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SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS & INSTRUMENTATION ENGINEERING

UNIT – I – Process Control System Components – SIC1406

ORIFICE METER - DESIGN OF ORIFICE FOR GIVEN FLOW CONDITION

BASIC PRINCIPLE OF ORIFICE METER

When an orifice plate is placed in a pipe carrying the fluid whose rate of flow is to be measured, the orifice plate causes a pressure drop which varies with the flow rate. This pressure drop is measured using a differential pressure sensor and when calibrated this pressure drop becomes a measure flow rate. The flow rate is given by.

$$Qa = (Cd.A2 / \sqrt{1-(A2/A1)}\hat{}2) * (\sqrt{2(P1-P2)/P})$$

Where, Qa = flow rate

Cd = Discharge coefficient

A1 = Cross sectional area of pipe

A2 = Cross sectional area of orifice

P1, P2 = Static Pressures

Description of Orifice Meter

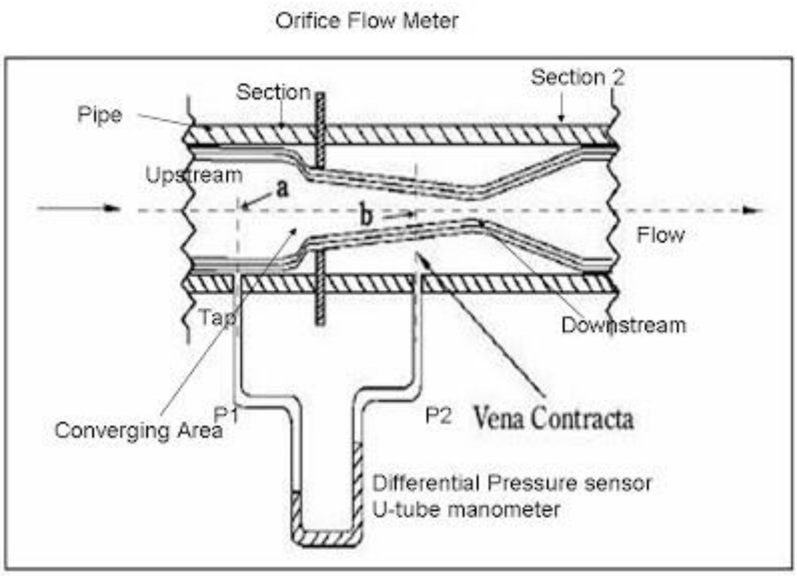

Fig-1: Orifice plate

The main parts of an orifice flow meter are as follows:

A stainless steel orifice plate which is held between flanges of a pipe carrying the fluid whose flow rate is being measured.

- It should be noted that for a certain distance before and after the orifice plate fitted between the flanges, the pipe carrying the fliud should be straight in order to maintain laminar flow conditions.
- Openings are provided at two places 1 and 2 for attaching a differential pressure sensor (U-tube manometer, differential pressure gauge etc) as shown in the diagram.

Operation of Orifice Meter

- The detail of the fluid movement inside the pipe and orifice plate has to be understood.
- The fluid having uniform cross section of flow converges into the orifice plate's opening in its upstream. When the fluid comes out of the orifice plate's opening, its cross section is minimum and uniform for a particular distance and then the cross section of the fluid starts diverging in the down stream.
- At the upstream of the orifice, before the converging of the fluid takes place, the pressure of the fluid (P1) is maximum. As the fluid starts converging, to enter the orifice opening its pressure drops. When the fluid comes out of the orifice opening, its pressure is minimum (p2) and this minimum pressure remains constant in the minimum cross section area of fluid flow at the downstream.
- This minimum cross sectional area of the fluid obtained at downstream from the orifice edge is called **vena-contracta.**
- The differential pressure sensor attached between points 1 and 2 records the pressure difference (P1 – P2) between these two points which becomes an indication of the flow rate of the fluid through the pipe when calibrated.

Applications of Orifice Meter

1. The concentric orifice plate is used to measure flow rates of pure fluids and has a wide applicability as it has been standardized.
2. The eccentric and segmental orifice plates are used to measure flow rates of fluids containing suspended materials such as solids, oil mixed with water and wet steam.

Advantages of Orifice Meter

1. It is very cheap and easy method to measure flow rate.
2. It has predictable characteristics and occupies less space.

3. Can be use to measure flow rates in large pipes.

Limitations of Orifice Meter

1. The vena-contracta length depends on the roughness of the inner wall of the pipe and sharpness of the orifice plate. In certain cases it becomes difficult to tap the minimum pressure (P2) due to the above factor.
2. Pressure recovery at downstream is poor, that is, overall loss varies from 40% to 90% of the differential pressure.
3. In the upstream straightening vanes are a must to obtain laminar flow conditions.
4. Gets clogged when the suspended fluids flow.
5. The orifice plate gets corroded and due to this after sometime, inaccuracy occurs. Moreover the orifice plate has low physical strength.
6. The coefficient of discharge is low.

Note: the materials used for maintaining orifice plate are stainless steel, phosper bronze, nickel and monel.

ROTOMETER

The rotameter is an industrial flowmeter used to measure the flowrate of liquids and gases. The rotameter consists of a tube and float. The float response to flowrate changes is linear, and a 10-to-1 flow range or turndown is standard.

Principle of Operation

The rotameter's operation is based on the variable area principle: fluid flow raises a float in a tapered tube, increasing the area for passage of the fluid. The greater the flow, the higher the float is raised. The height of the float is directly proportional to the flowrate. With liquids, the float is raised by a combination of the buoyancy of the liquid and the velocity head of the fluid. With gases, buoyancy is negligible, and the float responds to the velocity head alone. The float moves up or down in the tube in proportion to the fluid flowrate and the annular area between the float and the tube wall. The float reaches a stable position in the tube when the upward force exerted by the flowing fluid equals the downward gravitational force exerted by the weight of the float. A change in flowrate upsets this balance of forces. The float then moves up or down, changing the annular area until it again reaches a position where the forces are in equilibrium. To satisfy the force equation, the rotameter float assumes a distinct position for every constant flowrate. However, it is important to note that because the float position is gravity dependent, rotameters must be vertically oriented and mounted.

Rotameter Selection

- What is the minimum and maximum flow rate for the flow meter?
- What is the minimum and maximum process temperature?
- What is the size of the pipe?
- Would you like a direct reading rotameter or is a look up table acceptable?
- What accuracy do you need?
- Do you require a valve to regulate the flow?
- Will there be back pressure?
- What is the maximum process pressure?

Types of Rotameters

Fig-2: **Glass Tube Rotameters**

The basic rotameter is the glass tube indicating-type. The tube is precision formed of borosilicate glass, and the float is precisely machined from metal, glass or plastic. The metal float is usually made of stainless steel to provide corrosion resistance. The float has a sharp metering edge where the reading is observed by means of a scale mounted alongside the tube. End fittings and connections of various materials and styles are available. The important elements are the tube and float, often called the tube-and-float combination, because it is this portion of the rotameter which provides the measurement. In fact, similar glass tube and stainless steel float combinations are generally available, regardless of the type of case or end fittings the application can demand, so as best to meet customer requirements. The scale of the rotameter can be calibrated for direct reading of air or water, or it may have a scale to read a percent of range or an arbitrary scale to be used with conversion equations or charts.

Fig-3: Metal Tube Flowmeters

For higher pressures and temperatures beyond the practical range of glass tubes, metal tubes are used. These are usually manufactured in aluminium, brass or stainless steel. The position of the piston is determined by magnetic or mechanical followers that can be read from the outside of the metal metering tube. Similar to glass tube rotameters, the spring-and-piston combination determines the flowrate, and the fittings and materials of construction must be chosen so as to satisfy the demands of the applications. These meters are used for services where high operating pressure or temperature, water hammer, or other forces would damage glass metering tubes.

Construction and Working:

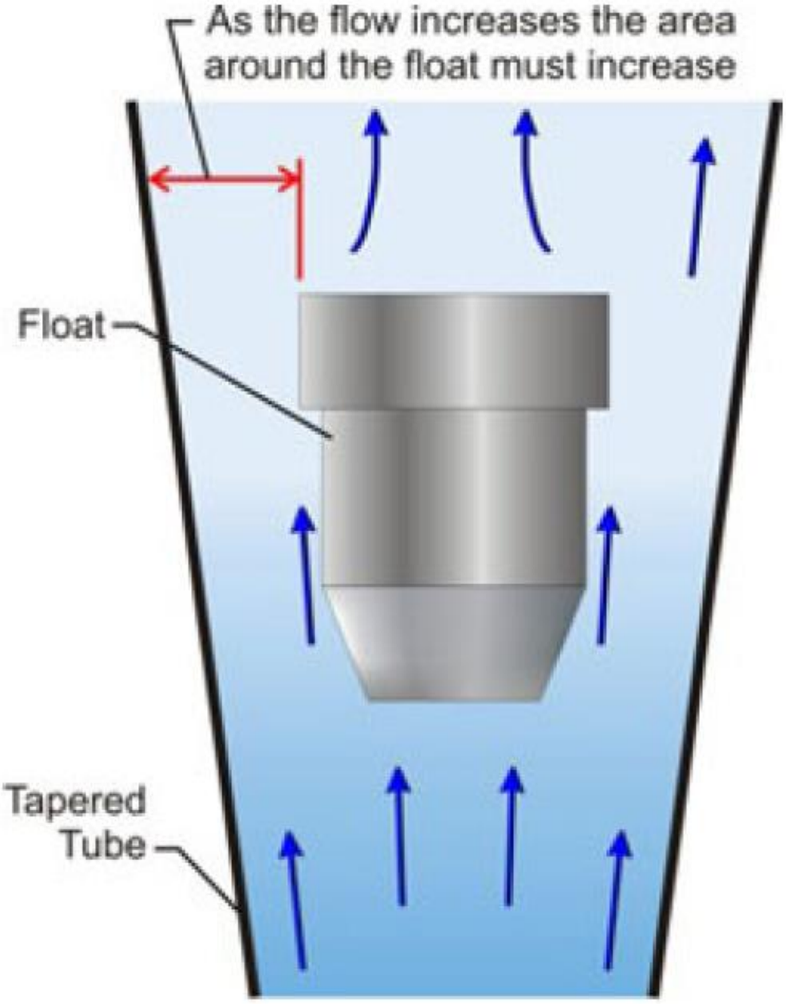

Fig-4: Rotameter

Rotameters are a subset of meters called variable area flow meters that measure the flow rate by allowing the fluid to travel through a tapered tube where the cross sectional area of the tube gradually becomes greater as the fluid travels through the tube. The flow rate inside the rotameter is measured using a float that is lifted by the fluid flow based on the buoyancy and velocity of the fluid opposing gravity pulling the float down. For gasses the float responds to the velocity alone, buoyancy is negligible.

The float moves up and down inside the rotameter's tapered tube proportionally to the flow rate of the fluid. It reaches a constant position once the fluid and gravitational forces have equalized. Changes in the flow rate cause rotameter's float to change position inside the tube. Since the float position is based on gravity it is important that all rotameters be mounted vertically and oriented with the widest end of the taper at the top. It is also important to remember that if there is no flow the float will sink to the bottom of the rotameter due to its own weight. The operator reads the flow from a graduated scale on the side of the rotameter, which has been calibrated to a specific fluid with a known specific gravity. Specific gravity or the weight of the fluid has a great impact on the rotameter's accuracy and reliability. All of Global Water's rotameters have been calibrated using water as the standard fluid with a specific gravity of 1.0.Rotameters can be calibrated for other fluids by understanding the basic operating principles. Rotameter accuracy is determined by the accuracy of the pressure, temperature, and flow control during the initial calibration. Any change in the density and weight of the float will have impacts on the rotameter's flow reading. Additionally any changes that would affect the fluid such as pressure or temperature will also have an affect on the rotameter's accuracy. Given this, rotameters should be calibrated yearly to correct for any changes in the system that may have occurred.

