INSTRUMENTATION AND PROCESS CONTROL

Course code: CHT 602

6^{th} semester, Chemical Engineering department

UCPES Berhampur

PRESSURE MEASUREMENT

1. Name different methods of measurement of pressure

2. Describe pressure measurement by Bourdon tube, Bellows, and Diaphragm

3. Describe pressure measurement by Pirani gauge, Mcleod Gauge, ionization gauge.

PRESSURE MEASUREMENT

Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed.

Unit = N/m^2, Pa, atm, mm Hg, torr, psi etc

PRESSURE CONVERSION

1atm= 101.325 kPa

= 14.69 psi

= 760 mm Hg

= 1.01325 bar

= 760 torr

DIFFERENT TYPES OF PRESSURE

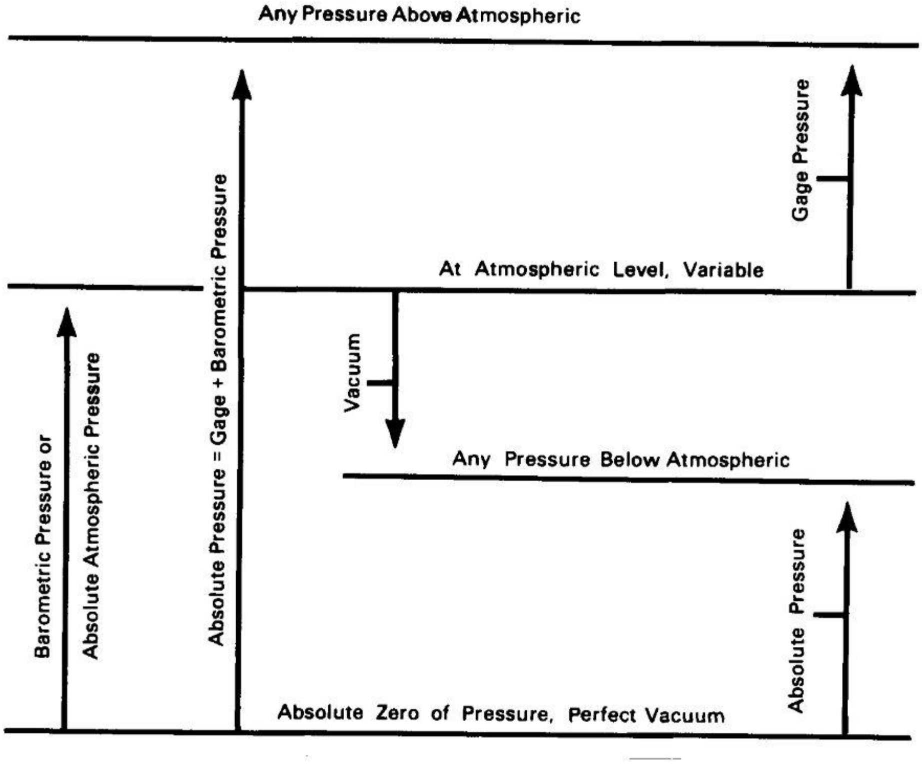
a. **Gauge pressure**
   A gauge that indicates zero at atmospheric pressure measures the difference between actual and atmospheric pressure. This difference is called gauge pressure. It is abbreviated as psig.

b. **Absolute pressure**
   Absolute pressure is actual total pressure (including atmospheric pressure) acting on a surface. It is abbreviated as psia.

c. **Vacuum or Differential pressure**
   Gauges that indicate gauge pressure may be designed to indicate pressure below zero. Such a gauge is called a vacuum gauge. Gauges that indicate absolute pressure cannot indicate pressure below zero, because zero is a perfect vacuum. In a differential

pressure measurement, the gauge pressure is the difference between the absolute pressure of the fluid and the atmospheric pressure.

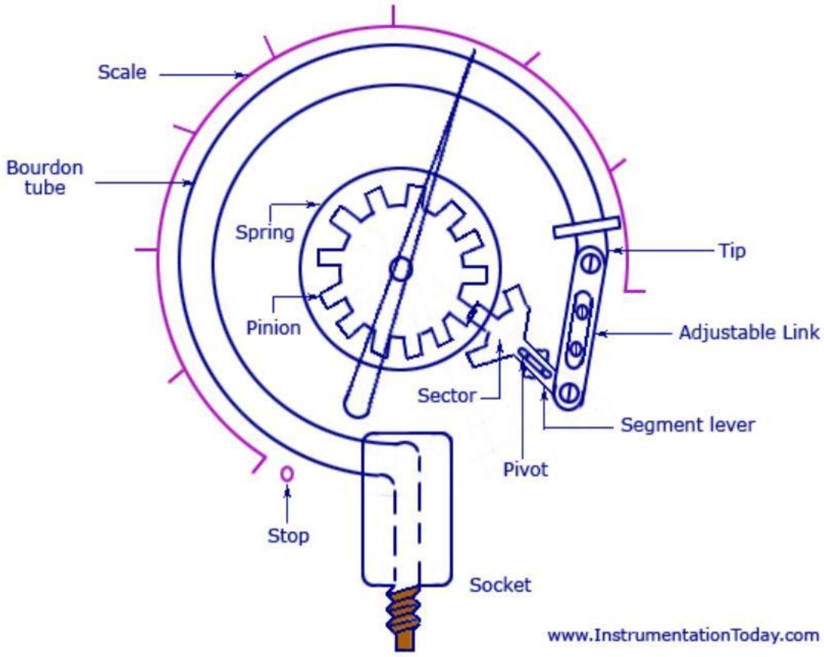
d. **Static pressure and Velocity pressure**
When the fluid is in equilibrium, the pressure at a particular point is identical in all directions and dependent of orientation. This is called static pressure.
Velocity pressure is the difference between the total pressure and static pressure.



METHODS OF PRESSURE MEASUREMENT

1. Manometer method
2. Elastic pressure transducer
3. Pressure measurement by measuring vacuum
4. Pressure measurement by balancing the force produced on a known area by a measured force
5. Electrical pressure transducer

C-type Bourdon Tube Pressure Gauge



Bourdon Tube Pressure Gauge

Construction

- It made up of phosphor bronze, steel and beryllium copper.
- It consists of a long thin-walled cylindrical of non-circular cross section seated at one end.
- It attached by a light line work to the mechanism which operates the pointer.
- The other end of the tube is fixed and is open for the application of the pressure which is to be measured.

Working

- As the fluid under pressure enters the tube, its section of the tube changes from oval to circular, which straightens the tube.
- The resulting movement of the free end of the tube causes the pointer to move over the scale.
- The tip of the tube is connected to a segmental lever through an adjustable length link.
- Segmental lever is connected to a pinion arrangement for translation of motion.
- The pinion is connected to the pointer which gives the condition.

Advantages

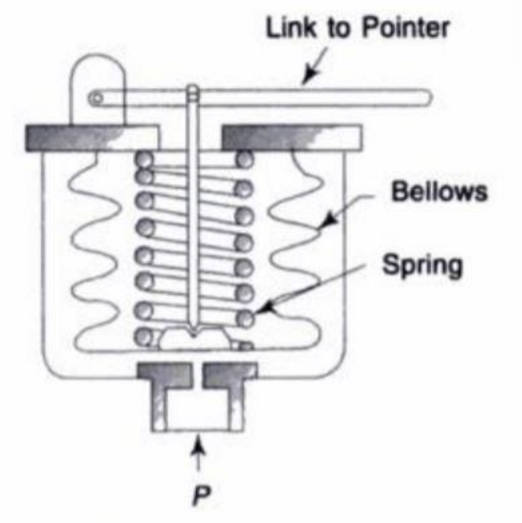
I. There cost is low.
II. They have simple construction.
III. They have been time-tested in application.

