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Chapter-1

Basic Concept of control system

1.1 Definition of Control System

A control system is a system, which provides the desired response by controlling the output.

The following figure shows the simple block diagram of a control system.

Here, the control system is represented by a single block. Since, the output is controlled by varying input; the control system got this name.

Examples − Traffic lights control system, washing machine

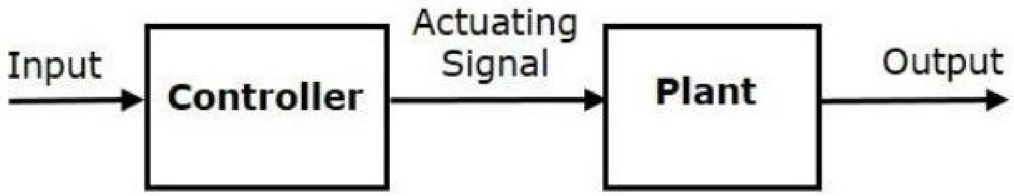
Traffic lights control system is an example of control system. Here, a sequence of input signal is applied to this control system and the output is one of the three lights that will be on for some duration of time. During this time, the other two lights will be off. Based on the traffic study at a particular junction, the on and off times of the lights can be determined. Accordingly, the input signal controls the output. So, the traffic lights control system operates on time basis.

1.2 Open Loop and Closed Loop Control Systems

Control Systems can be classified as open loop control systems and closed loop control systems based on the **feedback path**.

In **open loop control systems**, output is not fed-back to the input. So, the control action is independent of the desired output.

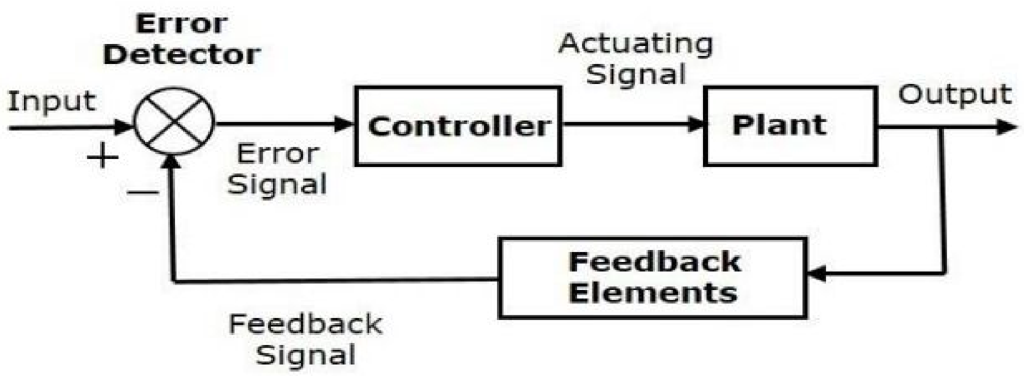
The following figure shows the block diagram of the open loop control system.



Here, an input is applied to a controller and it produces an actuating signal or controlling signal. This signal is given as an input to a plant or process which is to be controlled. So, the plant produces an output, which is controlled. The traffic lights control system which we discussed earlier is an example of an open loop control system.

In **closed loop control systems**, output is fed back to the input. So, the control action is dependent on the desired output.

The following figure shows the block diagram of negative feedback closed loop control system.



Error detector: The error detector produces an error signal, which is the difference between the input and the feedback signal.

Feedback Elements: This feedback signal is obtained from the block (feedback elements) by considering the output of the overall system as an input to this block. Instead of the direct input, the error signal is applied as an input to a controller.

Controller: Controller produces an actuating signal which controls the plant. In this combination, the output of the control system is adjusted automatically till we get the desired response. Hence, the closed loop control systems are also called the automatic control systems.

Traffic lights control system having sensor at the input is an example of a closed loop control system.

The differences between the open loop and the closed loop control systems are mentioned in the following table.