There are several advantages to a rotameter over a more complicated flow meter including:

Rotameters can be installed in areas with no power since they only require the properties of the fluid and gravity to measure flow, so you do not have to be concerned with ensuring that the instrument is explosion proof when installed in areas with flammable fluids or gases. Rotameters can be installed with standard pipe fittings to existing piping or through a panel. You do not have to worry about straight runs of pipe as with a magnetic or turbine flow meter. Rotameters are simple devices that are mass manufactured out of inexpensive materials keeping investment costs low.

Rotameters offer wide flow measurement ranges or rangeability. A typical ratio of 10:1 from maximum to minimum flow rate can be expected. Operators will be able to measure minimum flow rates as low as 1/10 of the rotameter's maximum flow rate without impairing the repeatability.

The rotameter's scale is linear because the measure of flow rate is based on area variation. This means that the flow rate can be read with the same degree of accuracy throughout the full range. Pressure loss due to the rotameter is minimal and relatively constant because the area through the tapered tube increases with flow rate. This results in reduced pumping costs.

There are also a few disadvantages to the use of rotameters that you should keep in mind: Because gravity plays a key roll in the flow measurement the rotameter must always be installed vertically with the fluid flowing up through it.

The graduated scale on the side of the rotameter will only be valid for the specific fluid and conditions where it was calibrated. The specific gravity of the fluid is primary property to consider, however the fluid's viscosity and any temperature changes may also be significant. Rotameter floats are generally designed to be insensitive to viscosity, but the operator should verify that any rotameters installed in their system are calibrated to their specific setup prior to relying on the flow measurements provided. It is difficult for rotameters to be adapted for machine reading, although a magnetic float may be used in some instances. Rotameters are typically made of transparent material, however all operators should check the chemical compatibility of the meter with their fluid prior to full installation.

Rotameter Disadvantages:

- Typical accuracy for a rotameter is 1% to 10% of full scale. Several other types of flow meter have typical accuracy better than this.
- As noted above the rotameter doesn't work well for machine reading or continuous recording of flow rate.

Design of Rotometer

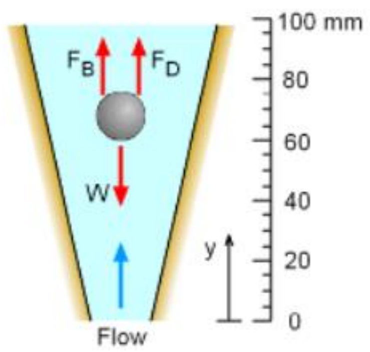

Fig-5: Rotameter structure

A common device used to measure volumetric flow rate is the rotameter. The rotameter consists of a transparent tapered tube with a float in it. When the flow enters the rotameter, the float will rise to a position where both the drag force and buoyant force will be balanced by its own weight. That is,

$$F_D + F_B = W$$

$$\frac{C_D A_{fr} \rho_f u_m^2}{2} + V_b \rho_f g = V_b \rho_b g$$

Solving for flow velocity, u_m,gives,

$$u_m = \sqrt{\frac{2V_b\, g(\rho_b - \rho_f)}{C_D A_{fr} \rho_f}}$$

Note that u_m is the mean velocity passing through the annular space between the float and the tube; V_b is the volume of the float; ρ_b and ρ_f are the density of the float and fluid, respectively; C_D is the drag coefficient; A_{fr} is the projected area of the float; and g is the acceleration of gravity. The volumetric flow rate is then given by

$$Q = u_m A_m$$

where A_m is the area of the annular space.

The discussion of rotameters has taken into account the drag force, which is due to viscous effects. Although this chapter is mainly focused on discussion of incompressible and inviscid flow, for illustration purposes, it is appropriate to introduce the flow measurement technique using the rotameter here, which includes viscous drag effect (modeled as C_D)

Transmitters

RTD

The acronym "RTD" is derived from the term "Resistance Temperature Detector" . The most stable, linear and repeatable RTD is made of platinum metal. The temperature coefficient of the RTD element is positive and almost constant. Typical RTD elements are specified with 0°C values of 50, 100, 200, 500, 1000 or 2000Ω. Of these options, the 100Ω platinum RTD is the most stable over time and linear over temperature. The RTD element requires a current excitation. If the magnitude of the current source is too high, the element will dissipate power and start to self-heat. Consequently, care should be taken to insure that less than 1 mA of current is used to excite the RTD element.

SIGNAL CONDITIONING:

Signal conditioning is the manipulation of a signal in a way that prepares it for the next stage of processing. Many applications involve environmental or structural measurement, such as temperature and vibration, from sensors.

Why do we need a signal conditioning circuit? The term "signal conditioning circuit" is used to the circuits, which convert raw signal from transducers (load cell, tacho-generators, temperature sensors etc) into a signal industrial accepted range (0-10 Vdc or 0-5Vdc or 4-20 mA etc)

Signal Conditioning Circuit for RTD (Resistance Temperature Detector)

Theory of RTD (Resistance Temperature Detector):

An RTD (resistance temperature detector) is a temperature detector based upon a variation in electric resistance. The commonest metal for this application is platinum. RTDs rely on the positive temperature coefficient for a conductor's resistance. In a conductor the number of electrons available to conduct electricity does not significantly change with temperature. But when the temperature increases, the vibration of atoms around their equilibrium positions increase in amplitude. This result in a greater dispersion of electrons, which reduces their average speed. Hence, the resistance increases when the temperature rises.

The relationship between temperature and resistance of RTD is given by-

$$R_T = R_0\,(1 + \alpha T) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where R_T is resistance at $T\,^{\circ}C$.

R_0 is resistance at 0ºC, and α is temperature coefficient of resistance. α represents the change in resistance per degree centigrade change in temperature. For example, Pt100 is platinum RTD with resistance R_0 of 100 Ω at 0ºC. For platinum α = 0.00385 and at 100 ºC, Pt100 will have a resistance of

$$R_{100} = 100 \times (1 + 0.00385 \times 100) = 138.5$$

Measurement of RTD with Wheatstone-Bridge Circuit:

Mostly RTD instruments used Wheatstone bridge circuit for measurement purpose. Bridge contains RTD at one arm and other remaining three arms connected with standard resistances. Bridge is generally a resistance measuring device which converts the resistance of RTD into electrical signal.

Here the as mention above the equation (1) may be written as

$$R_T - R_0 = \alpha R_0\,\Delta T$$

$$\Delta R \quad = R_0\,\Delta T$$

For given values of α and R_0, ΔR and ΔT, , and hence measuring the ΔR (With the help of Wheatstone bridge circuit) change in temperature can be found out.

As shown in the fig. below

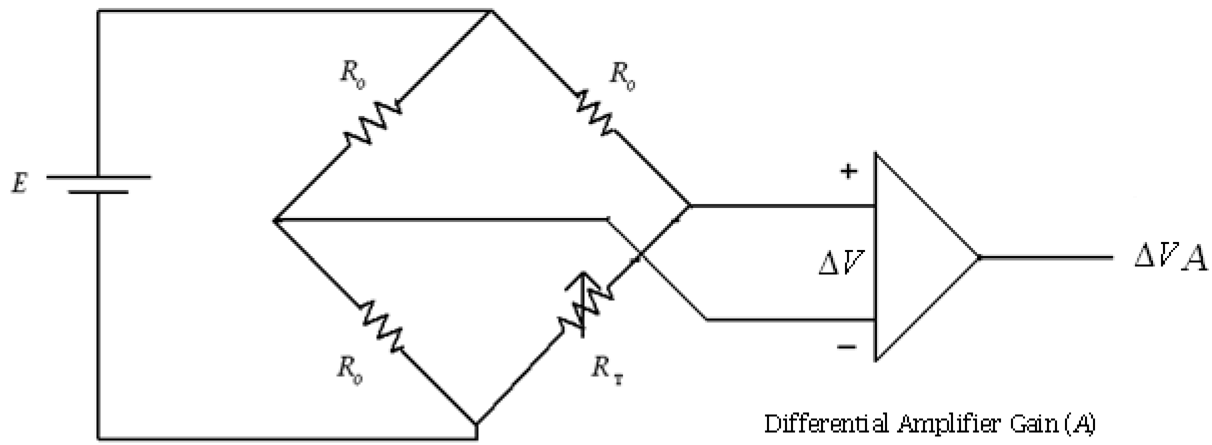

Fig-6: Signal conditioning circuit of RTD

To measure the out-put voltage of signal conditioning circuit for RTD, following equations are required-

1. $R_T = R_0 (1 + aT)$

R_T is the resistance of platinum, R_0 is the resistance at 0ºC, α is the temperature coefficient of platinum wire and T is the temperature.

2.BRIDGE OUTPUT $\Delta V = \left(\frac{R_T}{R_T + R_0} - \frac{1}{2}\right) E$

Here, R_T is the resistance of platinum wire and R_0 are the standard resistances and E is the input voltage applied to the bridge.

3. Differential amplifier output $V_{out} = \Delta VA$,

where A is the voltage gain of the amplifier

Zero and Span Adjustment in D/P Transmitters and Temperature Transmitters

Every instrument has at least one input and one output. For a pressure sensor, the input would be some fluid pressure and the output would (most likely) be an electronic signal. For a loop indicator, the input would be a 4-20 mA current signal and the output would be a human-readable display. For a variable-speed motor drive, the input would be an electronic signal and the output would be electric power to the motor.

Calibration and ranging are two tasks associated with establishing an accurate correspondence between any instrument's input signal and its output signal. Simply defined, calibration assures the instrument accurately senses the real-world variable it is supposed to measure or control. Simply defined, ranging establishes the desired relationship between an instrument's input and its output.

Zero and span adjustments

The purpose of calibration is to ensure the input and output of an instrument reliably correspond to one another throughout the entire range of operation. We may express this expectation in the form of a graph, showing how the input and output of an instrument should relate. For the vast majority of industrial instruments this graph will be linear:

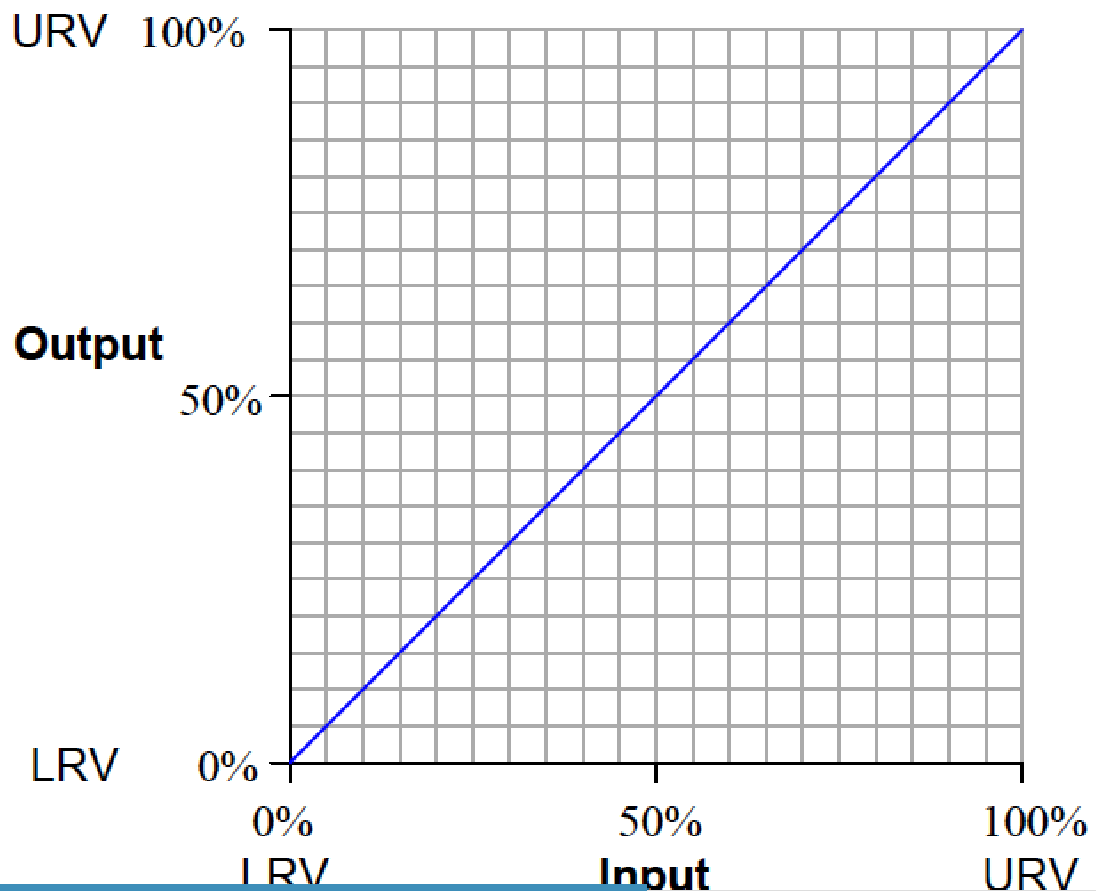

Fig-7: Input versus Output curve for an industrial instrument

This graph shows how any given percentage of input should correspond to the same percentage of output, all the way from 0% to 100%.