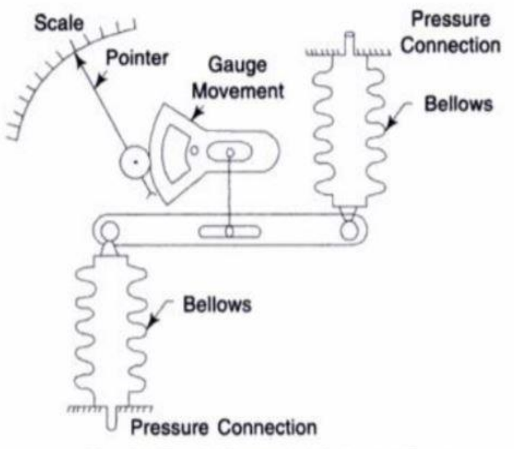
IV. These tubes are available in a wide variety of ranges, including very high ranges.
V. They are adaptable to transducer designs for electronic instruments.
VI. They allow high accuracy, especially in relation to cost.

Disadvantages

I. They have low spring gradient (i.e. below 50 psig).
II. They are susceptible to shock and vibration.
III. They are susceptible to hysteresis.

Bellows pressure elements





Simple bellows pressure element

Differential bellows pressure element

- Bellows are made of an alloy which is ductile, high strength &has very little hysteresis effect.
- Pressure is applied to one side of the bellows and the resulting deflection is counter balanced by a spring.
- In another arrangement one pressure is applied to the inside of one sealed bellows while the other pressure is applied to the inside of another sealed bellow.
- By suitable linkage and calibration of the scale, the pressure difference is indicated by a pointer on the scale.
- Pressure acting on the outside of the bellows compresses the bellows and moves its free end against the opposing force of the spring.
- A rod resting on the bellows transmits the motion to a pointer.
- Range= large static pressure (upto 2000 psig)
  Large differential pressure (upto 50 psi)

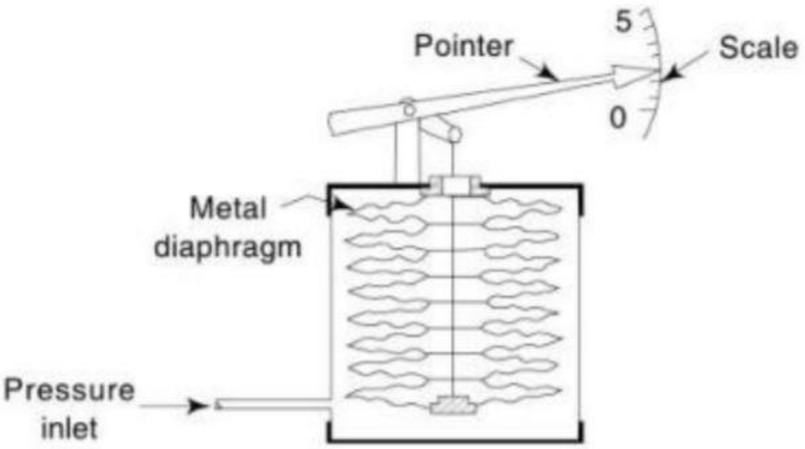
Advantages

1. Its cost is moderate.
2. It is able to deliver high force.
3. It is adaptable for absolute and differential pressures.
4. It is good in the low-to-moderate pressure range.

Disadvantages

1. It needs ambient temperature compensation.
2. It is unsuitable for high pressure.
3. The availability of metals and work hardening of some of them is limited.

Metallic Diaphragm Gauge



Metallic Diaphragm Gauge

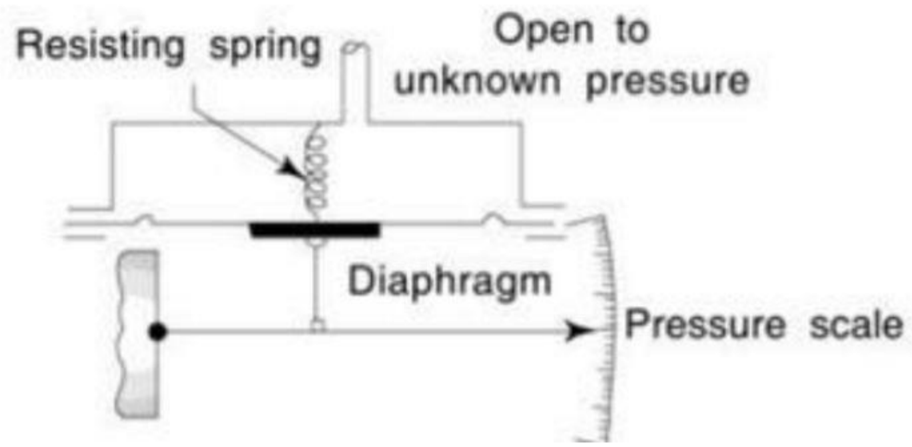
Construction:

Since the elastic limit has to be maintained, the deflection of the diaphragm must be kept in a restricted manner. This can be done by cascading many diaphragm capsules as shown in the figure. A main capsule is designed by joining two diaphragms at the periphery. A pressure inlet line is provided at the central position.

Working:

When the pressure enters the capsule, the deflection will be the sum of deflections of all the individual capsules. This will also deflect the lever connected to the diaphragm. Through pivot, this movement of lever is transferred to the pointer and scale mechanism. As shown in figure, corrugated diaphragms are also used instead of the conventional ones.

Slack Diaphragm Gauge



Slack Diaphragm Gauge

Construction:

It is made up of rubber or other flexible material. Making a diaphragm slack rather than tight allows it to move large distance in response to a small pressure. A pointer is attached with the diaphragm via linkage. Pressure is applied at the input and is indicated on the scale.

Working:

The diagram of a diaphragm pressure gauge is shown below. Unknown pressure is applied to the input of the gauge which will exerts force on the slack diaphragm. When a force acts against a thin stretched diaphragm, it causes a deflection of the diaphragm with its center deflecting the most. This movement is transferred to the pointer mechanism via leaf spring as shown in figure.

Non-metallic or slack diaphragms are used for measuring very small pressures. The commonly used materials for making the diaphragm are polythene, neoprene, animal membrane, silk, and synthetic materials. Due to their non-elastic characteristics, the device will have to be opposed with external springs for calibration and precise operation.

- Range= (0.01-0.40) mm Hg

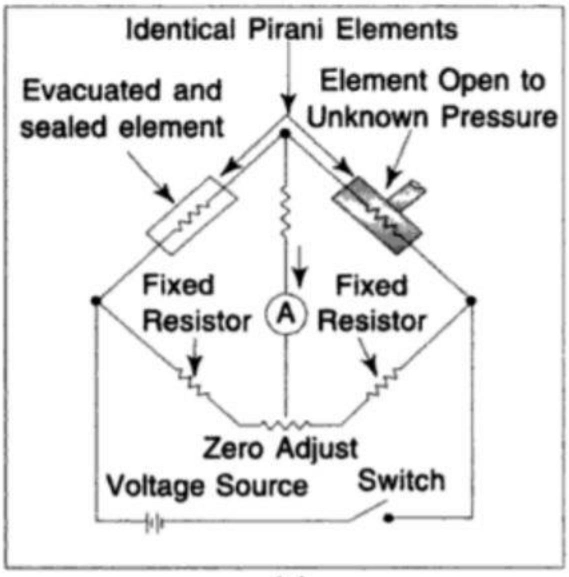
Advantages

1) Their cost is moderate.
2) They possess high-range characteristics.
3) They are adaptable to absolute and differential pressure measurement.
4) They have a good linearity.
5) They are available in several materials for good corrosion resistance.
6) They are small in size.
7) They are adaptable to slurry services.