Open Loop Control Systems	**Closed Loop Control Systems**
Control action is independent of the desired output.	Control action is dependent of the desired output.
Feedback path is not present.	Feedback path is present.
These are also called as **non-feedback control systems**.	These are also called as **feedback control systems**.
Easy to design. But, Inaccurate.	Difficult to design. But, Accurate.
These are economical.	These are costlier.

If either the output or some part of the output is returned to the input side and utilized as part of the system input, then it is known as **feedback**. Feedback plays an important role in order to improve the performance of the control systems. In this chapter, let us discuss the types of feedback & effects of feedback.

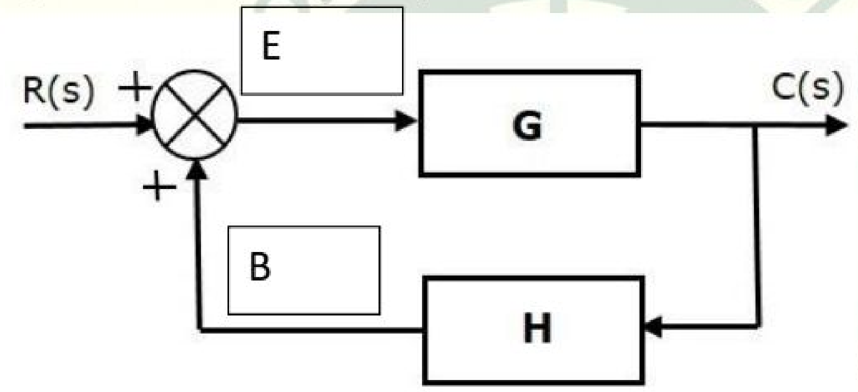
1.1.1 Types of Feedback

There are two types of feedback −

- Positive feedback
- Negative feedback

Positive Feedback

The positive feedback adds the reference input, R(s)R(s) and feedback output. The following figure shows the block diagram of **positive feedback control system**.



The concept of transfer function will be discussed in later chapters. For the time being, consider the transfer function of positive feedback control system is,

The output from the system is equal to: Output C(S) = G x E

Note that the error signal, E is also the input to the feed-forward block: G

The output from the summing point is equal to: Error,E = Input +H x Output

If H = 1 (unity feedback) then:

The output from the summing point will be: Error (E) = Input + Output(B)

The output is equal to: Output = G x (Input +H x Output)

Therefore: G x Input = Output - G x H x Output

Rearranging the above gives us the closed-loop transfer function of:

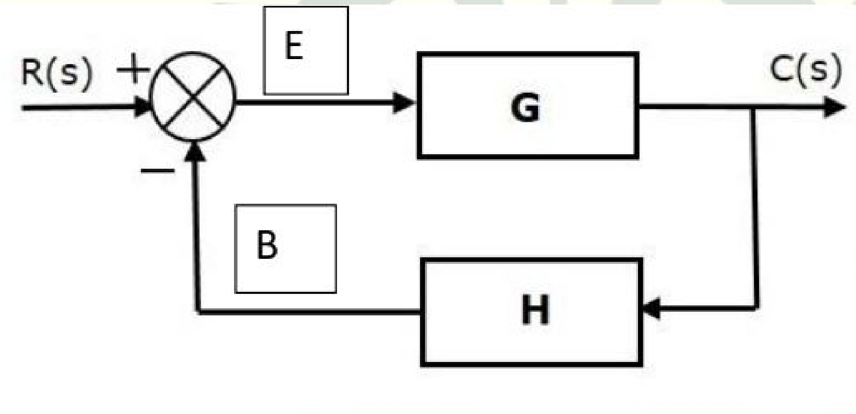
T=G/1-GH

Where,

- **T** is the transfer function or overall gain of positive feedback control system.
- **G** is the open loop gain, which is function of frequency.
- **H** is the gain of feedback path, which is function of frequency.

Negative Feedback

Negative feedback reduces the error between the reference input, R(s)R(s) and system output. The following figure shows the block diagram of the **negative feedback control system**.