Things become more complicated when the input and output axes are represented by units of measurement other than "percent." Take for instance a pressure transmitter, a device designed to sense a fluid pressure and output an electronic signal corresponding to that pressure. Here is a graph for a pressure transmitter with an input range of 0 to 100 pounds per square inch (PSI) and an electronic output signal range of 4 to 20 milliamps (mA) electric current:

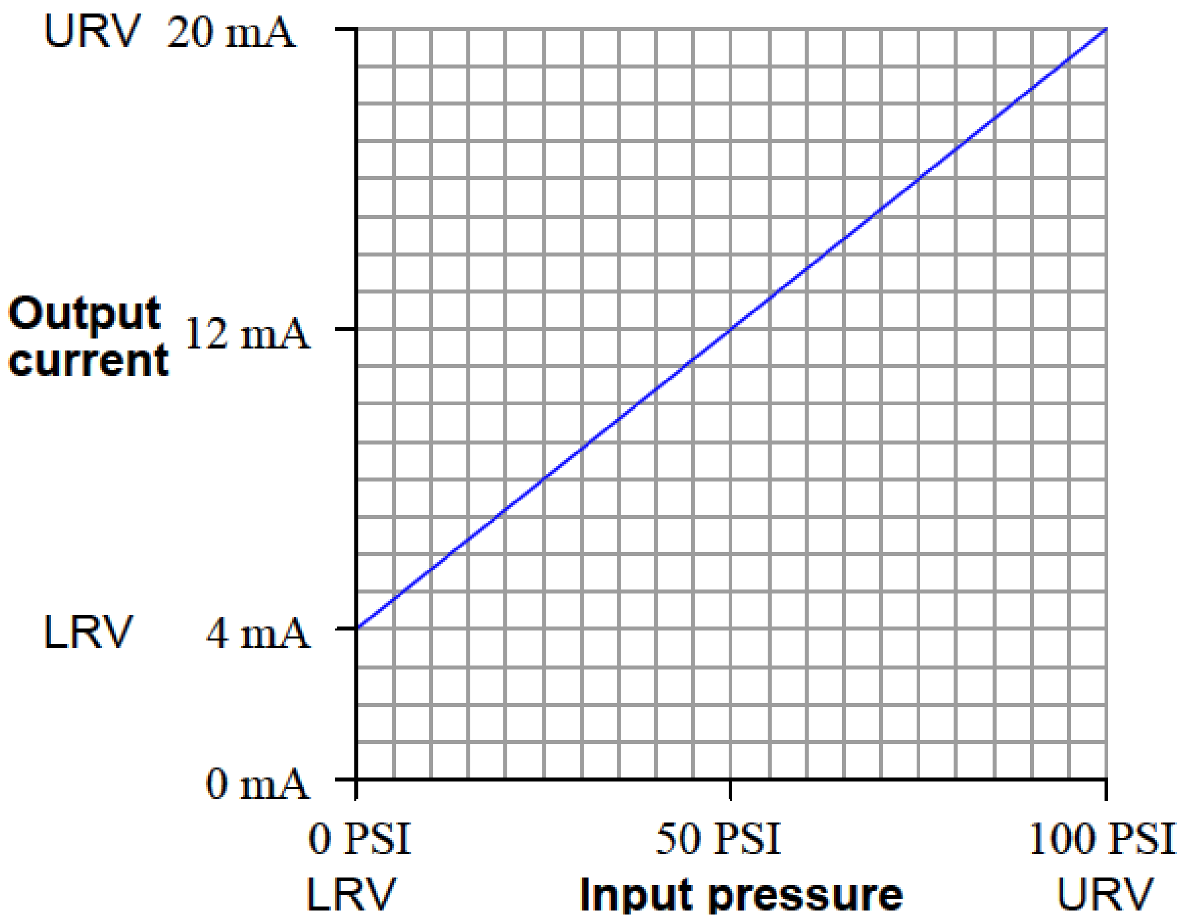

Fig-8: Input versus Output response for a pressure transmitter

Although the graph is still linear, zero pressure does not equate to zero current. This is called a live zero, because the 0% point of measurement (0 PSI fluid pressure) corresponds to a non-zero ("live") electronic signal. 0 PSI pressure may be the LRV (Lower Range Value) of the transmitter's input, but the LRV of the transmitter's output is 4 mA, not 0 mA. Any linear, mathematical function may be expressed in "slope-intercept" equation form:

y = mx + b

Where,

y = Vertical position on graph

x = Horizontal position on graph
m = Slope of line
b = Point of intersection between the line and the vertical (y) axis

This instrument's calibration is no different. If we let x represent the input pressure in units of PSI and y represent the output current in units of milliamps, we may write an equation for this instrument as follows:

$$y = 0.16x + 4$$

On the actual instrument (the pressure transmitter), there are two adjustments which let us match the instrument's behavior to the ideal equation. One adjustment is called the zero while the other is called the span. These two adjustments correspond exactly to the b and m terms of the linear function, respectively: the "zero" adjustment shifts the instrument's function vertically on the graph (b), while the "span" adjustment changes the slope of the function on the graph (m). By adjusting both zero and span, we may set the instrument for any range of measurement within the manufacturer's limits.

The relation of the slope-intercept line equation to an instrument's zero and span adjustments reveals something about how those adjustments are actually achieved in any instrument. A "zero" adjustment is always achieved by adding or subtracting some quantity, just like the y-intercept term b adds or subtracts to the product mx. A "span" adjustment is always achieved by multiplying or dividing some quantity, just like the slope m forms a product with our input variable x.

Zero adjustments typically take one or more of the following forms in an instrument:

- Bias force (spring or mass force applied to a mechanism)
- Mechanical offset (adding or subtracting a certain amount of motion)
- Bias voltage (adding or subtracting a certain amount of potential)

Span adjustments typically take one of these forms:

- Fulcrum position for a lever (changing the force or motion multiplication)
- Amplifier gain (multiplying or dividing a voltage signal)
- Spring rate (changing the force per unit distance of stretch)

It should be noted that for most analog instruments, zero and span adjustments are interactive. That is, adjusting one has an effect on the other. Specifically, changes made to the span adjustment almost always alter the instrument's zero point1. An instrument with interactive zero and span adjustments requires much more effort to accurately calibrate, as one must switch back and forth between the lower- and upper-range points repeatedly to adjust for accuracy.

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UNIT – II – Process Control System Components – SIC1406

PRESSURE RELIEVING DEVICES

Pressure relief devices are used to provide a means of venting excess pressure which could rupture a boiler or pressure vessel. A pressure relief device is the last line of defense for safety. If all other safety devices or operating controls fail, the pressure relief device must be capable of venting excess pressure.

Functions

The pressure is relieved by allowing the pressurized fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits.

Codes And Standards

- All pressure relief devices for set pressure of more than 15 psi are designed, constructed, inspected, stamped and certified in accordance with the ASME Boiler and Pressure Vessel Code (ASME Code). Each device is stamped with a certification mark, and one of the eight certification designators. See Figure below.

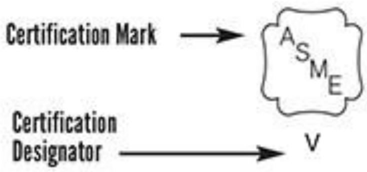


Fig-1: Codes and Standards

The most common types of pressure relief devices are:

- Safety Valve – This device is typically used for steam or vapor service. It operates automatically with a full-opening pop action and recloses when the pressure drops to a value consistent with the blowdown requirements prescribed by the applicable governing code or standard.
- Relief Valve – This device is typically used for liquid service. It operates automatically by opening farther as the pressure increases beyond the initial opening pressure and recloses when the pressure drops below the opening pressure.
- Safety Relief Valve – This device includes the operating characteristics of both a safety valve and a relief valve and may be used in either application.

Conventional Safety Relief Valve

A conventional safety Relief Valve is a pressure Relief Valve which has its spring housing vented to the discharge side of the Valve. The operational characteristics (opening pressure, closing pressure, and relieving capacity) are directly affected by changes of the back pressure on the Valve.

Balanced Safety Relief Valve

A balanced safety Relief Valve is a pressure Relief Valve which incorporates means of minimizing the effect of back pressure on the operational characteristics (opening pressure, closing pressure, and relieving capacity).

- Temperature and Pressure Safety Relief Valve – This device is typically used on potable water heaters. In addition to its pressure-relief function, it also includes a temperature-sensing element which causes the device to open at a predetermined temperature regardless of pressure. The set temperature on these devices is usually 210°F.
- Rupture Disk – This device is classified as nonreclosing since the disk is destroyed upon actuation. This type of device may be found in use with a pressure vessel where a spring-loaded pressure relief device is inappropriate due to the operating conditions or environment.

Advantages of pressure relief valves are:

- They are reliable when properly sized and operated.
- They are versatile and can be used for many services.
- The disadvantages of pressure relief valves are:
- The relieving pressure is affected by the back pressure (pressure that exists at the outlet of a safety relief valve).
- They are subject to chatter if built-up back pressure is too high.

Problems that can prevent normal operation of pressure relief devices

Pressure relief devices must operate as designed in order to perform their required function. Care must be taken during design to prevent problems during normal operation:

1. The inlet piping connected to the device must not be smaller than the inlet opening of the device.
2. The discharge piping connected to the device must be no smaller than the discharge opening of the device.
3. Multiple devices discharging into a discharge manifold or header is a common practice. The discharge manifold or header must be sized so that the cross sectional area is equal to or greater than the sum of the discharge cross sectional areas of all the devices connected to the discharge manifold or the header.

4. Constant leakage of the device can cause a build-up of scale or other solids around the discharge opening. This build-up can prevent the device from operating as designed.
5. Discharge piping connected to the device must be supported so as not to impart any loadings on the body of the device.
6. Some devices, especially on larger boilers, may have a discharge pipe arrangement which incorporates provisions for expansion as the boiler heats up or cools down. These expansion provisions must allow the full range of movement required to prevent loads being applied to the device body.
7. Drain holes in the device body and discharge piping, when applicable, must be open to allow drainage of liquids from over the device disk on spring-loaded valves. Any liquid allowed to remain on top of the device disk can adversely affect the operating characteristics of the device.
8. Most jurisdictional requirements state that device must be "piped to a point of safe discharge". This must be accomplished while keeping the run of the discharge piping as short as possible.

The difference between a relief valve and safety valve are as follows:

1. Relief valve opening is directly proportional to the pressure rise. Safety valve opening will happen at after reaching the set pressure.

2. Safety valve can be operated manually with use of easing gear (as in boilers) whereas Relief valve can not.

3. Safety valve is set at 3% above the working pressure Relief valve is set at 10% above working pressure.

4. Safety valve is used in a vapour or steam system, whereas Relief valve can be used in Fluid or compressed air system.

Pressure Relief Valve

The pressure relief valves are used to protect the hydraulic components from excessive pressure. This is one of the most important components of a hydraulic system and is essentially required for safe operation of the system. Its primary function is to limit the system pressure within a specified range. It is normally a closed type and it opens when the pressure exceeds a specified maximum value by diverting pump flow back to the tank. The simplest type valve contains a poppet held in a seat against the spring force as shown in Figure 2. The fluid enters from the opposite side of the poppet. When the system pressure exceeds the pre-set value, the poppet lifts and the fluid is escaped through the orifice to the storage tank directly. It reduces the system pressure and as the pressure reduces to the set limit again the valve closes. This valve does not provide a flat cut-off pressure limit with flow rate because the spring must be deflected more when the flow rate is higher.

