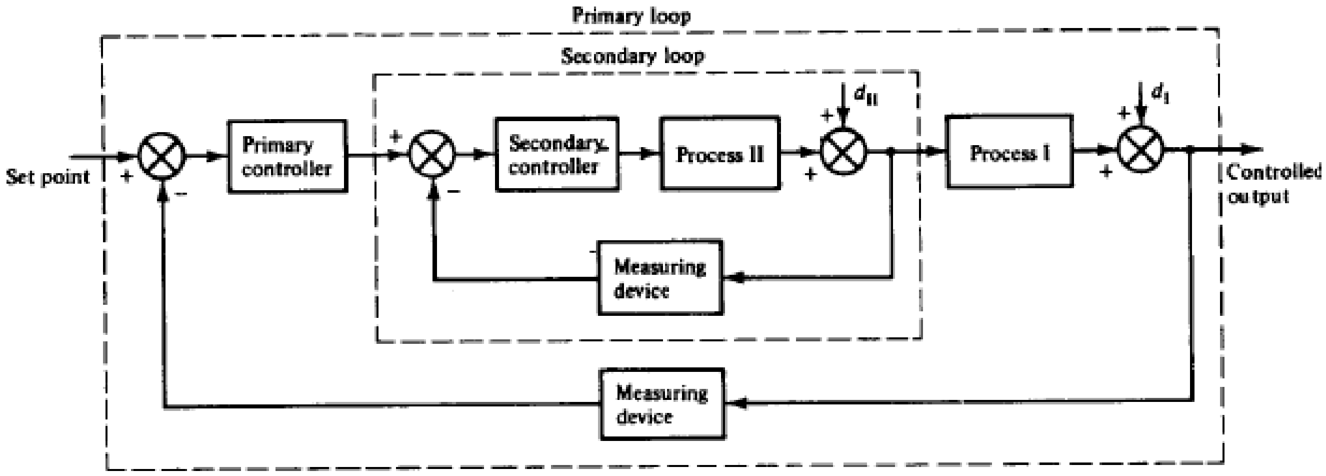
For this system, if feedback control (Refer figure in your notebook) is effective only to control the changes in T due to T_i. In order to control the changes in T due to T_c, cascade control must be used.

In cascade control of CSTR, the coolant temperature T_c is measured. The control action is provided before its change affects the reacting mixture. We can see that there are two measurements, T and T_c, but there is only a single manipulated variable F_c. The cascade control loop works in the following two steps:

1. The first loop measures the temperature of the reacting mixture T, compares it with the desired value of temperature at the first Temperature controller and gives it s output as the setpoint to the second Temperature Controller. This is the primary loop or Master loop.
2. The second loop measures the coolant temperature T_c and controls the flow of cooant F_c accordingly. This is the secondary or slave loop.

This control configuration consisting of two loops is the cascade control. It is very common in chemical processes.

Generalized Block Diagram of Cascade Control



Consider a process consisting of two parts, Process I and Process II. The output of process I is the main controlled variable which we want to control. Its control is done using the primary controller. The output of Process II affects the main controlled variable, hence it is also controlled, using a secondary controller. The measurement of both the processes are done using separate measuring devices. The loop consisting of primary controller, Process I and the corresponding measuring device is the primary loop. The loop consisting of Secondary controller, Process II and the corresponding measuring device is the secondary loop. In the CSTR system, reaction in the tank is the Process I and the controlled output is temperature T. Process II is the jacket and its output T_c affects process I. One important characteristic of cascade control is that the disturbances in the secondary control loop are corrected by the secondary controller before it affects the value of primary controlled output.