Similarly;

Transfer function of negative feedback control system is,

T=G/1+GH

Where,

- **T** is the transfer function or overall gain of negative feedback control system.
- **G** is the open loop gain, which is function of frequency.
- **H** is the gain of feedback path, which is function of frequency.

1.3 Effects of Feedback

Let us now understand the effects of feedback.

1.3.1 Effect of Feedback on Overall Gain

- From Equation 2, we can say that the overall gain of negative feedback closed loop control system is the ratio of 'G' and (1+GH). So, the overall gain may increase or decrease depending on the value of (1+GH).
- If the value of (1+GH) is less than 1, then the overall gain increases. In this case, 'GH' value is negative because the gain of the feedback path is negative.
- If the value of (1+GH) is greater than 1, then the overall gain decreases. In this case, 'GH' value is positive because the gain of the feedback path is positive.

In general, 'G' and 'H' are functions of frequency. So, the feedback will increase the overall gain of the system in one frequency range and decrease in the other frequency range.

1.3.1 Effect of Feedback on Stability

- A system is said to be stable, if its output is under control. Otherwise, it is said to be unstable.
- In Equation 2, if the denominator value is zero (i.e., GH = -1), then the output of the control system will be infinite. So, the control system becomes unstable.

Therefore, we have to properly choose the feedback in order to make the control system stable.

1.4 Examples of open loop and close loop control system

1.4.1 Practical Examples of Open Loop Control System

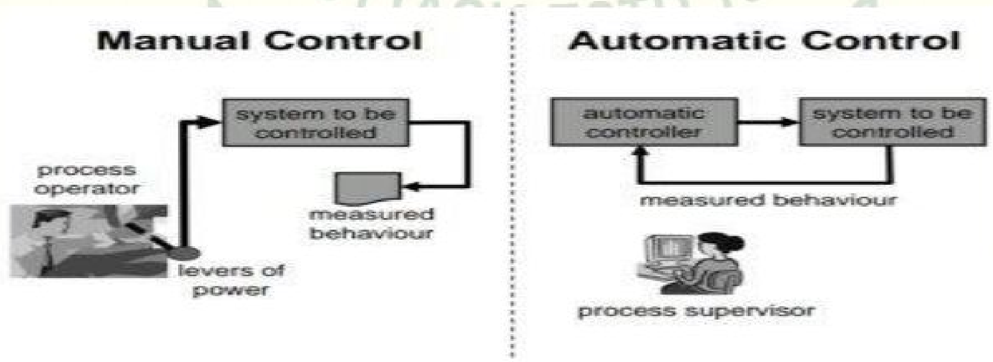
1. Electric Hand Drier – Hot air (output) comes out as long as you keep your hand under the machine, irrespective of how much your hand is dried.
2. Automatic Washing Machine – This machine runs according to the pre-set time irrespective of washing is completed or not.
3. Bread Toaster – This machine runs as per adjusted time irrespective of toasting is completed or not.
4. Automatic Tea/Coffee Maker – These machines also function for pre adjusted time only.

5. Timer Based Clothes Drier – This machine dries wet clothes for pre-adjusted time, it does not matter how much the clothes are dried.
6. Light Switch – Lamps glow whenever light switch is on irrespective of light is required or not.
7. Volume on Stereo System – Volume is adjusted manually irrespective of output volume level.

1.4.2 Practical Examples of Closed Loop Control System

1. Automatic Electric Iron – Heating elements are controlled by output temperature of the iron.
2. Servo Voltage Stabilizer – Voltage controller operates depending upon output voltage of the system.
3. Water Level Controller – Input water is controlled by water level of the reservoir.
4. Missile Launched and Auto Tracked by Radar – The direction of missile is controlled by comparing the target and position of the missile.
5. An Air Conditioner – An air conditioner functions depending upon the temperature of the room.
6. Cooling System in Car – It operates depending upon the temperature which it controls.

1.5 Manual vs anautomatic control system



In manual control system, the process operator observes the process condition and controls the system by doing manual adjustments.

The Automatic control system uses any one of the continuous controller (P, PI, and PID) to control the process based on the measurements and input.