Direct type of relief valve

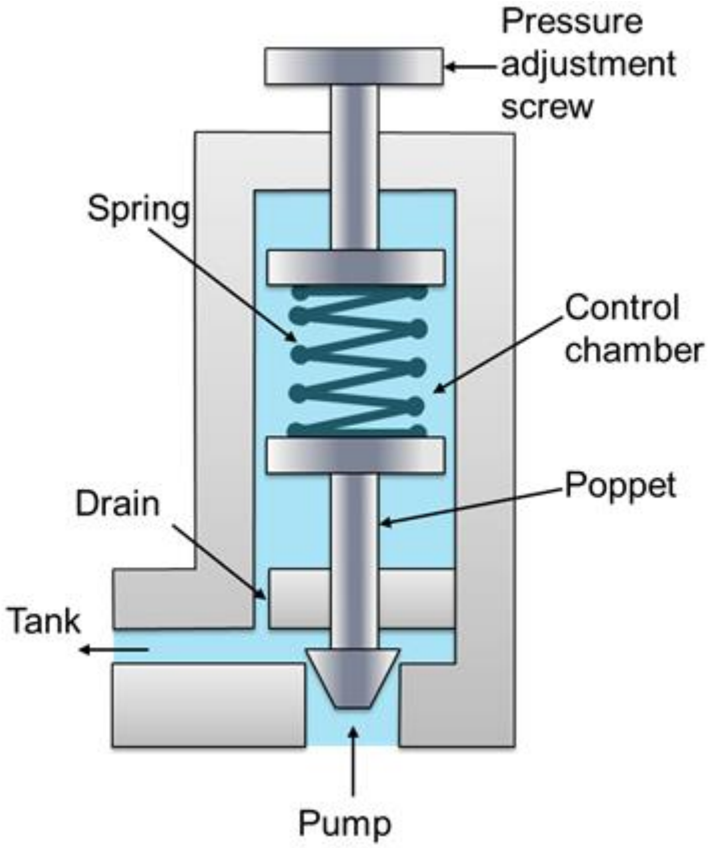


Fig-2: Pressure Relief Valve

Schematic of direct pressure relief valve is shown in figure. This type of valves has two ports; one of which is connected to the pump and another is connected to the tank. It consists of a spring chamber where poppet is placed with a spring force. Generally, the spring is adjustable to set the maximum pressure limit of the system. The poppet is held in position by combined effect of spring force and dead weight of spool. As the pressure exceeds this combined force, the poppet raises and excess fluid bypassed to the reservoir (tank). The poppet again reseats as the pressure drops below the pre-set value. A drain is also provided in the control chamber. It sends the fluid collected due to small leakage to the tank and thereby prevents the failure of the valve.

Unloading Valve

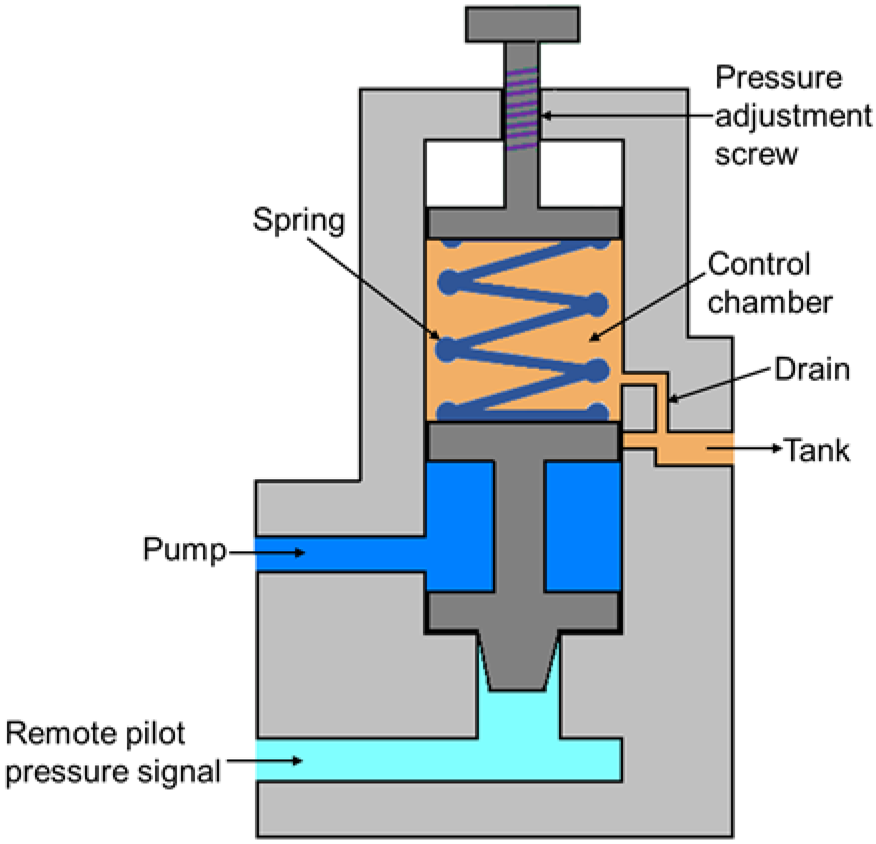


Fig-3: Unloading Valve

Construction of the unloading valve is shown in Figure .This valve consists of a control chamber with an adjustable spring which pushes the spool down. The valve has two ports: one is connected to the tank and another is connected to the pump. The valve is operated by movement of the spool. Normally, the valve is closed and the tank port is also closed. These valves are used to permit a pump to operate at the minimum load. It works on the same principle as direct control valve that the pump delivery is diverted to the tank when sufficient pilot pressure is applied to move the spool. The pilot pressure maintains a static pressure to hold the valve opened. The pilot pressure holds the valve until the pump delivery is needed in the system. As the pressure is needed in the hydraulic circuit; the pilot pressure is relaxed and the spool moves down due to the self-weight and the spring force. Now, the flow is diverted to the hydraulic circuit. The drain is provided to remove the leaked oil collected in the control chamber to prevent the valve failure. The unloading valve reduces the heat buildup due to fluid discharge at a preset pressure value.

Sequence valve

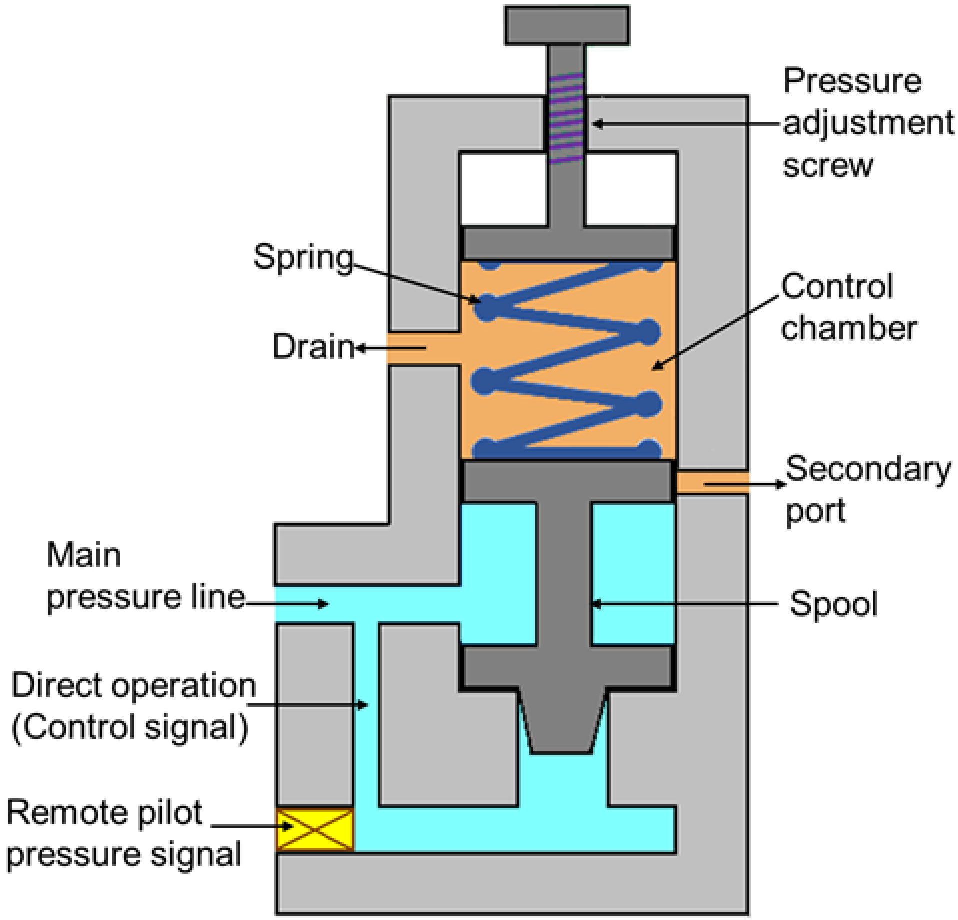


Fig-4: Sequence valve

The primary function of this type of valve is to divert flow in a predetermined sequence. It is used to operate the cycle of a machine automatically. A sequence valve may be of direct-pilot or remote-pilot operated type.

Schematic of the sequence valve is shown in Figure-4. Its construction is similar to the direct relief valve. It consists of the two ports; one main port connecting the main pressure line and another port (secondary port) is connected to the secondary circuit. The secondary port is usually closed by the spool. The pressure on the spool works against the spring force. When the pressure exceeds the preset value of the spring; the spool lifts and the fluid flows from the primary port to the secondary port. For remote operation; the passage used for the direct operation is closed and a separate pressure source for the spool operation is provided in the remote operation mode.

Counterbalance Valve:

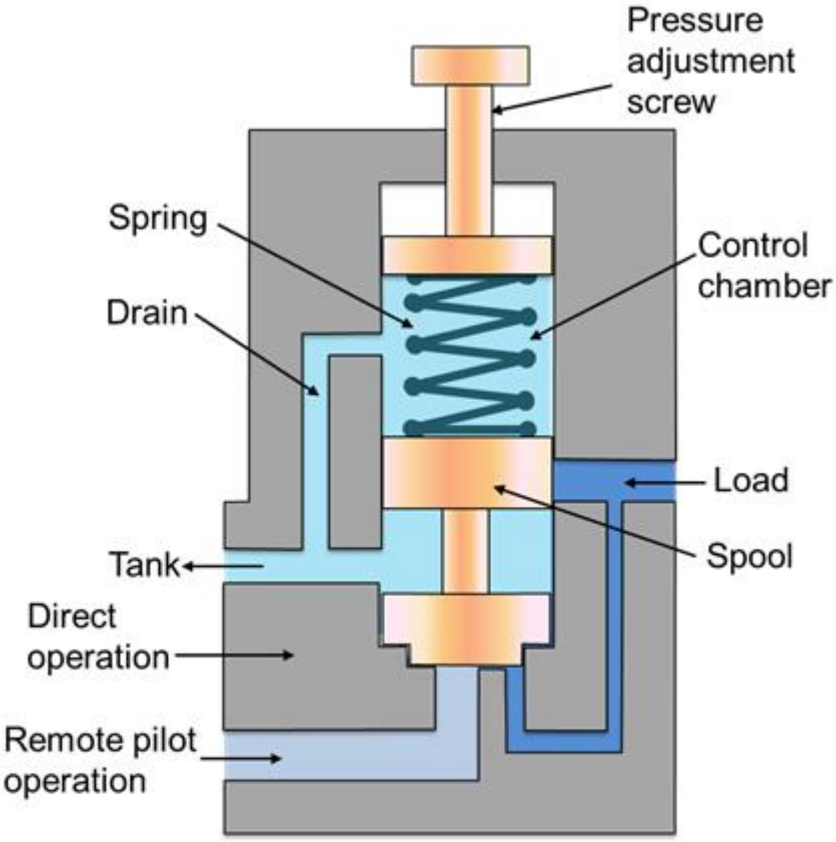


Fig-5: Counter Balance Valve

The schematic of counterbalance valve is shown in Figure .It is used to maintain the back pressure and to prevent a load from failing. The counterbalance valves can be used as breaking valves for decelerating heavy loads. These valves are used in vertical presses, lift trucks, loaders and other machine tools where position or hold suspended loads are important. Counterbalance valves work on the principle that the fluid is trapped under pressure until pilot pressure overcomes the pre-set value of spring force. Fluid is then allowed to escape, letting the load to descend under control. This valve is normally closed until it is acted upon by a remote pilot pressure source. Therefore, a lower spring force is sufficient. It leads to the valve operation at the lower pilot pressure and hence the power consumption reduces, pump life increases and the fluid temperature decreases.