Disadvantages

1) They lack good vibration and shock resistance.
2) They are difficult to repair.
3) They are limited to relativity low pressures.

Pirani Gauge



Pirani Gauge

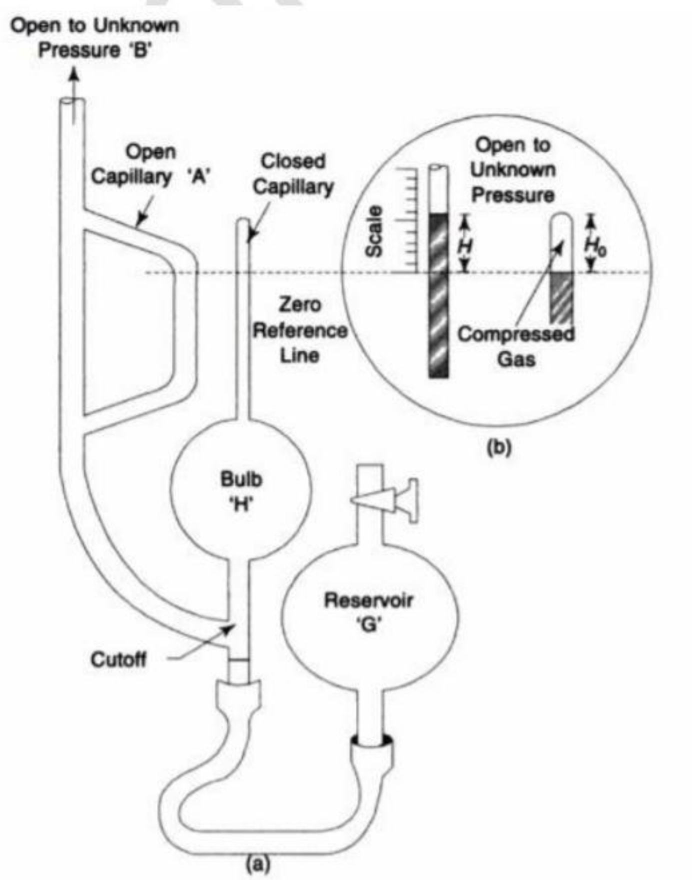
Construction:

- It consists of two wire filaments.
- One filament serves as a reference and is sealed in an evacuated glass, while the other filament is kept in a container connected to the source of pressure.
- These two filaments are connected in a bridge circuit.

Working:

- If the resistance of the two pirani element are equal, no current flows through the ammeter. But if the resistance of one pirani element changes, current will flow through the ammeter.
- This current flow indicates a change in pressure of the gas being measured.
- Because gases differ in heat conductivity, the gauge must be calibrated for the gas being measured.
- Range= (10^{-5}-1) torr

McLeod Gauge



McLeod Gauge (a) before measurement (b) during measurement

A McLeod gauge is connected to the unknown gas whose pressure measured is required. The gas enters the gauge through B and fills the tubes down to the level of the mercury reservoir. The pressure is equal throughout the tubes and the bulb mercury is pumped up from the reservoir G. As the mercury rises above the cut-off, it traps gas inside the bulb. The mercury is then pumped higher in the gauge until all the gas in the bulb is compressed into the closed capillary tube. The operator allows the mercury to rise until it reaches a zero reference line on the closed capillary tube. The mercury rises faster in the open capillary tube A.

The compression of gas in the closed capillary tube makes the pressure of the trapped gas higher than the measured pressure. This pressure difference causes a difference in the mercury levels in the two tubes. The difference in height is used to calculate the pressure.

The pressure can also be calculated using following equation:

$P = KH\, H_o(1 - KH)$

Where P= Measured pressure

K= a constant, determined by the geometry of the gauge

H= difference in heights of the two mercury column

H_o= height of the top of the closed capillary tube above the zero line.

Ionization Gauge

Principle:

Boyle's law or the pressure-volume law states that the volume of a given amount of gas held at constant temperature varies inversely with the applied pressure when the temperature and mass are constant.

$$V \propto 1/P$$

Another way to describing it is saying that their products are constant.

When pressure goes up, volume goes down. When volume goes up, pressure goes down.

From the equation above, this can be derived:

$P1V1 = P2V2 = P3V3$ etc.

The density (ρ) of a gas is defined as

$\rho = m / V$

where m= mass of gas

V= Volume of Gas

So now from above equation of pressure and volume, we can write for pressure and density as

$P1/\rho1=P2/\rho2$

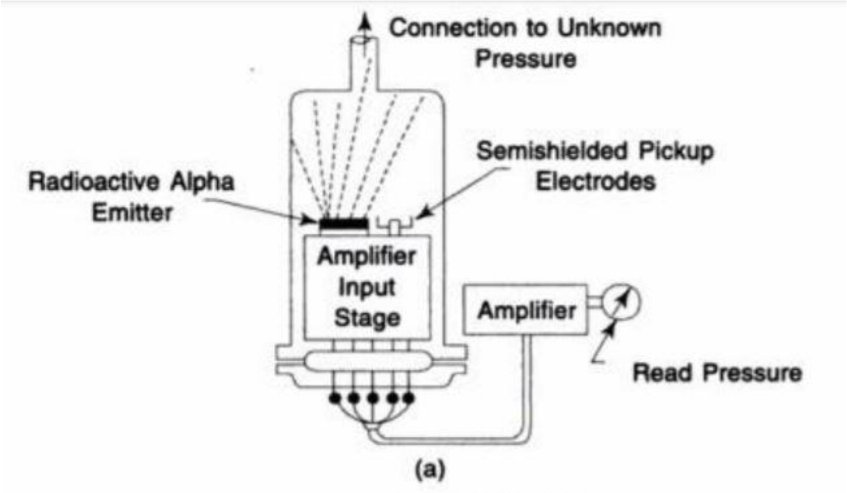
Ionization gage measure vacuum by measuring the current produced by ionized gas molecules. It is known as ion current. The gas molecules are ionized as a stream of electrons collide with them. This current will be proportional to the density and pressure of the gas

There are two method to produce gas ions. Based on this method, there are two types of ionization gauge.

1. Alphatron ionization gauge

2. Hot filament ionization gauge

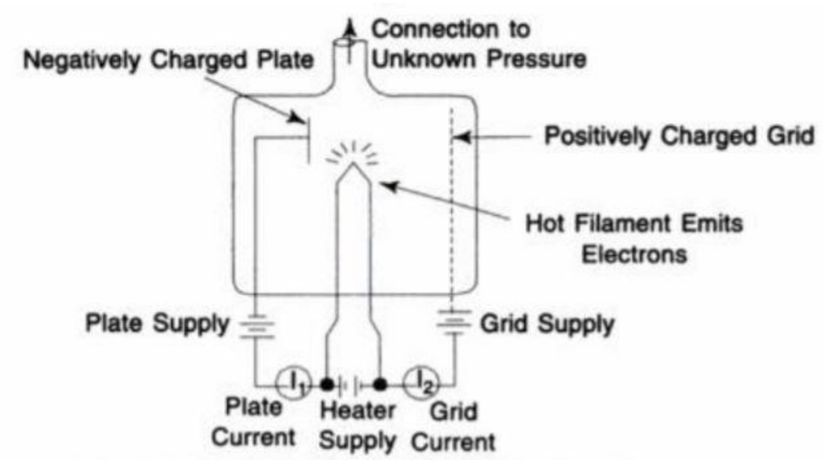
Alphatron ionization Gauge:



Alphatron ionization Gauge

The device uses alpha particles in order to ionize the gas in the vacuum chamber. The number of ions formed in the chamber is directly proportional to the gas density and pressure, if the chamber dimensions are shorter than the range of alpha particles. The figure below shows the schematic diagram of an alphatron.