The manual control is very useful during emergencies, plant start-up and plant shut down.

Automatic control gives high efficiency and it is necessary at hazardous environments.

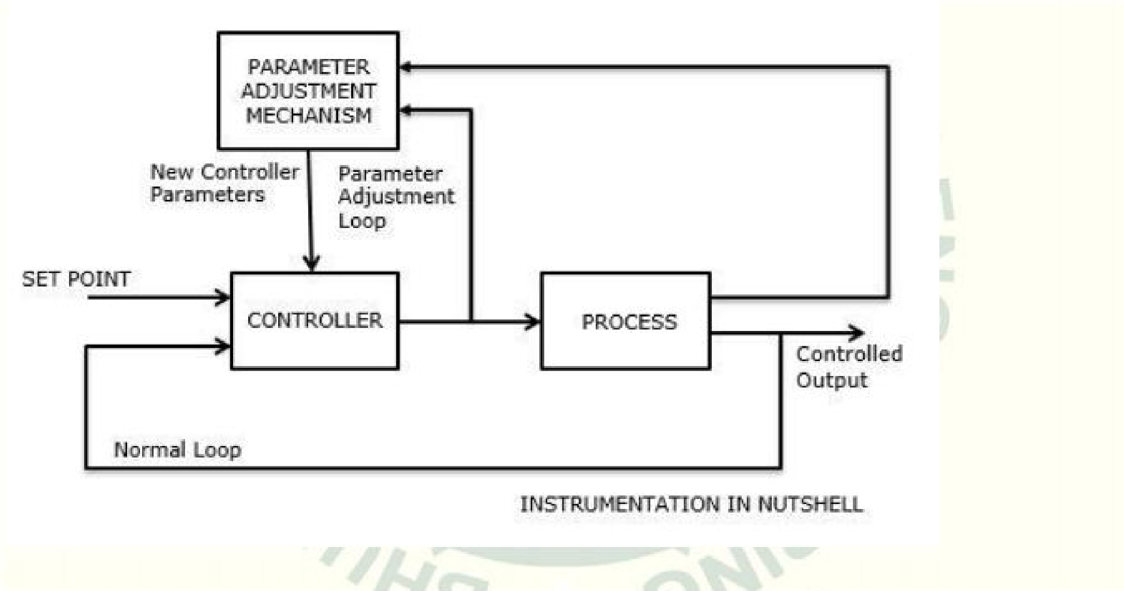
Difference between Manual and Automatic control system

Manual control system	**Automatic control system**
This is not a self-operating type system.	This type of system is a self-operating system.
Manual Control system is an open loop control system.	Automated Control System is a type of closed loop control system.
Manual control System is less reliable.	Automatic Control System is more reliable.
This type of system is less efficient.	This type of system is more efficient
Manual control System is less accurate compared to automatic.	Automatic Control System is more accurate than manual type system.
Work time is more.	This type of system decreases the work time.
This type of system required less maintenance.	This type of system required more maintenance
Less cost compared to automatic.	This is a costly method to use.
Due to this is operated by a humans continuous working is not possible.	Continuous working is possible.
Skilled members are required to operate the	Less skilled members can operate this

manual type of system.	system.

1.7 Adaptive Control

Adaptive control detects the changes in the characteristics of the process and adjusts the controller parameters automatically to compensate for the changing conditions of the process and in turn to optimize the loop response.



An adaptive control system consists of a normal feedback loop and a parameter adjustment loop. The normal loop includes the controller and the process.

The parameter adjustment loop consists of the parameter adjustment mechanism and a controller with adjustable parameters.

The parameter adjustment loop is usually slower than the normal loop.

The different types of adaptive control differ only by the mechanism it used for parameter adjustment.

The adaptive control differs from all other control schemes. The adaptive control adjust the controller parameters whereas in other strategies a process variable is adjusted.

Need for Adaptive Control

1. The key reason is that most of the processes are nonlinear. The control loops are generally designed to maintain the controlled variable at its setpoint by compensating for all disturbance occurring in the process.