Pressure Reducing Valve

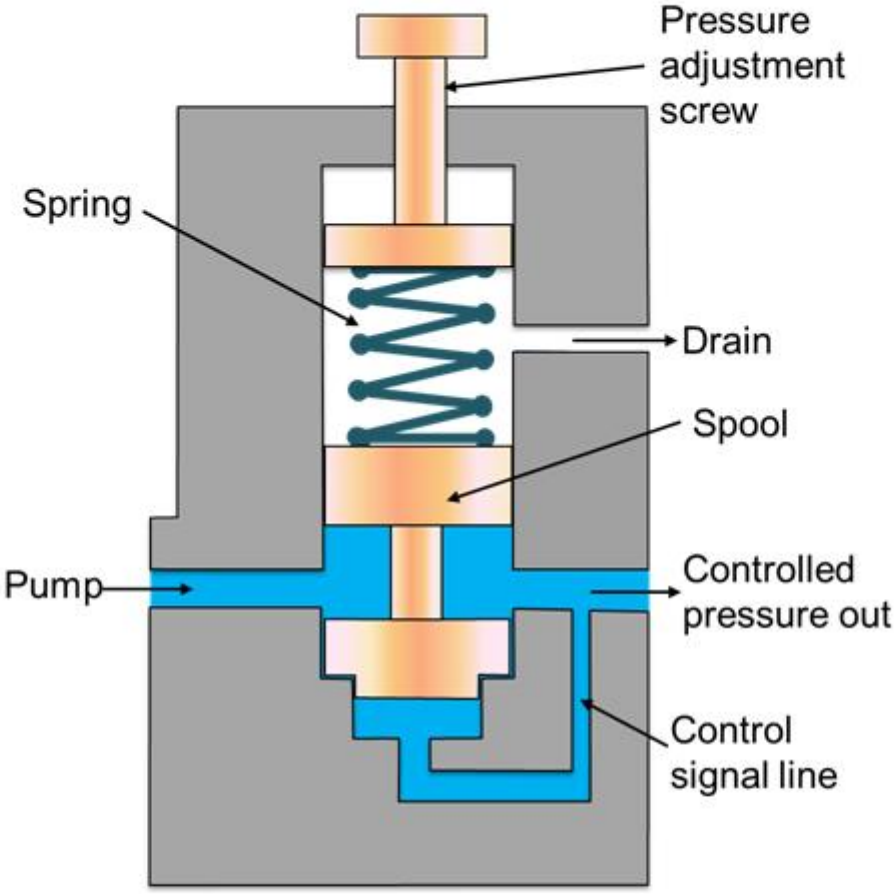


Fig-6: Pressure Reducing Valve

Sometimes a part of the system may need a lower pressure. This can be made possible by using pressure reducing valve as shown in Figure .These valves are used to limit the outlet pressure. Generally, they are used for the operation of branch circuits where the pressure may vary from the main hydraulic pressure lines. These are open type valve and have a spring chamber with an adjustable spring, a movable spool as shown in figure. A drain is provided to return the leaked fluid in the spring (control) chamber. A free flow passage is provided from inlet port to the outlet port until a signal from the outlet port tends to throttle the passage through the valve. The pilot pressure opposes the spring force and when both are balanced, the downstream is controlled at the pressure setting. When the pressure in the reduced pressure line exceeds the valve setting, the spool moves to reduce the flow passage area by compressing the spring. It can be seen from the figure that if the spring force is more, the valve opens wider and if the controlled pressure has greater force, the valves moves towards the spring and throttles the flow.

Safety valve

Safety valve is a valve that act as a protection of equipment from exploding or damaging and it is mainly installed in pressure vessels such as chemical plants, electric power boilers and gas storage tanks.

Safety Valve is a type of valve that automatically actuates when the pressure of inlet side of the valve increases to a predetermined pressure, to open the valve disc and discharge the fluid (steam or gas) ; and when the pressure decreases to the prescribed value, to close the valve disc again. Safety valve is so-called a final safety device which controls the pressure and discharges certain amount of fluid by itself without any electric power support.

Functions of Safety Valve

1. Nozzle" inside the Safety Valve starts to receive a higher pressure from the inlet side of the valve.
2. When the pressure becomes higher than the set pressure, "Disc" starts to lift and discharge the fluid.
3. When the pressure decreases until the predetermined pressure, the force of the spring closes "Disc".

(Role of the spare parts)
Nozzle --- Pressure Entrance
Disc ----- Lid
Spring --- Pressure Controller

Components of the Safety Valve

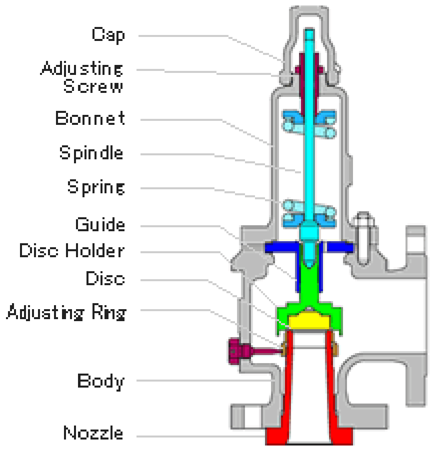


Fig-7: Components of safety valve

TYPES OF SAFETY VALVE

Spring-loaded Pressure-relief Valves:

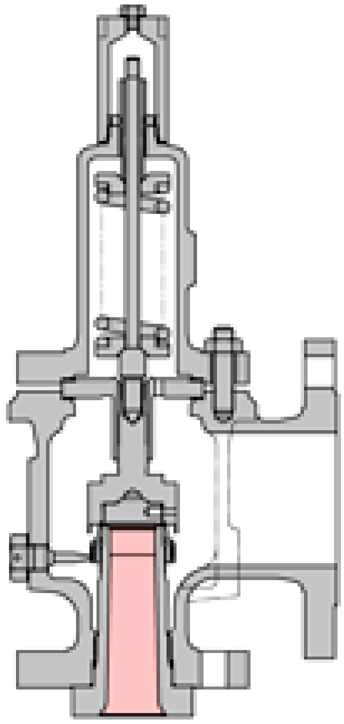


Fig-8: **Spring-loaded Pressure-relief Valves:**

Generally, the safety valve s are referred to the Spring-loaded Pressure-relief valves, the most common type (See the left figure). The load of the spring is designed to press the "Disc" against the inlet pressure. Depending on the fluid type, such as steam, gas or liquid, we are offering a Bellows model to clear the back pressure effect.

Pilot-operated Pressure-relief Valves

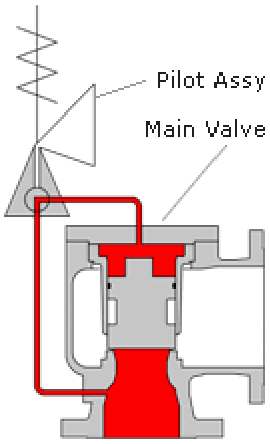


Fig-9: Pilot-operated Pressure-relief Valves

Pilot-operated Pressure-relief Valves are composed of Pilot Assay and Main Valve. Although Spring-loaded Pressure-relief valves adopts the force of the spring against the inlet pressure, the reliving pressure and reseating pressure of the Pilot-operated Pressure-relief Valves is controlled by Pilot Assy, which acts nearly as same as Spring-loaded Pressure-relief valves. There is no adjusting function in the Main Valve. Pilot-operated Pressure-relief Valves have larger size variations compared to Spring-loaded type, which is applied in a severe condition such as high pressure.

Dead-Weight Pressure-relief Valves:

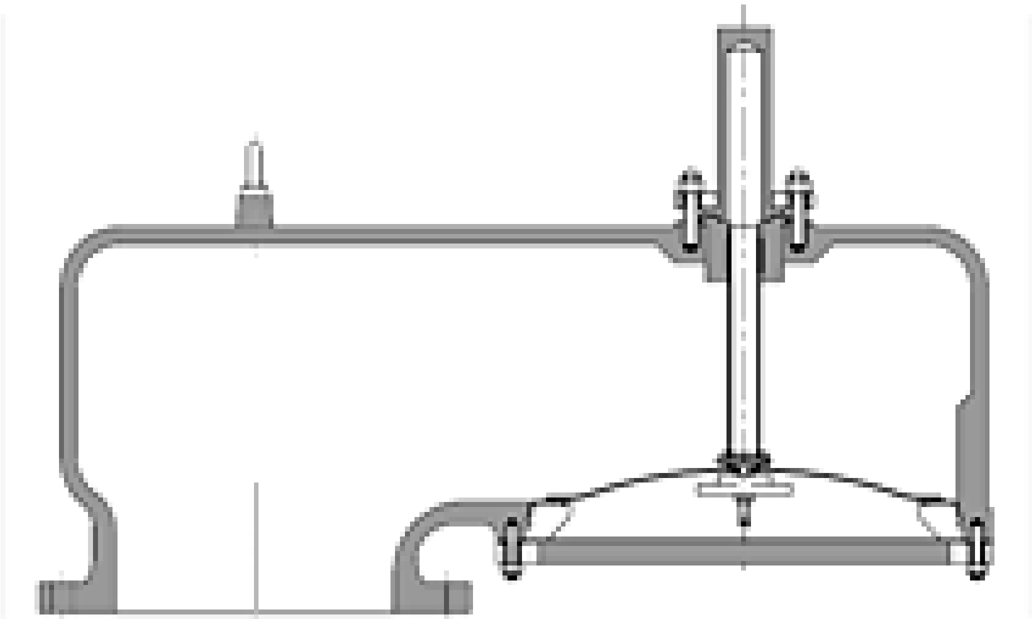


Fig-10: Dead-Weight Pressure-relief Valves:

In case the design pressure of the pressure vessel is set at very low pressure, Dead-weight Pressure-relief valve adjusts relieving pressure only by the disc weight. The Vacuum relief valve has been adopting this functional characteristic which absorbs the pressure when the inside of the pressure vessel falls into a negative pressure.

Safety Relief Valves

Introduction

Safety relief devices remain closed during normal service operation & have been designed to automatically release a certain gas flow out of the pressurized line through the safety relief valve, as soon as the pressure within the section to be protected will have risen to the preset pressure, safety relief valve gets opened.

Safety relief valve closes automatically as soon as the pressure decreases below the set limit.

Principle:

The pressure is relieved by allowing the pressurised fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits.

The most common causes of safety relief valve overpressure are:

- Blocked discharge
- Exposure to external fire, often referred to as "Fire Case"
- Thermal expansion
- Chemical reaction
- Heat exchanger tube rupture

Applications for safety relief valves:

Safety relief valves are used in numerous industries and industrial applications where, for example, gases pass through pipelines or where special process vessels have to be filled with gas at a certain pressure.

These include, among other things:

- Pipeline, plant and container construction
- Industrial furnace construction
- Insulators and reactors (e.g. "glovebox" systems)
- hydrogen-powered vehicles
- Additive manufacturing (3D printer)

Pilot-operated Relief Valve Principle:

Pilot operated relief valves (PORV) are used for emergency relief during overpressure events (e.g., a tank gets too hot and the expanding fluid increases the pressure to dangerous levels).