Hot Filament Ionization Gauge:



Hot Filament Ionization Gauge:

In the hot Filament type, a column of gas is introduced into which, a potential difference V is applied to heater to create free electron in the space. This causes the electron with a charge to acquire a kinetic energy. This energy may be high enough to initiate ionization, and positive ions will be produced when the electrons collide with the gas molecules.

The grid is maintained at a large positive potential with respect to the cathode and the plate. The plate is at a negative potential with respect to the cathode. The positive ions available between the grid and the cathode will be drawn by the cathode, and those between the grid and the plate will be collected by the plate. These ions create a currents I1 and I2 which is proportional to density and pressure of the gas.

AUTOMATIC CONTROL SYSTEM

1. Define the automatic control system and explain the application with example.
2. Explain elementary idea about transfer function for a first order system and time constant.
3. Describe different idea about different types of automatic controllers.
4. Explain principle of PLC and Explain computer Aided measurement and control

AUTOMATIC CONTROL SYSTEMS

Process

A process is defined as a set of operations that perform physical or chemical transformation or a series of transformations in which the fluid or solid materials are converted into more useful state.

Automatic control systems

Automatic control system is a preset closed-loop control system that requires no operator action. This assumes the process remains in the normal range for the control system.

Components of a process control system

1) **Sensor and Transmitter :** it also called primary and secondary elements used for the measurement of variable to be controlled and transmission of the measured value to the controller.
2) **Controller :** it is the brain of the control system that takes decision to maintain the process variables at its desired value(set point).
3) **Final control element** : such as valve, conveyors, electric motors, variable speed pumps, etc. are used to take action for implementing the decision taken by the controller.

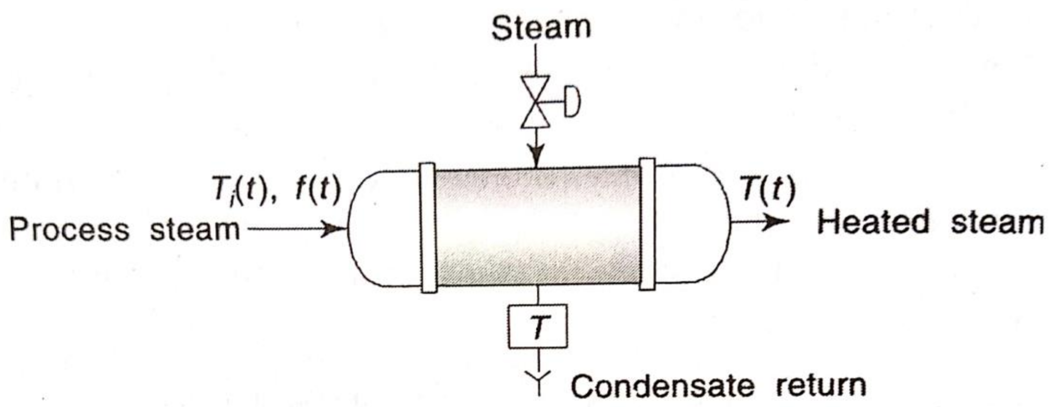
The following terms are also used in an automatic process control system

1) **Control variable** or process variable is a variable that must be controlled, or maintained at some desired value.
2) **Set point (SP)** or reference point is the desired value of the controlled variable to be maintained all time.

3) **Manipulated variable** is the variable used to maintain the control variable at its set point.
4) **Disturbance** is any variable that causes variation in the controlled variable. There are number of disturbances in any process loop, e.g. inlet process temperature, inlet process flow, the heat content, etc. in the example of heat exchanger.

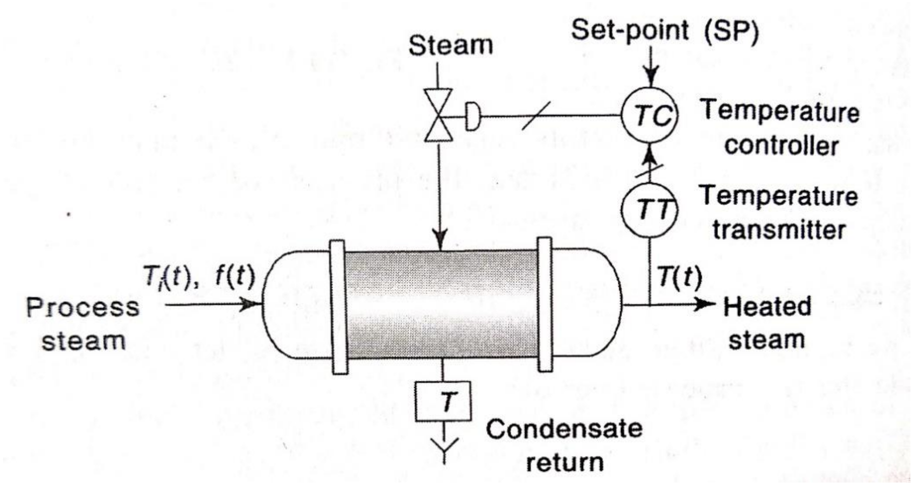
EXAMPLES OF PROCESS CONTROL SYSTEM

1. heat exchanger control system



Heat Exchanger

This heat exchanger is used to heat the process fluid from some inlet temperature $T_i(t)$ up to a desired outlet temperature T(t). The energy gained by the process fluid is provided by the latent heat of condensation of the steam. There are number of variables in this process that can change causing the outlet temperature to deviate from its desired value. Therefore, action must be taken to correct any deviation so as to maintain the outlet process temperature at its desired value T(t).

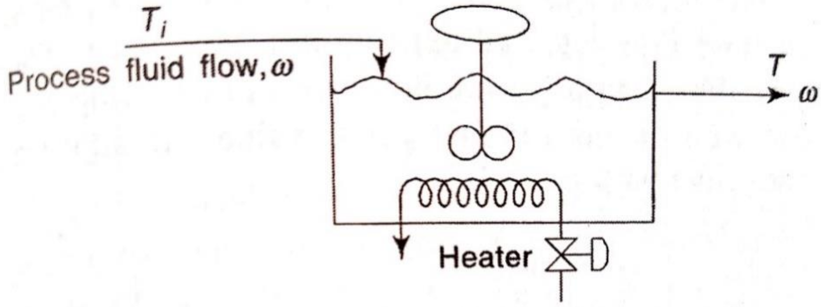


Heat Exchanger Control System

The steam valve can be manipulated (by throttling and opening the steam flow) to correct the deviation. The above can be done by manual control in which the operator has to frequently monitor the temperature to take corrective action to maintain the desired value by opening or closing of steam flow valve. This type of manual control system will be operator dependent and vary from operator to operator. Also, it would be extremely difficult for operator to monitor hundreds of variables and take corrective action to maintain the desired value. Therefore, this manual control can be replaced with an automatic process control by designing and implementing a suitable control system as shown in the figure.