The controller performance is optimum only for a particular range in which the process is linearized. Once the process starts to operate beyond the linearized range, the controller fails to produce desired performance. It is because of the fact that the parameters of the controller is not suitable for the current operating conditions.

2. The changes in transfer function of process which occurs due to parameter variations or variation in the coefficients or wear and tear of important components.

3. The nature and magnitude of disturbances vary with time. There may be an occurrence of an unpredictable and unknown disturbance in the process.

4.There may be a change in nature of inputs to the process and the properties of raw materials.

In all the above cases, a conventional controller cannot perform at a satisfactory level. This demands the need for a special type of controller that adapt in accordance with the uncertainties in the process and in turn Adaptive Control

Types of Adaptive Control

There are two major approaches to determine the controller parameters adaptation. They are,

1. Programmed or Gain Scheduled Adaptive Control

2. Self-Adaptive Control

The Programmed Adaptive Control is compared to feed forward compensation because it adjust the controller parameters based on the measurement of an auxiliary variable and the knowledge of operating conditions of process. Also, there is no feedback to check the correctness of adaptation.

The Self-Adaptive Control is comparable to feedback compensation because the adaptation of controller parameters is based on the measurement of closed loop performance and aim to optimize it. Model Reference Adaptive Control (MRAC) and Self Tuning Regulator (STR) are two mechanisms that come under self-adaptive control.

Applications of Adaptive Control

1. Adaptive control is used in the robotic manipulators of robotic systems which demands high positioning accuracy.

2. Adaptive control is used for altitude control of satellites. The observation satellites should be operated at lower altitudes where the air-drag makes the quick reorientation of satellite is necessary to increase the observation time.

3. Adaptive control is used in the autopilot of air crafts and steering control of ships.

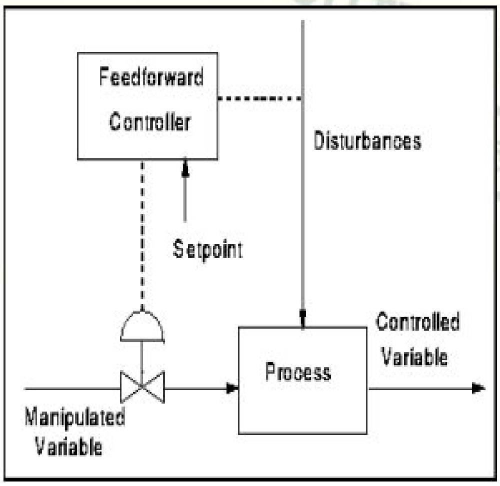
4. Adaptive control is used in the control of strip temperature for the continuous annealing and processing in metallurgical processes.

5. Adaptive control is used in distillation columns to provide high product quality and a considerable reduction of thermal energy usage.

6. Adaptive control is used to stabilize PID based pH control system in chemical industries. Without adaptive control, the process gain (K_p) increases as the pH value becomes neutral and it leads to change in total loop gain and finally to instability of loop. The adaptive control keeps the total loop gain at the desired value (usually 0.5) by lowering the controller gain (K_c).

1.7.1 Feedforward control system:

A feedforward controller avoids the slowness of the feedback control.



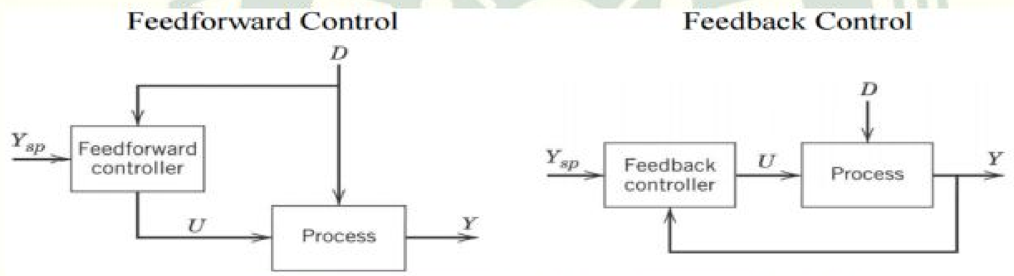
Using feed forward control the performance of control systems can be enhanced greatly.