The difference between PORV and conventional PRV is that pilot valves use system pressure to seal the valve. A PRV typically uses a spring to hold the disc or piston on seat. The essential parts of a PORV are a pilot valve (or control pilot), a main valve, a pilot tube, the dome, a disc or piston, and a seat. The volume above the piston is called the dome.

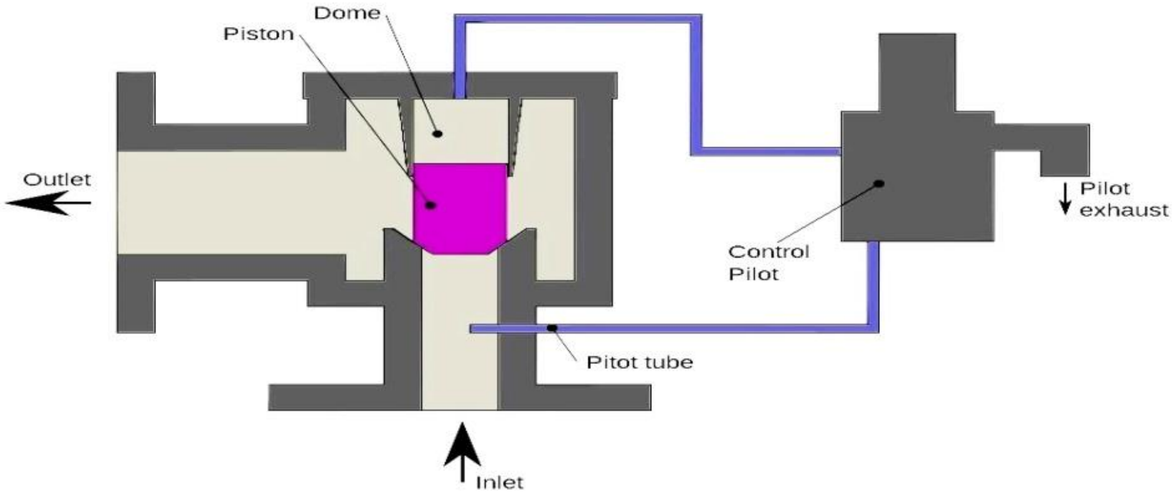


Fig-11: Pilot-operated Relief Valve

PORV are also called pilot-operated safety valve (POSV), pilot-operated pressure relief valve (POPRV), or pilot-operated safety relief valve (POSRV), depending on the manufacturer and the application.

Technically POPRV is the most generic term, but PORV is often used generically (as in this article) even though it should refer to valves in liquid service.

Functioning:

The pressure is supplied from the upstream side (the system being protected) to the dome often by a small pilot tube. The downstream side is the pipe or open air where the PORV directs its exhaust. The outlet pipe is typically larger than the inlet.

The upstream pressure tries to push the piston open but it is opposed by that same pressure because the pressure is routed around to the dome above the piston. The area of the piston on which fluid force is acting is larger in the dome than it is on the upstream side; the result is a larger force on the dome side than the upstream side. This produces a net sealing force.

The pressure from the pilot tube to the dome is routed through the actual control pilot valve. There are many designs but the control pilot is essentially a conventional PRV with the special job of controlling pressure to the main valve dome.

The pressure at which the control pilot relieves at is the functional set pressure of the PORV. When the pilot valve reaches set pressure it opens and releases the pressure from the dome. The piston is then free to open and the main valve exhausts the system fluid. The control pilot opens either to the main valve exhaust pipe or to atmosphere.

Snap acting:

At set pressure the valve snaps to full lift, it can be quite violent on large pipes with significant pressure. The pressure has to drop below the set pressure in order for the piston to reseat (see blowdown in relief valve)

Modulating

The pilot is designed to open gradually, so that less of the system fluid is lost during each relief event. The piston lifts in proportion to the over-pressure. Blowdown is typically short.

Advantages:

- Smaller package on the larger pipe sizes.
- More options for control.
- Seals more tightly as the system pressure approaches but does not reach set pressure.
- Control pilot can be mounted remotely.
- Some designs allow for changes in orifice size within the main valve.
- can be used in engines

Disadvantages

- More complex, resulting in various fail-open failure modes.
- More expensive at smaller sizes (starts to even out as pipe size increases).
- Small parts in pilot valve are sensitive to contaminant particles.

Example Problems

1. A pressure-relief valve has a pressure setting of 200 bar. Determine the power loss across the valve if all the pump flow of 120 L/min flows back to the reservoir through this valve.

   Solution: Pump flow Q = 120 L/min = 2 L/s = 0.002 3 m /s Pressure setting of the valve = 200 bar = 200 × 5 10 N/ 2 m Therefore, the power loss across the pressure-relief valve is 5 200 10 0.002 1000 × × = 40 kW

2. A pressure-relief valve has a pressure setting of 140 bar. Compute the kW loss across this valve if it returns all the flow back to the tank from a 0.0016 3 m / s pump.

Solution: We have

kW power=PQ

= (140 *10^5) (0.0016 *10 ^-3)

=22.4 kW

Bourdon Tube

Bourdon Tubes are known for its very high range of differential pressure measurement in the range of almost 100,000 psi (700 MPa). It is an elastic type pressure transducer.

The device was invented by Eugene Bourdon in the year 1849. The basic idea behind the device is that, cross-sectional tubing when deformed in any way will tend to regain its circular form under the action of pressure. The bourdon pressure gauges used today have a slight elliptical cross-section and the tube is generally bent into a C-shape or arc length of about 27 degrees. The detailed diagram of the bourdon tube is shown below.

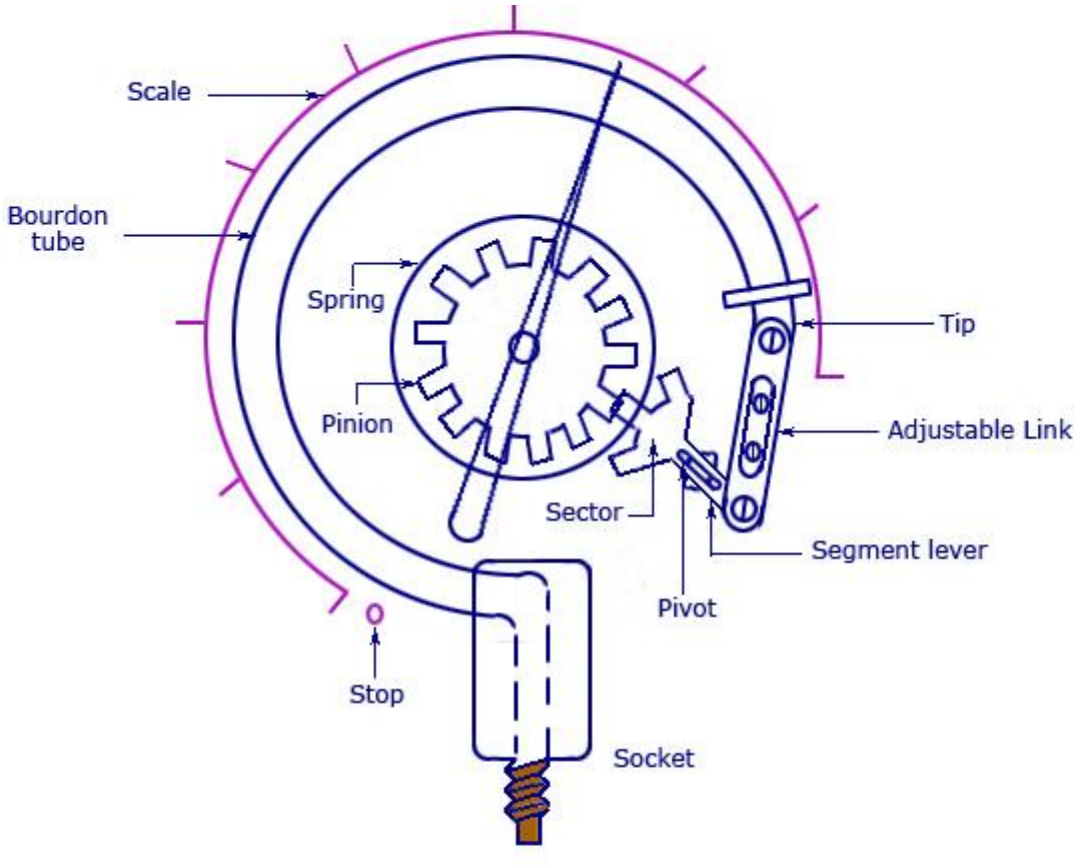


Fig-12: Bourdon Tube Pressure Gauge

As seen in the figure, the pressure input is given to a socket which is soldered to the tube at the base. The other end or free end of the device is sealed by a tip. This tip is connected to a segmental lever through an adjustable length link. The lever length may also be adjustable. The segmental lever is suitably pivoted and the spindle holds the pointer as shown in the figure. A hair spring is sometimes used to fasten the spindle of the frame of the instrument to provide necessary tension for proper meshing of the gear teeth and thereby freeing the system from the backlash. Any error due to friction in the spindle bearings is known as lost motion. The mechanical construction has to be highly accurate in the case of a Bourdon Tube Gauge. If we consider a cross-section of the tube, its outer edge will have a larger surface than the inner portion. The tube walls will have a thickness between 0.01 and 0.05 inches.

Working:

As the fluid pressure enters the bourdon tube, it tries to be reformed and because of a free tip available, this action causes the tip to travel in free space and the tube unwinds. The simultaneous actions of bending and tension due to the internal pressure make a non-linear movement of the free tip. This travel is suitable guided and amplified for the measurement of the internal pressure. But the main requirement of the device is that whenever the same pressure is applied, the movement of the tip should be the same and on withdrawal of the pressure the tip should return to the initial point.

A lot of compound stresses originate in the tube as soon as the pressure is applied. This makes the travel of the tip to be non-linear in nature. If the tip travel is considerably small, the stresses can be considered to produce a linear motion that is parallel to the axis of the link. The small linear tip movement is matched with a rotational pointer movement. This is known as multiplication, which can be adjusted by adjusting the length of the lever. For the same amount of tip travel, a shorter lever gives larger rotation. The approximately linear motion of the tip when converted to a circular motion with the link-lever and pinion attachment, a one-to-one correspondence between them may not occur and distortion results. This is known as angularity which can be minimized by adjusting the length of the link.

Other than C-type, bourdon gauges can also be constructed in the form of a helix or a spiral. The types are varied for specific uses and space accommodations, for better linearity and larger sensitivity. For thorough repeatability, the bourdon tubes materials must have good elastic or spring characteristics. The surrounding in which the process is carried out is also important as corrosive atmosphere or fluid would require a material which is corrosion proof. The commonly used materials are phosphor-bronze, silicon-bronze, beryllium-copper, inconel, and other C-Cr-Ni-Mo alloys, and so on.

In the case of forming processes, empirical relations are known to choose the tube size, shape and thickness and the radius of the C-tube. Because of the internal pressure, the near elliptic or rather the flattened section of the tube tries to expand as shown by the dotted line in the figure below (a). The same expansion lengthwise is shown in figure (b). The arrangement of the tube, however forces an expansion on the outer surface and a compression on the inner surface, thus allowing the tube to unwind. This is shown in figure (c).