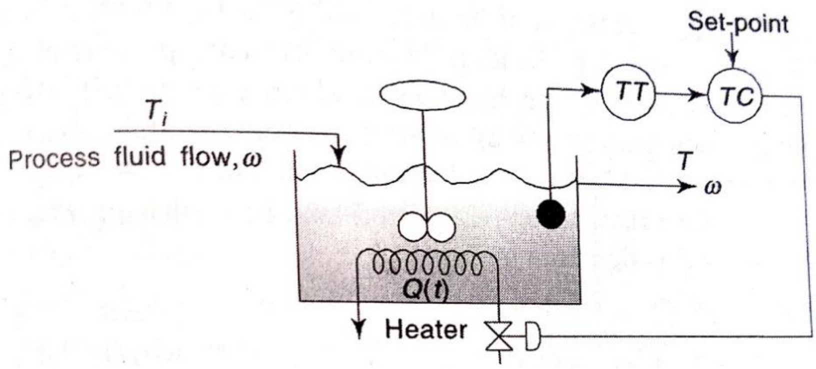
The outlet temperature T(t) is measured by a sensor and transmitted by TT to the temperature controller TC. Temperature controller compares this measured value with the desired value and depending upon the difference it sends the signal to final control element which manipulates the steam flow by opening or closing the valve.

2. Stirred-tank Heat Exchanger Control System



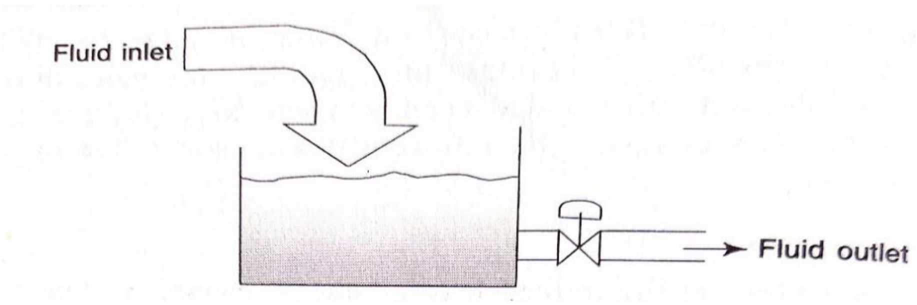
Stirred Tank Heat Exchanger

The process fluid flows into the tank from a pipe and overflows out of the tank. Thus, the volume of the tank is constant. The heating fluid flow can be changed by adjusting the opening of the valve in the heating medium line. The objective of this stirred-tank heat exchanger is to keep the exit temperature T at its desired value when disturbances like change in inlet process fluid flow rate and temperature, heating fluid temperature, pressure of the heating fluid upstream of the valve, etc. occur. The automatic control can be achieved by measuring the outlet temperature by putting a temperature sensor, comparing the value with the desired value and adjusting the heat input of the heater accordingly as shown in the fig.



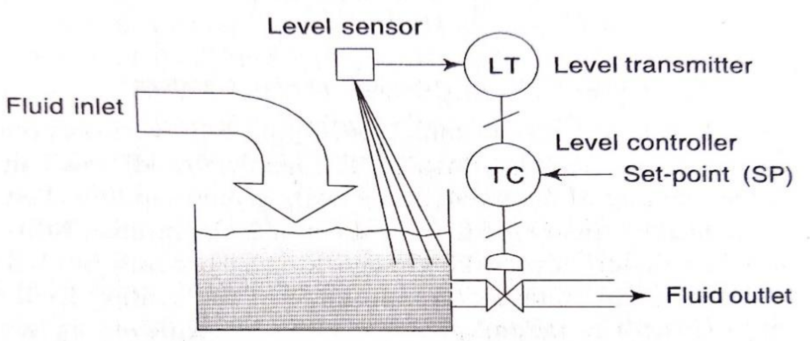
Stirred Tank Heat Exchanger Control System

3. Liquid Tank Level Controller



Liquid Tank Level

The process fluid flow into the tank from a pipe. A desired level of fluid is to be maintained by opening or closing the outlet fluid valve. The objective of this tank is to keep the fluid level at its setpoint value when disturbances like change in inlet fluid flow rate and temperature, etc. occur. The automatic control can be achieved by measuring the liquid level by putting a level sensor, comparing the value with the desired value and adjusting the fluid outlet accordingly as shown in fig.



Liquid tank level controller

BLOCK DIAGRAM REPRESENTATION OF PROCESS CONTROL SYSTEMS

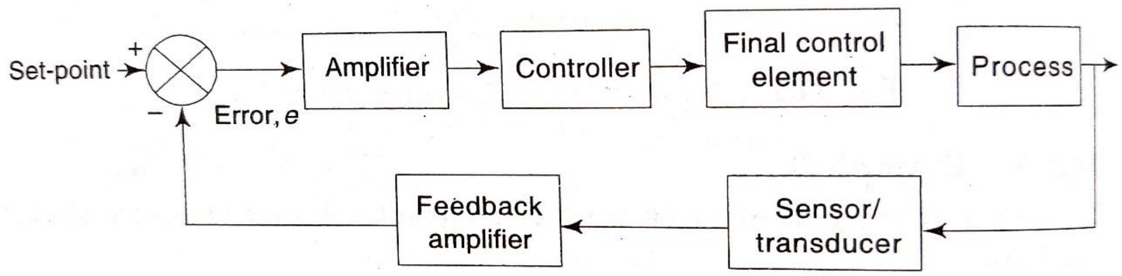


Fig. 14.8 *Block Diagram Representation of an Industrial Process Control System*

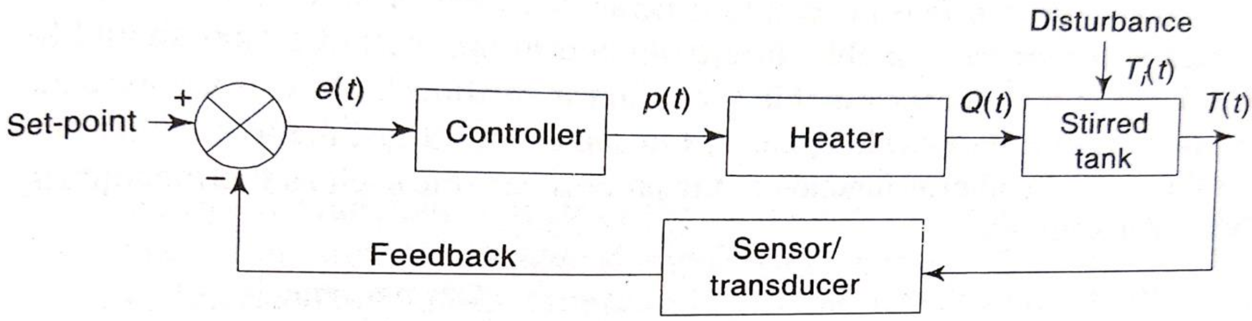


Fig. 14.9 *Block Diagram of Stirred-tank Temperature Control System*

TRANSFER FUNCTION OF CONTROL SYSTEM

The transfer function of a control system is the relationship between the input signal and the output signal and defined as the ratio of the output signal divided by the input signal. The transfer function is a mathematical expression that represents the ratio of the Laplace transformations of a process output to that of an input. For example