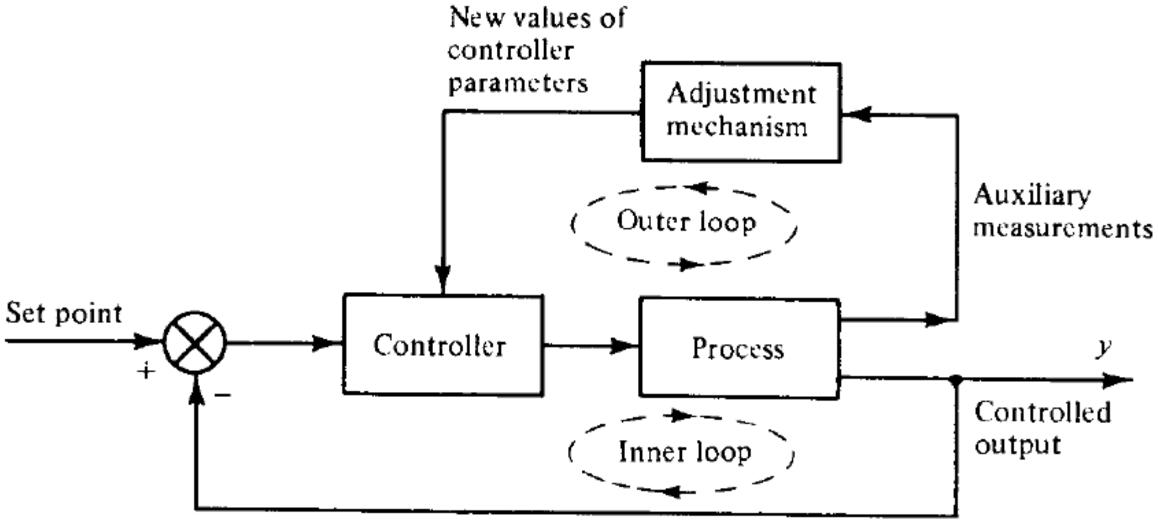
Adaptive Control

An adaptive control system is one whose parameters are automatically adjusted to meet the corresponding variations in the process under control, in order to optimize the response of control loop. There are different types of adaptive control schemes, depending upon the way the parameters are updated. The two main reasons for using adaptive control method are,

1. Most processes are nonlinear in practical. Controller parameters are designed for linear processes. Hence they need to be updated.
2. The characteristics of the process changes with time and environment. The parameters of the controller should be updated according to the changes in process.

The above changes require a revise of control parameters, that is a change in P, PI, PD or PID controller gains. The tuning of an adaptive mechanism means the adjustment of the parameters of the controller whenever there are changes in the process characteristics. The implementation of adaptive controller requires complex mathematical computations.

Method I – Programmed or Scheduled Adaptive Control



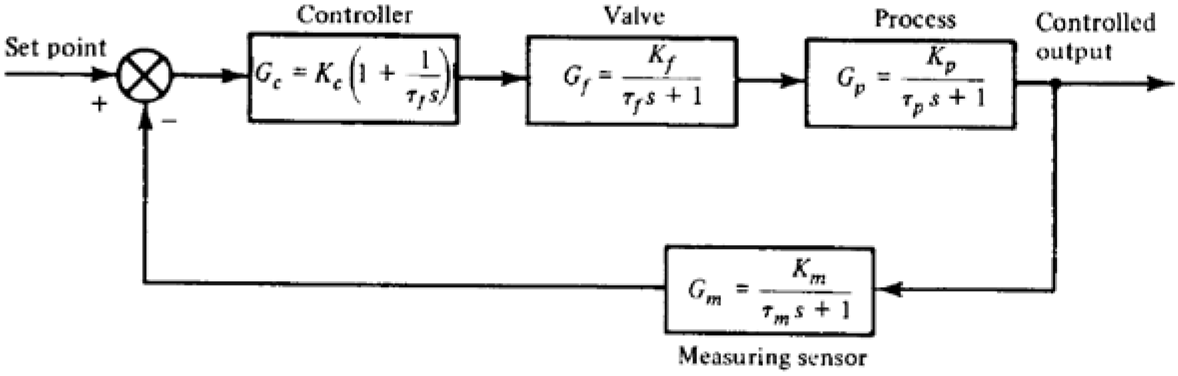
Programmed adaptive control system.