Process variables such as pressure, level, flow, temperature are interrelated and so one variable may affect another as a disturbance in the process.

Feed forward system measure important disturbance variables and take corrective action before they upset the process.

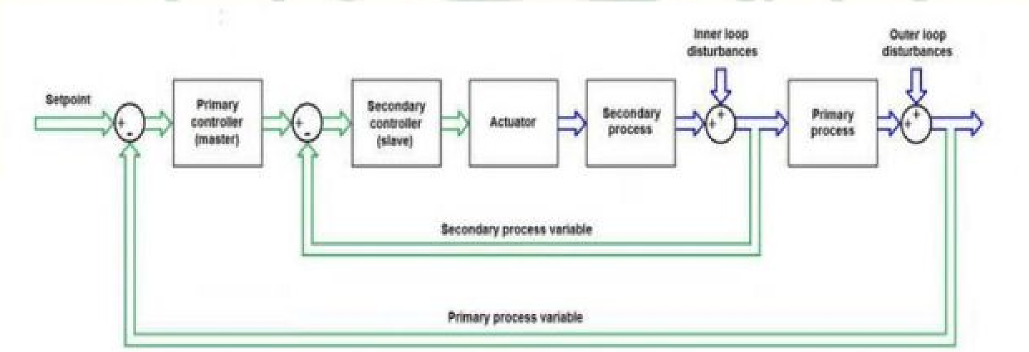
Here the set point is fixed in the feed forward controller after doing little complex mathematical derivations. The feed forward controller determines the needed change in the manipulated variable, so that, when the effect of the disturbance is combined with the effect of the change in the manipulated variable, there will be no change in the controlled variable at all.

The disturbance is measured at the input side of the process and the manipulating variable also, so the controlling process is done before a disturbance affects the process.



1.7.2 Fundamentals of cascade control

A cascade control system reacts to physical phenomena shown in blue and process data shown in green.



Cascade control block diagram

Elements of cascade control

The Cascade Control Block Diagram shows a generic cascade control system with two controllers, two sensors, and one actuator acting on two processes in series.

A primary or master controller generates a control effort that serves as the set point for a secondary or slave controller. That controller in turn uses the actuator to apply its control effort directly to the secondary process. The secondary process then generates a secondary process variable that serves as the control effort for the primary process.

The geometry of this block diagram defines an inner loop involving the secondary controller and an outer loop involving the primary controller. The inner loop functions like a traditional feedback control system with a set point, a process variable, and a controller acting on a process by means of an actuator. The outer loop does the same except that it uses the entire inner loop as its actuator.

Requirements

Naturally, a cascade control system can't solve every feedback control problem, but it can prove advantageous if under the right circumstances:

- The inner loop has influence over the outer loop. The actions of the secondary controller must affect the primary process variable in a predictable and repeatable way or else the primary controller will have no mechanism for influencing its own process.
- The inner loop is faster than the outer loop. The secondary process must react to the secondary controller's efforts at least three or four times faster than the primary process reacts to the primary controller. This allows the secondary controller enough time to compensate for inner loop disturbances before they can affect the primary process.
- The inner loop disturbances are less severe than the outer loop disturbances. Otherwise, the secondary controller will be constantly correcting for disturbances to the secondary process and unable to apply consistent corrective efforts to the primary process.