$$G(s)=Y(s)/M(s)$$

G(s)= symbol for transfer function

X(s)=input in deviation form

Y(s)=output in deviation form

The transfer function describes the dynamic characteristic of the system

Laplace transformation

Laplace transformation of a function f(t) is written as F(s), where

$$F(s) = \int_0^\infty f(t).e^{-st}dt$$

Some examples of Laplace transformation example

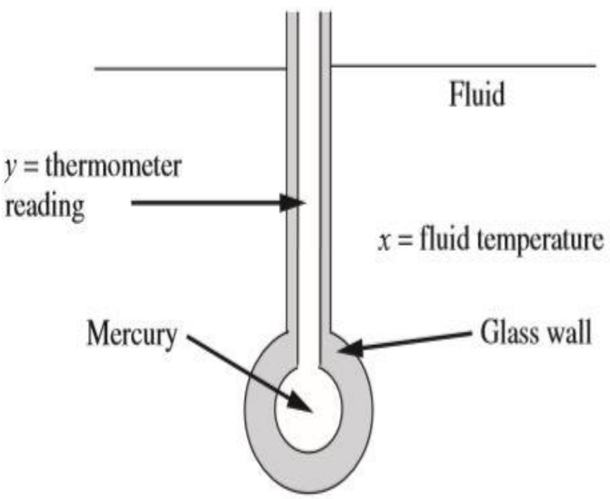
f(t)	F(s)
1. $\delta(t)$	1
2. $u(t)$	$\frac{1}{s}$
3. t	$\frac{1}{s^2}$
4. t^n	$\frac{n!}{s^{n+1}}$
5. e^{-at}	$\frac{1}{s+a}$
6. te^{-at}	$\frac{1}{(s+a)^2}$
7. $t^n e^{-at}$	$\frac{n!}{(s+a)^{n+1}}$
8. $\sin bt$	$\frac{b}{s^2+b^2}$
9. $\cos bt$	$\frac{s}{s^2+b^2}$

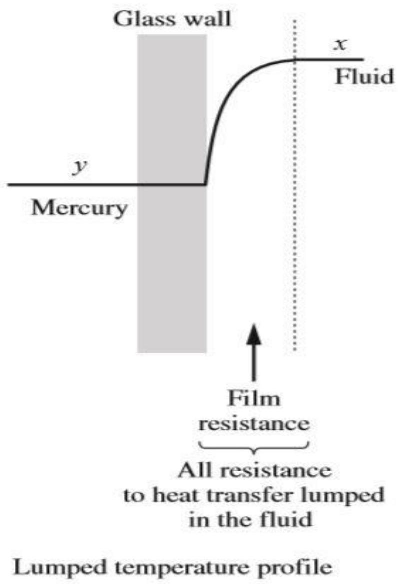
Transfer function for a first order system

MERCURY THERMOMETER

We develop the transfer function for a first-order system by considering the unsteady-state behaviour of an ordinary mercury-in-glass thermometer.

Consider the thermometer to be located in a flowing stream of fluid for which the temperature x varies with time. Our problem is to calculate the response or the time variation of the thermometer reading y for a particular change in x. (the symbols x and y have been selected to represent surrounding temperature and thermometer reading, respectively.)





Cross sectional view of thermometer

Assumption

1. All the resistance to heat transfer resides in the film surrounding the bulb (i.e., the resistance of glass and mercury is neglected).

2. All the thermal capacity is in the mercury.

3. glass wall doesn’t expand.

4. thermometer is initially at steady state. This means that, before time 0, there is no change in temperature with time.

At time 0, the thermometer will be subjected to some change in the surrounding temperature x (t).

By applying the unsteady-state energy balance

(Input rate) – (Output rate) = (Rate of accumulation)

$$hA(x - y) - 0 = mC\frac{dy}{dt} \quad \text{-------------------------- (1)}$$

Where A = surface area of bulb for heat transfer

C = heat capacity of mercury

m = mass of mercury in bulb

t = time

h = film coefficient of heat transfer

The above equation states that the rate of flow of heat through the film resistance surrounding the bulb causes the internal energy of the mercury to increase at the same rate. The increase in internal energy is manifested by a change in temperature and a corresponding expansion of mercury, which causes the mercury column, or "reading" of the thermometer, to rise.

The coefficient h will depend on the flow rate and properties of the surrounding fluid and the dimensions of the bulb. We will assume that h is constant for a particular installation of the thermometer.

For steady state condition

$$hA(x_s - y_s) = 0 \quad \text{------------------------- (2)}$$

Eq (1) – Eq(2)

$$hA\left[(x - x_s) - (y - y_s)\right] = mC\frac{d(y - y_s)}{dt}$$

Notice that $d(y-y_s)/dt = dy/dt$ because y_s is a constant

If we define the deviation variables to be the difference the variables and their steady state values

$$X = x - x_s$$

$$Y = y - y_s$$

The eq(3) becomes

$$hA(X - Y) = mC\frac{dY}{dt}$$ ---------------- (4)

If we let mC/hA =τ, eq(4) becomes

$$X - Y = \tau\ dY/dt$$ ------------------------ (5)

The parameter **<u>τ is called the time constant</u>** of the system and has the **units of time**.

From above, we have

$$\tau = mC/hA$$

in Eq. (5), X is the input to the system (the bath temperature) and Y is the output from the system (the indicated thermometer temperature). Taking the Laplace transform of Eq. (5) gives

$$X(s) - Y(s) = \tau sY(s) - Y(0) = \tau sY(s)$$ -------------------------(6)

The Laplace transform of the differential equation results in an equation that is free of initial conditions because the initial values of X and Y are zero. Since we start from steady state, Y (0) must be zero,

$$Y(0) = y(0) - y_s = y_s - y_s = 0$$

Rearranging the eq(6)

$$\frac{Y(s)}{X(s)} = \frac{1}{\tau s + 1} = \frac{\text{output}}{\text{input}}$$ ---------------------- (7)

This is the transfer function of the first order system

Standard Form for First-Order Transfer Functions

The general form for a first-order system is

$$\tau \frac{dy}{dt} + y = K_p x(t) \tag{4.8}$$

where y is the output variable and $x(t)$ is the input forcing function. The initial conditions are

$$y(0) = y_s = K_p x(0) = K_p x_s$$

Introducing deviation variables gives

$$X = x - x_s$$
$$Y = y - y_s$$

Eq. (4.8) becomes

$$\tau \frac{dY}{dt} + Y = K_p X(t)$$
$$Y(0) = 0 \tag{4.9}$$

Transforming Eq. (4.9), we obtain

$$\tau s Y(s) + Y(s) = K_p X(s)$$

and rearranging, we obtain the standard first-order transfer function

$$\frac{Y(s)}{X(s)} = \frac{K_p}{\tau s + 1} \tag{4.10}$$

Types of process control system

(a) open loop control system

In an open loop control system, the input has no control over the output. In the given diagram, it is required to maintain the actual water level C_a in the tank as close as possible to the desired level C_d .

Water flows into the tank through valve V_i and flows out from the tank via valve V_o.

In the above example, the valve is adjusted to make output C_a equal to input C_d but not readjusted continuously to keep the two equals. The limitation of an open loop control system is that the difference between the desired and actual level (error e = $C_d - C_a$) gets developed due to disturbances acting on the system and parameter variation of the system.