The programmed or scheduled adaptive control is used when a measurable process variable produces a predictable effect on the process control loop. Compensation for this effect by a programmable adjustment mechanism. This is done in the following steps.

- Let there be an auxiliary process variable which reflects the changes in process.
- Program the adjustment mechanism based on the measurement of auxiliary process variable.
- Adjust the controller parameters based on the adjustment mechanism.

There is an inner loop and an outer loop. The inner loop is a normal feedback loop consisting of process and controller. The outer loop consists of measurement of auxiliary variables and the adjustment mechanism. Examples include **gain scheduling adaptive controller** and **adaptive control of air-fuel ratio** in combustion system.

Example (a) - Gain scheduling Adaptive Control



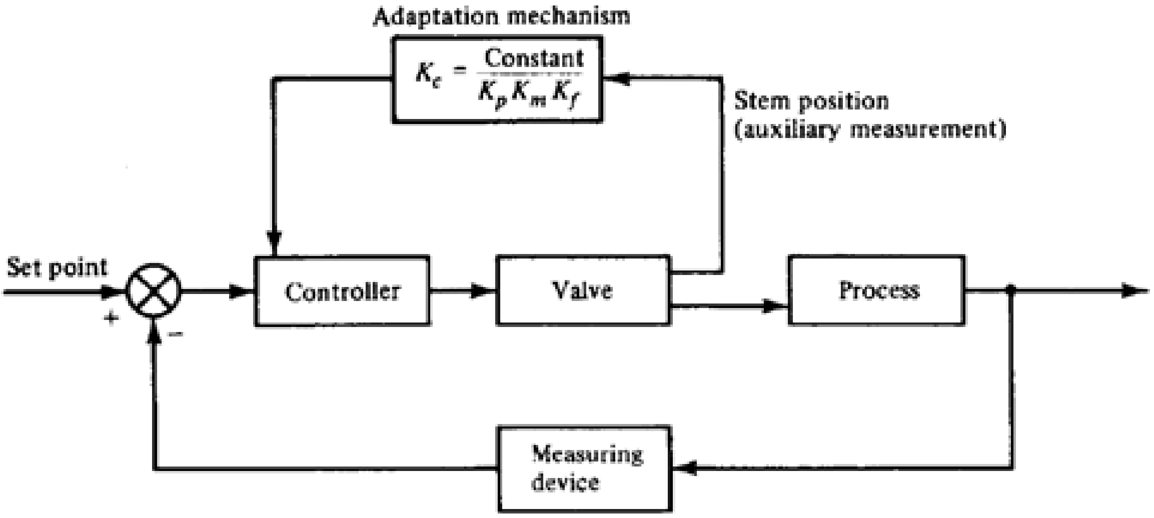
The above block diagram represents a typical feedback control system. The gains of controller, valve, Process and Measurement sensor are K_c, K_f, K_p and K_m respectively. Let the overall gain of the process control loop is to be kept as a constant. Overall gain is given by,

$$K_{overall} = K_c K_p K_m K_f = Constant$$

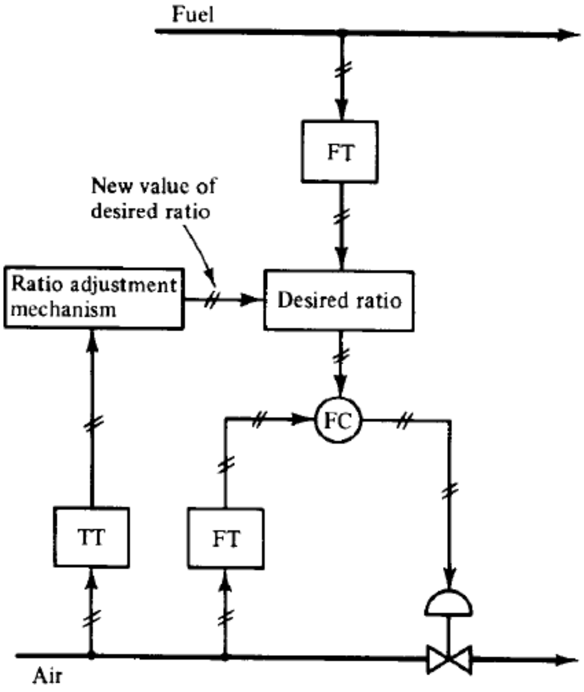
Let the process gain K_p and measurement sensor gain K_m are constant. The valve gain K_f changes according to the position of valve stem. If the overall gain is to be kept at a constant, the controller gain K_c will have to be updated according to the change in valve gain K_f. The update of the controller gain is done using the equation as follows:

$$K_C = \frac{Constant}{K_p K_m K_f}$$

In order to adjust the controller parameters according to change in valve position, gain scheduling adaptive control can be used. In this, the valve position is measured and is given as input to the adaptation mechanism. The controller parameter K_c is thus updated according to the above equation.



Example (b) - Combustion System.



(b)

In furnaces where air-fuel ratio is controlled using a Ratio Controller, there is significance for programmed adaptive controller. The desired value of air-fuel ratio that is suitable for combustion is dependent on temperature of the air. As temperature changes, the desired air-fuel ratio changes. Hence, used a sensor, temperature of the sir (auxiliary variable) is measured and is given to a Ratio Adjustment mechanism. Thus, according to the change in temperature, a new value of desired ratio is updated. The flow of air is thus controlled, according to the new value of desired air-fuel ratio.

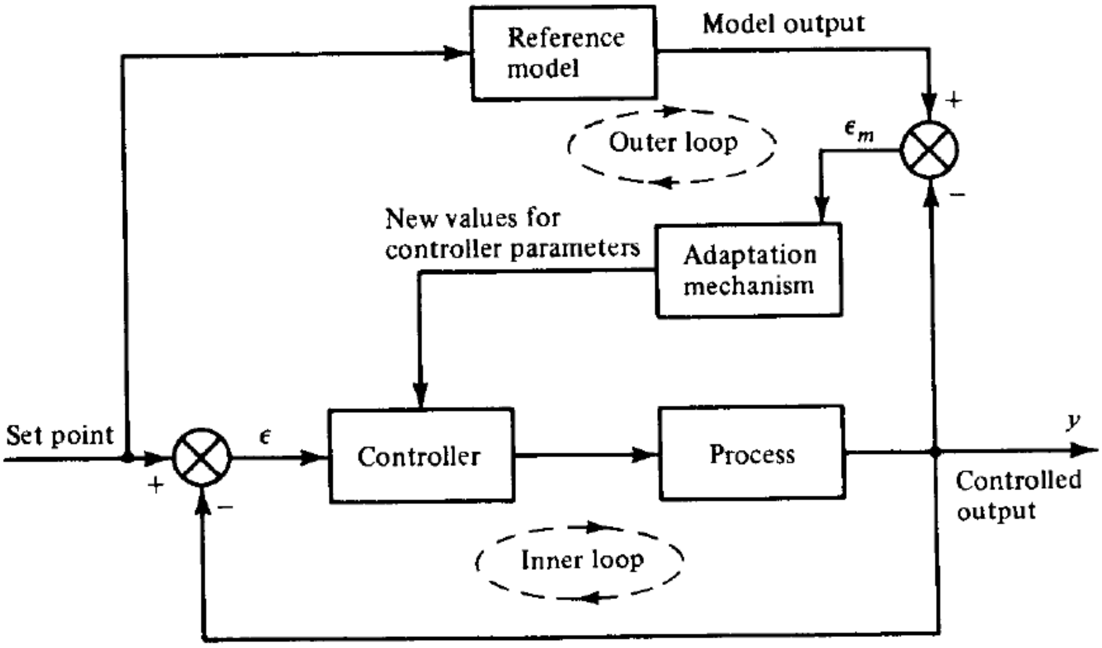
Method II – Self Adaptive Control

This is used during situations when the controlled output is measured online. The adjustment mechanism is designed according to the measured value of controlled output. Two examples are Model Reference Adaptive Control (MRAC) and Self Tuning Regulator.