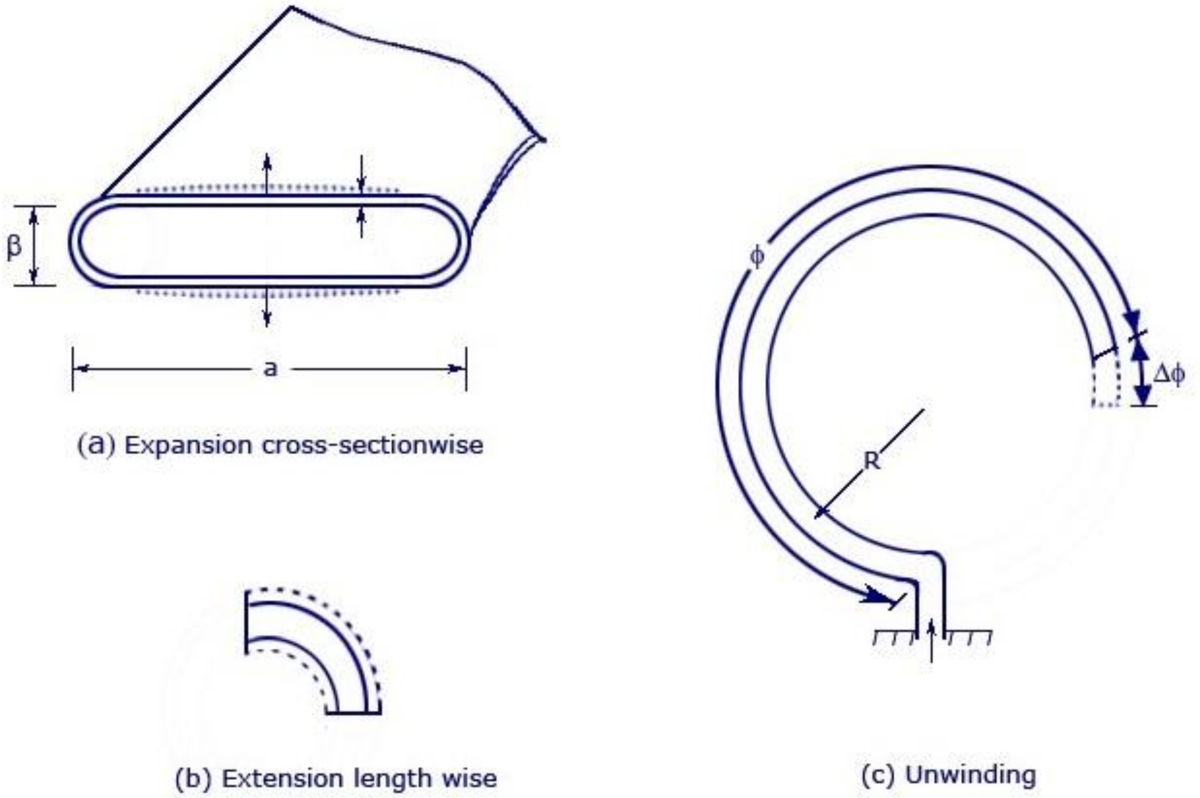


Fig-13: Expansion of Bourdon Tube Due to Internal Pressure

Like all elastic elements a bourdon tube also has some hysteresis in a given pressure cycle. By proper choice of material and its heat treatment, this may be kept to within 0.1 and 0.5 percent of the maximum pressure cycle. Sensitivity of the tip movement of a bourdon element without restraint can be as high as 0.01 percent of full range pressure reducing to 0.1 percent with restraint at the central pivot.

Advantages of Bourdon tube pressure gauge: These Bourdon tube pressure gauges give accurate results. Bourdon tube cost low. Bourdon tube are simple in construction. They can be modified to give electrical outputs. They are safe even for high pressure measurement. Accuracy is high especially at high pressures. Advantages of Bourdon tube pressure gauge: These Bourdon tube pressure gauges give accurate results. Bourdon tube cost low. Bourdon tube are simple in construction. They can be modified to give electrical outputs. They are safe even for high pressure measurement. Accuracy is high especially at high pressures.

Air Purge Method (Bubbler Level Measurement)

Air purge method is used for level measurement. It is also known as bubbler method. This is one of the most popular method for hydrostatic liquid level measuring system. which is suitable for any type of liquid level. The Bubbler System is an inexpensive but accurate means of measuring the fluid level in open or vented containers, especially those in harsh environments such as cooling tower sumps, swimming pools, reservoirs.

The system consists of a source of compressed air, air flow restrictor, sensing tube and pressure transmitter. The only component of the Bubbler System that is exposed to the elements is the sensing tube.

Construction

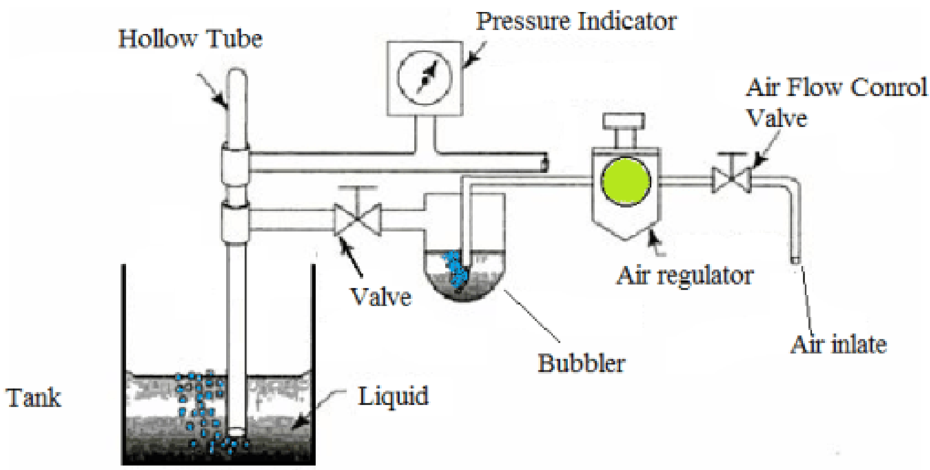


Fig-14: Air Purge method.

It is consist of a hollow tube which is inserted in the liquid of the tank. Two connection are made with the bubbler tube one to the pressure gauge and another to the regulated air supply, calibrated in terms of liquid level. a bubbler is connected in the series with air supply line which simply as a visual check to the flow of the supply of the air. A level recorder may be connected with the pressure gauge to keep continues record of liquid level as shown in fig.14

Working

When there is no liquid in the tank or the liquid in the tank is below the bottom end of the bubbler tube and the pressure gauge indicates zero. In other words, if there is no back pressure because the air escapes to the atmosphere. As the liquid level in the tank increases, the air flow is restricted by the depth of liquid and the air pressure acting against liquid head appears as back pressure to the pressure gauge.

This back pressure causes the pointer to move on a scale, calibrated in terms of liquid level. The full range of head pressure can be registered as level by keeping the air pressure fed to the tube, slightly above the maximum head in the tank. The range of the device is determined by the length of the tube. Because air is continuously bubbling from the bottom of the tube, the tank liquid does not enter the bubbler tube and hence the tube is said to be purging.

The common purging fluid is air, but, if air reacts with the tank fluid or is absorbed, different gases are chosen depending on the liquid properties.

Applications:

- can be used to measure the level of the wet well to control the intake pumps.
- can be a retrofit replacement for ultrasonic level transmitters.
- To Measure Specific Gravity.
- To measure tank level.

Advantages:

- The purge gas (compressed air) provides complete isolation from the measured liquid.
- Minimal Maintenance when an Auto Blow Down system for the dip tube is purchased and integrated with the Level Bubbler.
- The instrument panel can be located up to several hundred feet from what is being measured.
- They are very cost effective.
- It is most suitable for measuring the corrosive or abrasive liquid.
- Design and construction is very simple.
- Pressure gauge can be placed above or below the tank level and can be kept as far away as 50 ft (12.7m) from the tank with the help of piping.

Disadvantages:

- They are not considered appropriate for use in non-vented vessels.
- Their calibration gets changed according to variations in product density.
- Require compressed air.

What is Feedback Control System?

Before beginning the discussion on PID controllers, let us define a few key terms.

- **The process**: It is the system to be controlled
- **The process variable**: It is the quantity to be measured and controlled

- **Sensor or transmitter**: It is a device that measures process variable
- **The Controller**: It decides the control variable in order to bring the process variable as close as to the set point.
- **Final Control Element**: It is a device that directly manipulates the manipulating variable to control over the process.
- **Manipulating Variable**: It is the quantity which can be directly altered to control over the process variable.

What is PID Controller?

A PID controller is a three-term controller that has proportional, integral and derivative control coefficients. It is named after its three correcting terms and its sum produce a control action for manipulating variable.

It measures the output of a process and controls the input by maintaining the output at a desired value (also called as set point). The most common example of PID controller is controlling temperature in many industrial applications.

In the above example if we use a PID algorithm as a controller for whole process, then we can call it as a PID control system. A PID controller can be implemented by analog circuitry or by microprocessor technology.

SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS & INSTRUMENTATION ENGINEERING

UNIT – III – Process Control System Components – SIC1406

CONTROL VALVES:

Control valves automatically regulate pressure and/or flow rate, and are available for any pressure. If different plant systems operate up to, and at pressure/temperature combinations that require Class 300 valves, sometimes (where the design permits), all control valves chosen will be Class 300 for interchange-ability. However, if none of the systems exceeds the ratings for Class 150 valves, this is not necessary.

Necessity:

Process plants consist of hundreds, or even thousands, of control loops all networked together to produce a product to be offered for sale. Each of these control loops is designed to keep some important process variable such as pressure, flow, level, temperature, etc. within a required operating range to ensure the quality of the end product. Each of these loops receives and internally creates disturbances that detrimentally affect the process variable, and interaction from other loops in the network provides disturbances that influence the process variable.

To reduce the effect of these load disturbances, sensors and transmitters collect information about the process variable and its relationship to some desired set point. A controller then processes this information and decides what must be done to get the process variable back to where it should be after a load disturbance occurs. When all the measuring, comparing, and calculating are done, some type of final control element must implement the strategy selected by the controller.

Introduction:

The control valve is a controlled device that regulates the flow of a liquid or gas in a system. This regulation is accomplished by the varying resistance that the valve introduces into the system as the valve is stroked. As the valve modulates to the closed position the system pressure drop shifts to the valve and reduces the flow in the system.

Principles of Operation:

A control valve is comprised of an actuator mounted to a valve. The valve modulates flow through movement of a valve plug in relation to the port(s) located within the valve body. The valve plug is attached to a valve stem, which, in turn, is connected to the actuator. The actuator, which can be pneumatically or electrically operated, directs the movement of the stem as dictated by the external control device.

1. Pneumatic/Diaphragm Actuated:

Pneumatic Actuators are direct acting and utilize an air signal from an external control device to create a modulating control action. The force of the air signal is received into the actuator through a top port and distributed across the full area of the actuator's diaphragm. The diaphragm presses down on the diaphragm plate and spring return assembly, which then moves the valve stem and plug assembly downward to stroke the valve.

2. Electric Actuated:

Electric Actuators are motor driven devices that utilize an electrical input signal to generate a motor shaft rotation. This rotation is, in turn, translated by the unit's linkage into a linear motion, which drives the valve stem and plug assembly for flow modulation.

The valve is very important to the operation of the system. Without a properly sized valve the system will never operate at an efficient level.

Control valves contain four basic sections:

• Body:

The Body contains the orifice and is the main housing through which the controlled fluid flows.

• Trim:

The Trim is the part of the valve excluding the body that comes in contact with the fluid. It is composed of the valve seat, plug, disc and disc holder, and stem.

• Bonnet:

The Bonnet is an assembly that provides a mounting for the actuator and a guide through which the stem must pass. It is composed of the centerpiece, packing, packing guide, and packing nut. The packing provides a seal between the stem and bonnet to prevent leakage.

• Actuator:

The Actuator consists of either pneumatic or electric means to provide the force to stroke the valve. The control valve is the most widely used type of final element. Other types of final control elements are dampers or louvers, and variable pitch fan blades.

Final Control Element:

A final control element is defined as a mechanical device that physically changes a process in response to a change in the control system setpoint. Final control elements relevant to actuators include valves, dampers, fluid couplings, gates, and burner tilts to name a few. Final control elements are an essential part of process control systems, allowing an operator to achieve a desired process variable output by manipulating a process variable setpoint.

Valve characteristics

The cage of a valve can have different shapes of holes. The different shapes can control the flow in different characteristics. There are three main types of control characteristics. They are:

- Linear
- Equal percentage
- Quick opening

Linear valve characteristics:

This characteristic provides a linear relationship between the valve position and the flowrate. The flow through a linear valve varies directly with the position of the valve stem. This flow- travel relationship, if plotted on rectilinear coordinates, approximates a straight line, thereby giving equal volume changes for equal lift changes regardless of percent of valve opening.