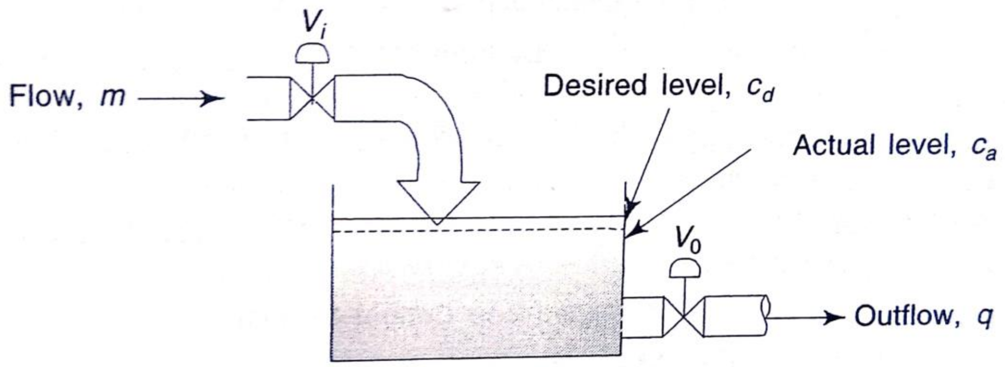


Fig. 14.20 *Water Level Control*

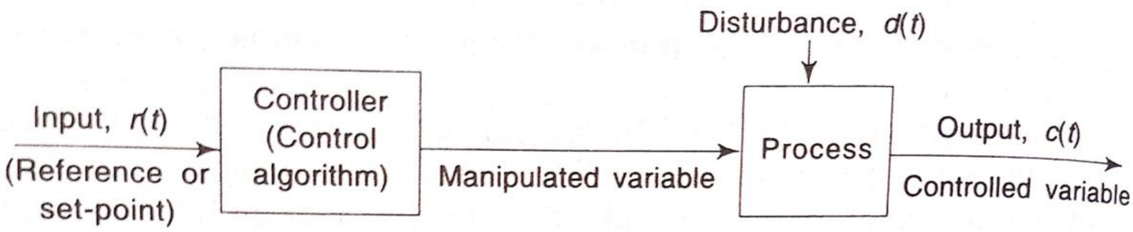


Fig. 14.21 *Block Diagram of Open-loop Control System*

Advantages

It is very simple system to design

Disadvantages

In an open loop control system, the input has no control over the output.

(b) closed-loop or feedback control system

In a closed loop control system, the input has control over the output. In this system the control variable is measured and fed back to the controller through a path. Some or all of the system outputs are measured and used by the controller, as shown in fig. the controller then compares a desired plant value with the actual measured output value and acts to reduce the difference between the two to zero value.

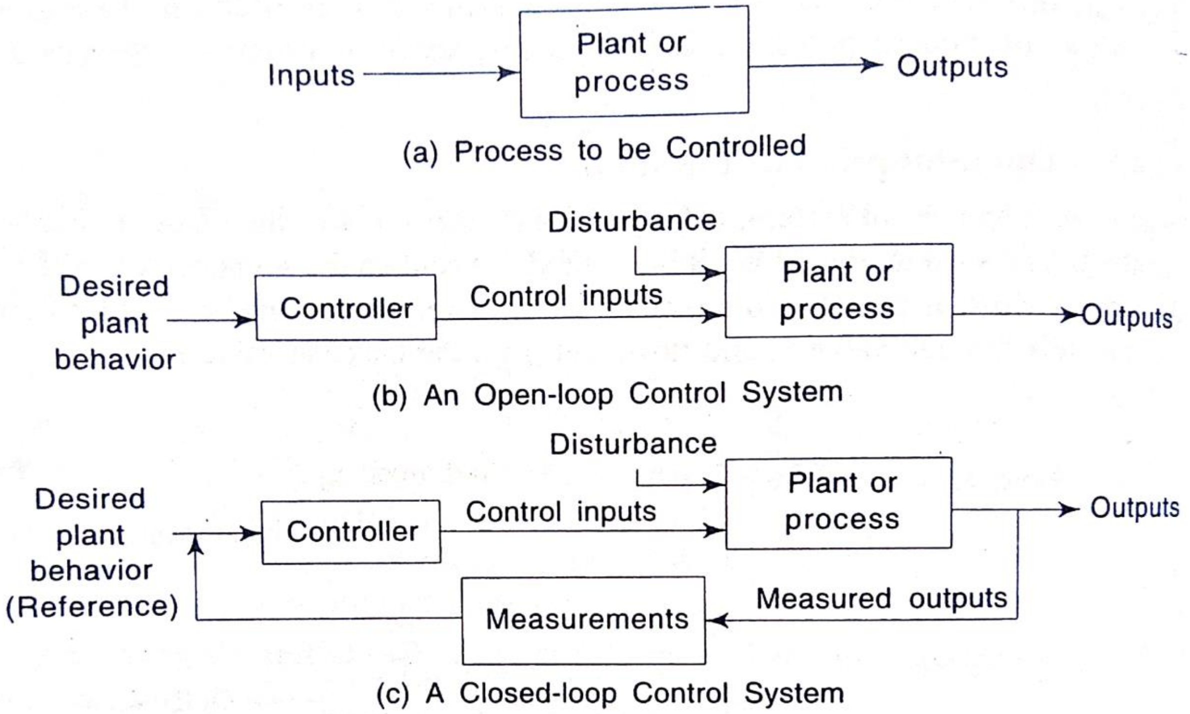


Fig. 14.22 *Feedback Control System*

In an example of a feedback control system for liquid tank level control is shown in fig. in which, the output C_a is measured continuously using level sensor and fed back to be compared with the input (desired, set or reference) level C_d. The error $e = C_d - C_a$ is used to adjust the control valve by means of an actuator.

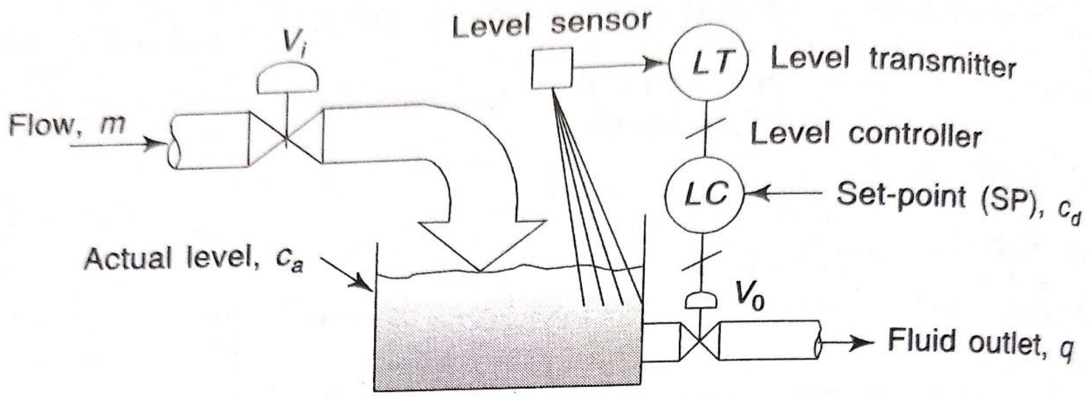


Fig. 14.24 *Liquid Tank Level Feedback Control System*

In closed-loop or feedback control system, the feedback loop causes the system to take corrective action if the actual level C_a deviates due to the disturbances from the desired level C_d. A block diagram of a closed loop or feedback control system is shown in fig.

Advantages

1. It is very simple technique that compensates for all disturbances.

2. the controller adjusts the controlled variable with the set point.

3. the feedback control loop doesn't care for the disturbances entering into the process. It tries only to maintain the controlled variable at set point by compensating for all disturbances.

Disadvantages

1. it doesn't take corrective action until after the disturbance has upset the process and generated an error signal.

2. the feedback controllers continue changing its output until measurement and set point are in agreement.

3. it solves the problems by trial and error method and thus causes oscillatory response of a feedback loop.