Example (a) - Model Reference Adaptive Control (MRAC)

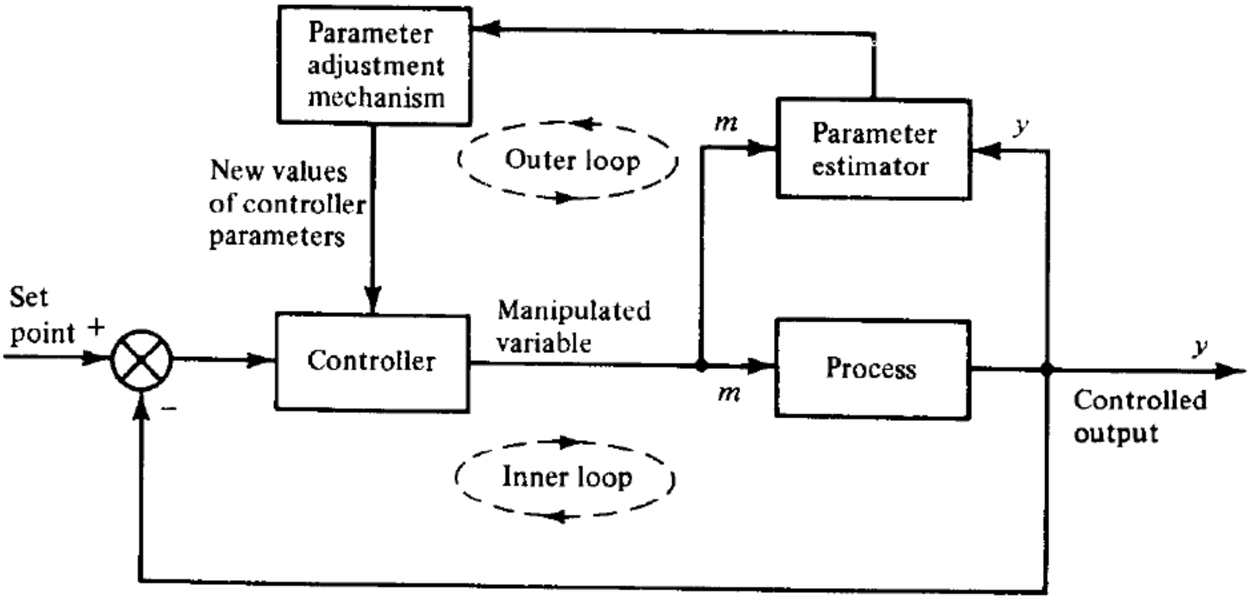
In this method, a reference process model (a mathematical model of the process-like a transfer function), is developed first. If the setpoint is given as input to the reference model, it will give an ideal model output. This is compared with the actual process output. The difference between model output and actual process output is the error denoted by e_m. The objective is to drive the process output towards actual output, that is the error should be minimized. In MRAC, the Integral Square Error (ISE) is reduced with the help of an adaptation mechanism. ISE is given by,

$$\text{minimize ISE} = \int_0^t [\epsilon_m(t)]^2 \, dt$$



The controller parameters are adjusted by the adaptation mechanism in such a way to minimize ISE. The MRAC consists on two loops. The inner loop is an ordinary feedback loop consisting of process and controller. The outer loop has the adaptation mechanism, which is used to update the controller parameters by minimizing ISE.

<u>Example (b) – Self Tuning Regulator (STR)</u>



Self-tuning Regulator method is an example of self-adaptive controller. There is an inner loop, which is normal feedback control consisting of the process and the controller. The controlled variable is measured and given to a parameter estimator. Another input to the parameter estimator is the control signal from the controller. The parameter estimator calculates the values for controller parameters using y and m. The calculated values of the controller parameters are given to a parameter adjustment mechanism. It updates the new values of controller parameters. Both the parameter estimator and adjustment mechanism involve mathematical computations. Hence Self Tuning Regulator method can be implemented only using digital computers.