In the water heater example

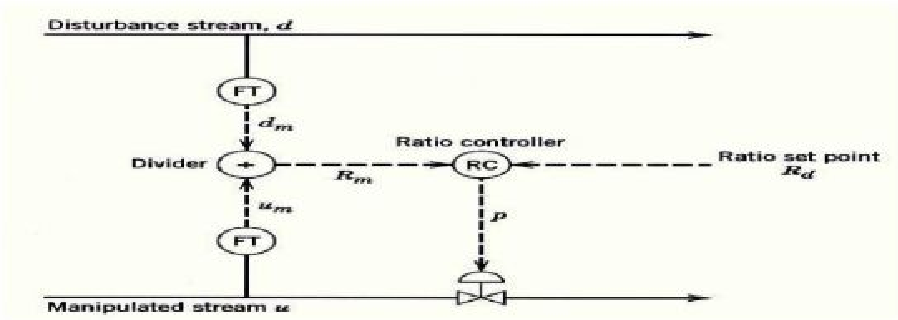
- Set point – temperature desired for the water in the tank
- Primary controller (master) – measures water temperature in the tank and asks the secondary controller for more or less heat
- Secondary controller (slave) – measures and maintains steam flow rate directly
- Actuator – steam flow valve
- Secondary process – steam in the supply line
- Inner loop disturbances – fluctuations in steam supply pressure
- Primary process – water in the tank
- Outer loop disturbances – fluctuations in the tank temperature due to uncontrolled ambient conditions, especially fluctuations in the inflow temperature
- Secondary process variable – steam flow rate
- Primary process variable – tank water temperature

1.7.3 Ratio control systems

Ratio control systems are usually used chemical factories, where more than one chemical should mix in a specific ratio.

Ratio control is a special type of feed forward controller.

The objective of the ratio control is to maintain a ratio between two process variable without considering the external disturbance

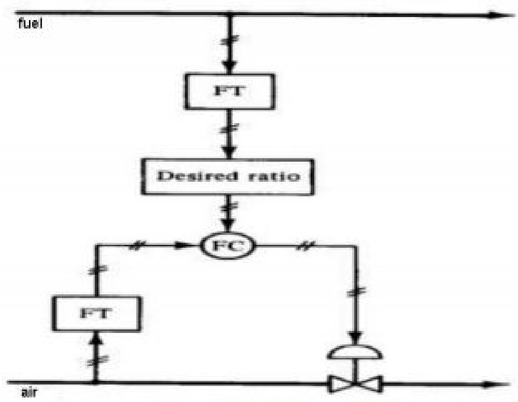


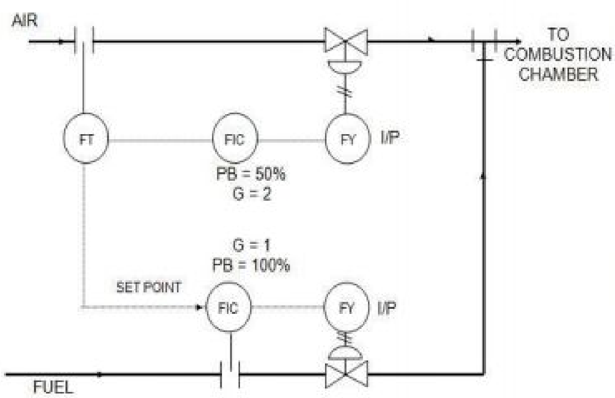
In the above-shown figure, there is a process with two process variables. The variables are usually flow rates, one is fixed as manipulated stream and the other flow is fixed as the disturbance stream.

Whatever the external load disturbance cause the manipulated stream, a ratio control keep a fixed ratio between the two or more variables irrespective if possible set point change.

In case of flow ratio control, the flow of both streams is measured using flow transmitter and the values are applied to a divider. The divider calculates the ratio between the two streams and applied to the ratio controller. Ratio controller compares the actual value with a set point to take a control action on a valve.

Even if there is an external disturbance in the manipulated or disturbance stream, a proportional change in ratio stabilizes the process. The ratio of one rate to the other can be changed by adjusting the gain of the secondary controller.





Ratio Control System

Ratio control is used when two fluids must be mixed together in a specific ratio.A practical way to do this is to use a standard control system to control the flow on one line.

The same transmitter signal is used as a set point for a second controller which controls the flow in a second line.

The ratio of one flow rate to the other can be changed by adjusting the gain (or proportional band) of the secondary controller.

Figure shows a typical ratio control system.

The air to fuel ratio of the fluid going to the combustion chamber is set at 2:1.