(c) Feedforward control system

The feedforward control system is a technique, which is used to take care of the limitation of feedback control system. In feedforward control system, disturbances are measured and compensated for them before the controlled variable deviates from set point. It is used to minimize the deviation of the controlled variable. A typical feedforward control system of heat exchanger is shown in the fig. In this example inlet temperature $T_i(t)$, and the process flow f(t),are two major disturbances. To implement a feedforward control system, these two disturbances must first be measured, and then a decision must be taken about how to manipulate the system valve to compensate for them. In the fig. the feedforward controller makes the decision about how to manipulate the steam valve to maintain the controlled variable at set point, depending on the inlet temperature and process flow.

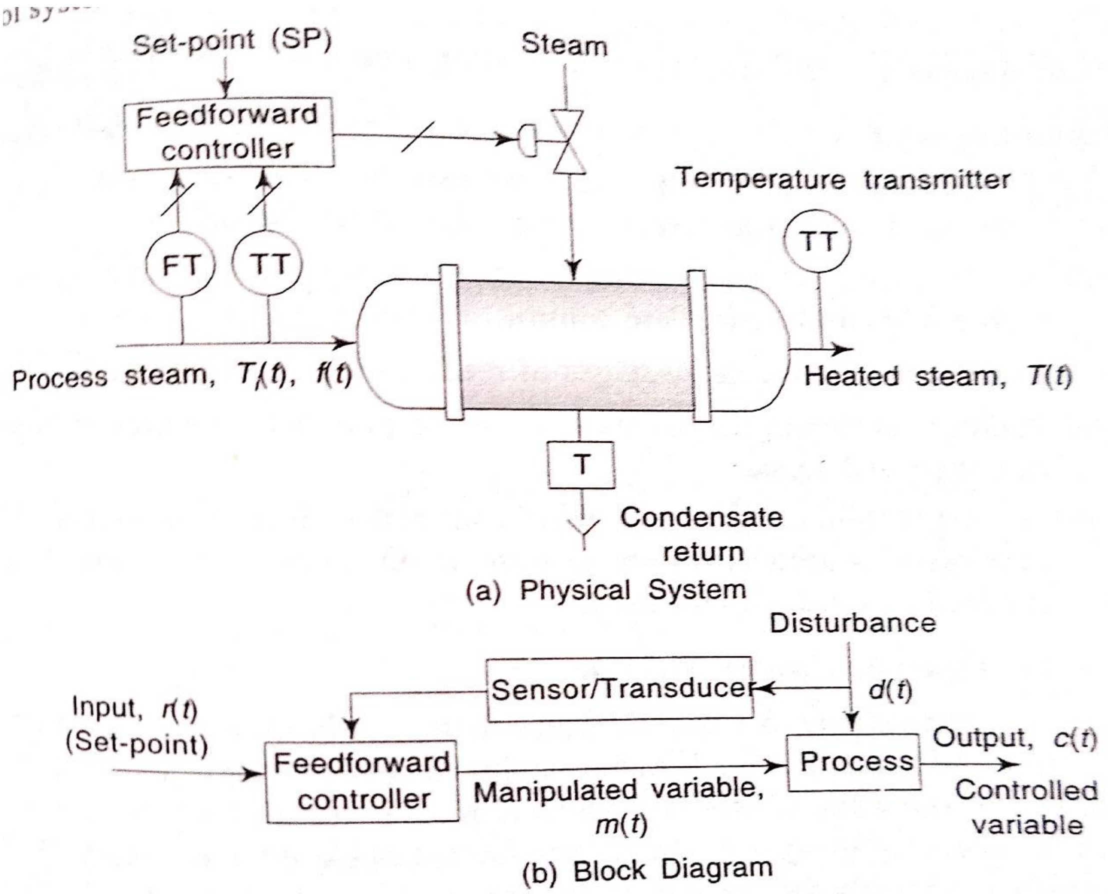


Fig. 14.26 *Heat Exchanger Feedforward Control System*

Advantages

1. Feedforward control acts before the output is disturbed and is capable of very good control performance with a accurate model.

2. A stable feedforward controller cannot induce instability in a system that is stable without feedforward control.

Disadvantages

1. Feedforward control systems can lead to poor performance if improperly designed and tuned.

2. The major limitation to feedforward control is its instability to reduce steady state offset to zero. However, this limitation is easily overcome by combining feedforward with feedback.

APPLICATION BASED CLASSIFICATION OF CONTROL SYSTEMS

On the basis of application control systems are classified as follows:

1. Sequential Control System

A sequential control system is one that performs a set of operations in a prescribed manner such as an automatic washing machine, automatic machining of castings for automobile industry, traffic control system, etc. The operations of a sequential control system can be event-driven or time-driven, based on how they are initiated or terminated.

Event-driven Sequential Control System

In an event-driven sequential control system, each step is initiated by the occurrence of an event. A traffic counter is a simple example of an event-driven system in which the counter is placed at the side of the road, and the sensor is stretched across the road. Each time a vehicle axle passes over the sensor, the counter increases its count by one. Thus an event (an axle passing over the sensor) drives the counter.

The event may be a single action, such as operator processing pushbutton, the closing of a limit switch, the opening of a pressure switch, or some other action that causes a switch to open or close. The event could also be combination of several actions, e.g. it may consist of the simultaneous occurrence of several actions. The event may also be occurrence of any one of several actions.

The ladder diagram used in Programmable Logic Controllers (PLCs) is a popular example of an event-driven process which was developed to represent systems consisting of switches, relays, solenoids, motor starters and other switching components used to control industrial equipment.

The automatic drilling machine is another example of event-driven sequential process. The drilling machine consists of an electric drill mounted on a movable platform. A hydraulic cylinder moves the platform and drill unit up and down between a drill reset position (up) and a hole drilled position (down). Upper and lower limit switches are used that are actuated when the cylinder reaches reset and drilled positions.

Manufacturing industries are principle user of event-driven sequential control system.

Time-driven Sequential Control System

In a time-driven sequential process, each step is initiated at a given time, or after a given time interval. An automatic washing machine is an example of a time-driven sequential control system. The functions such as washing operation, drain operation, the rinse operation, and the spin-dry operation are all initiated and terminated by a timer. Most batch process control systems are a time-driven sequential control systems. This system is described by a schematic and a timing diagram in which the schematic diagram depicts the physical configuration of the system whereas the timing diagram defines the sequential operation of the system.

2. Numerical Control System

Numerical control (NC) is a system that uses predetermined instructions (program) control a sequence of manufacturing operations. These instructions or program are coded numerical values for various functions such as position, direction, velocity, cutting speed, etc. These instructions are stored in a magnetic media or common memory space. The programs are divided into two parts, part program and machine program. The part program contains all the instructions required to produce a desired part whereas the machine program contains all the instructions required to accomplish a desired process such as boring, drilling, grinding, milling, punching, bending, welding, wire processing, etc. Numerical control is also referred to as flexible automation because of ease of modifying the program for various operations compared with changing cams, jigs, templates, etc.

With the increasing use of computer-aided design and computer-aided manufacturing (CAD/CAM) applications, more and more processes are being defined mathematically and therefore, the numerical control is becoming increasingly popular. The numerical control process starts with preparing specification (engineering drawing and mathematical definition) that completely defines the desired part or process. A programmer uses this specification and writes the program using special programming language APT

(Automatically Programmed Tools) for the sequence of operations necessary to produce the part or carry out the process, the tools to be used, the cutting speed and the feed rates.

Computerized Numerical Control System

Computerized numerical control (CNC) utilizes the storage and processing capabilities of a digital computer, and uses dedicated computer to accept the input instructions for performing the control functions required to produce the part.

Direct Numerical Control System

Direct numerical control (DNC) is used to facilitate computer-aided manufacturing (CAM) in which number of numerical control machines are connected to a central computer for real-time access to a common database of part programs and machine programs.