These valves are often used for liquid level control and certain flow control operations requiring constant gain.

Equal percentage valve characteristics:

The equal percentage valve plug produces the same percentage change in flow per fixed increment of valve stroke at any location on its characteristic curve.

For example, if 30% stem lift produces 5 gpm and a lift increase of 10% to 40% produces 8 gpm or a 60% increase over the previous 5 gpm, then a further stroke of 10% now produces a 60% increase over the previous 8 gpm for a total flow of 12.8 gpm. These types of valves are commonly used for pressure control applications and are most suitable for applications where a high variation in pressure drop is expected.

Quick opening valve characteristics:

A quick opening valve plug produces a large increase in flow for a small initial change in stem travel. Near maximum flow is reached at a relatively low percentage of maximum stem lift. Quick opening plugs are normally utilized in two position "On-Off" applications but may be used in some linear valve applications. This is possible because of its initial linear characteristic at a low percentage of stem travel.

The slope of this linear region is very steep which produces a higher initial gain than the linear plug but also increases the potential instability of the control valve.

Inherent valve characteristics:

An inherent flow characteristic is the relation between valve opening and flow under constant pressure conditions. The inherent characteristic of a valve is obtained when there is a constant pressure drop across the valve for all valve positions; the process fluid is not flashing, cavitating or approaching sonic velocity (choked flow); and the actuator is linear (valve stem travel is proportional to the controller output).

Some valves have inherent characteristics that cannot be changed, such as full port ball valves and butterfly valves. For other valve types, such as the globe type, the inherent characteristics can be changed to suit the application.

Installed flow characteristic:

When valves are installed with pumps, piping and fittings, and other process equipment, the pressure drop across the valve will vary as the valve travel changes.

When the actual flow in a system is plotted against valve opening, the curve is called the installed flow characteristic and it will differ from the inherent valve characteristic which assumed constant pressure drop across the valve. When in service, a linear valve will in general resemble a quick opening valve while an equal percentage valve will in general resemble a linear valve.

General rules:

How do you decide which valve control to use? Here are some rules of thumb:

Linear Characteristics:

- Used in liquid level or flow loops.
- Used in systems where the pressure drop across the valve is expected to remain fairly constant (i.e. steady state systems).
- Used when the pressure drop across the valve is a large proportion of the total pressure drop.

Equal Percentage Characteristics:

- Used in processes where large changes in pressure drop are expected.
- Used in processes where a small percentage of the total pressure drop is permitted by the valve.
- Used in temperature and pressure control loops.

Quick Opening Characteristics:

- Used for frequent on-off service.
- Used for processes where "instantly" large flow is needed (i.e. safety systems or cooling water systems).

Two rules of thumb for choosing the right flow characteristic:

1. If most of the pressure drop is taken through the valve and the upstream pressure is constant, a linear characteristic will provide better control.

2. If the piping and downstream equipment cause significant resistance to the system, equal percentage will provide better control.

Typical applications:

General applications of of quick opening, linear and equal percentage valves are :

i) Quick opening valve:

a) Frequent on-off service.

b) Used for systems where 'instant' large flow is needed (safety or cooling water systems).

ii) Linear valve:

a) Liquid level and flow control loops.

b) Used in systems where the pressure drop across the valve is expected to remain fairly constant.

iii) Equal percentage valve (most commonly used in valves):

a) Temperature and pressure control loops.

b) Used in systems where large changes in pressure drop across the valve are expected.

BASIC VALVE TYPES:

- Valves are available with a wide variety of valve bodies in various styles, materials, connections and sizes.
- Selection is primarily dependent on the service conditions, the task, and the load characteristics of the application.
- The most common types are ball valves, butterfly valves, globe valves, and gate valves.

Ball Valves:

- Ball valves are a quick opening valves that give a tight shutoff.
- When fully open, a ball valve creates little turbulence or resistance to flow. The valve stem rotates a ball which contains an opening.
- The ball opening can be positioned in the fully open or fully closed position but must not be used to throttle flow as any abrasive wear to the ball will cause leakage when the valve is closed.

- Ball valves are considered high recovery valves, having a low pressure drop and relatively high flow capacity.

Fig-1: Ball Valves

Best Suited Control:

Quick opening, linear

Recommended Uses:

• Fully open/closed, limited-throttling

• Higher temperature fluids.

Applications:

• Ball valves are excellent in chemical applications, including the most challenging services (e.g. dry chlorine, hydrofluoric acid, oxygen). • General sizes available are 1/2" to 12".

• Compliant with ASME is the flange rating, either 150, 300, 600, 900# or occasionally higher classes, enabling high performance ball valves to withstand up to 2250 psi.

• The operating temperature which is primarily dependent on seats and seals may be rated as high as 550°F.

• Standard valves comply with ASME face-to-face dimensions, making the ball valv easy to retrofit and replace.

Butterfly Valves:

- Butterfly valves consist of a disc attached to a shaft with bearings used to facilitate rotation.
- These are considered high recovery valves, since only the disc obstructs the valve flow path.
- The flow capacity is relatively high and the pressure drop across the valve is relatively low.
- The butterfly valves are used for limited throttling where a tight shut off is not required.
- When fully open, the butterfly creates little turbulence or resistance to flow.

Fig-2: Butterfly valve.

Best Suited Control: Linear, Equal percentage

Recommended Uses:

• Fully open/closed or throttling services

• Frequent operation

• Minimal fluid trapping in line

• Applications where small pressure drop is desired

Applications:

• Most economical for large lines in chemical services, water treatment, and fire protection systems. General sizes available are 2" to 48", although sizes up to 96" are available from certain manufacturers.

• Due to the valve design, incorporating a small face-to-face dimension and lower weight than most valve types, the butterfly valve is an economical choice for larger line sizes (i.e. 8" and above).

• The butterfly valve complies with ASME face-to-face dimensions and pressure ratings. This enables the valve to be easily retrofitted in line regardless of the manufacturer

• The ASME pressure classes adhered to by most manufacturers include 150, 300 and 600# allowing a maximum pressure of 1500 psi.

GLOBE VALVE:

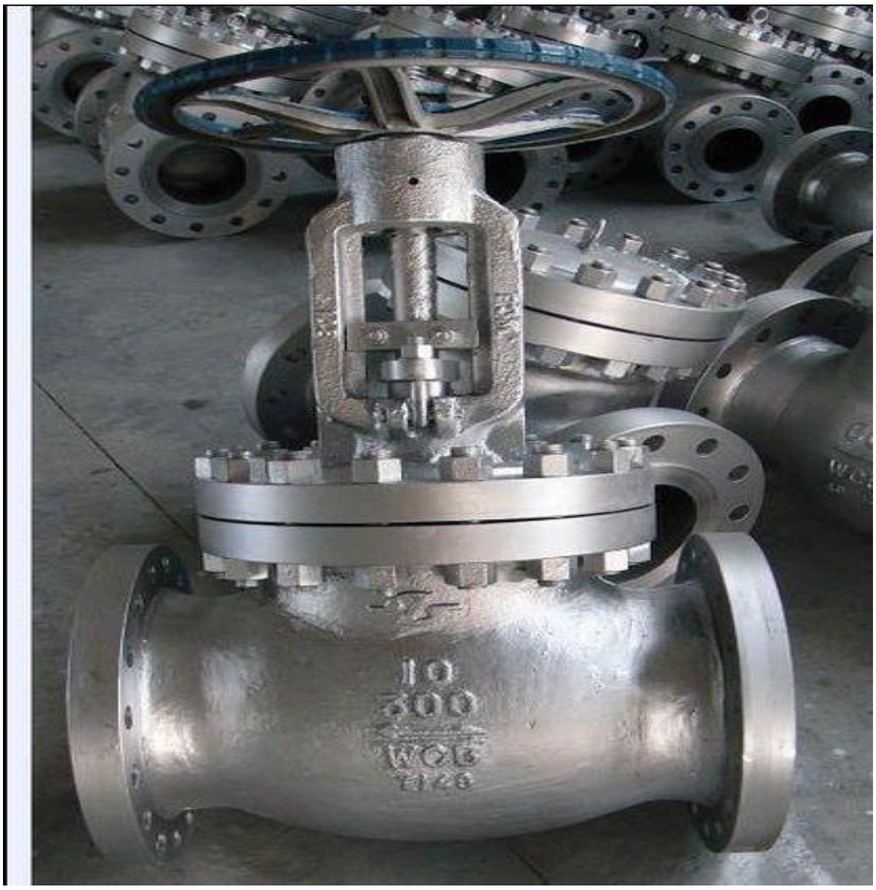


Fig-3: Globe Valve

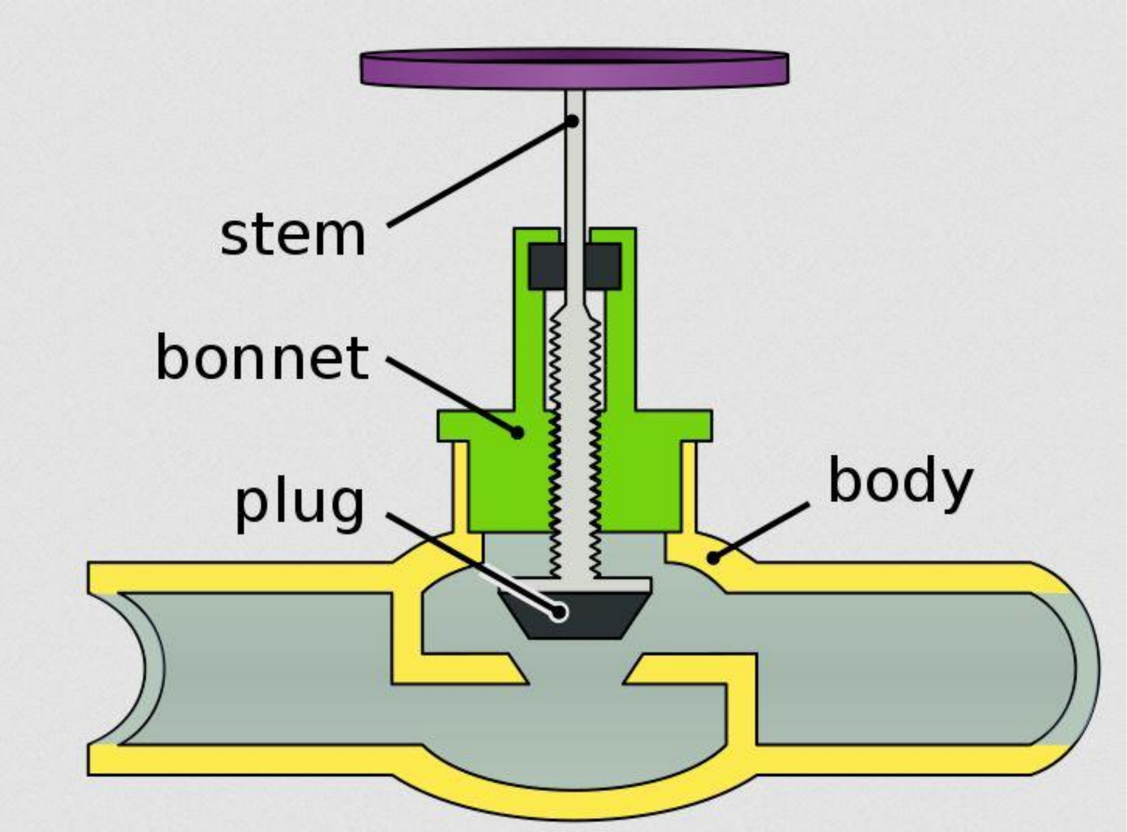


Fig-4: Schematic view of Globe valve

GATE VALVE:

- A gate valve, also known as a sluice valve, is a valve that opens by lifting a barrier (gate) out of the path of the fluid.
- Gate valves require very little space along the pipe axis and hardly restrict the flow of fluid when the gate is fully opened.
- The gate faces can be parallel but are most commonly wedge-shaped (in order to be able to apply pressure on the sealing surface).

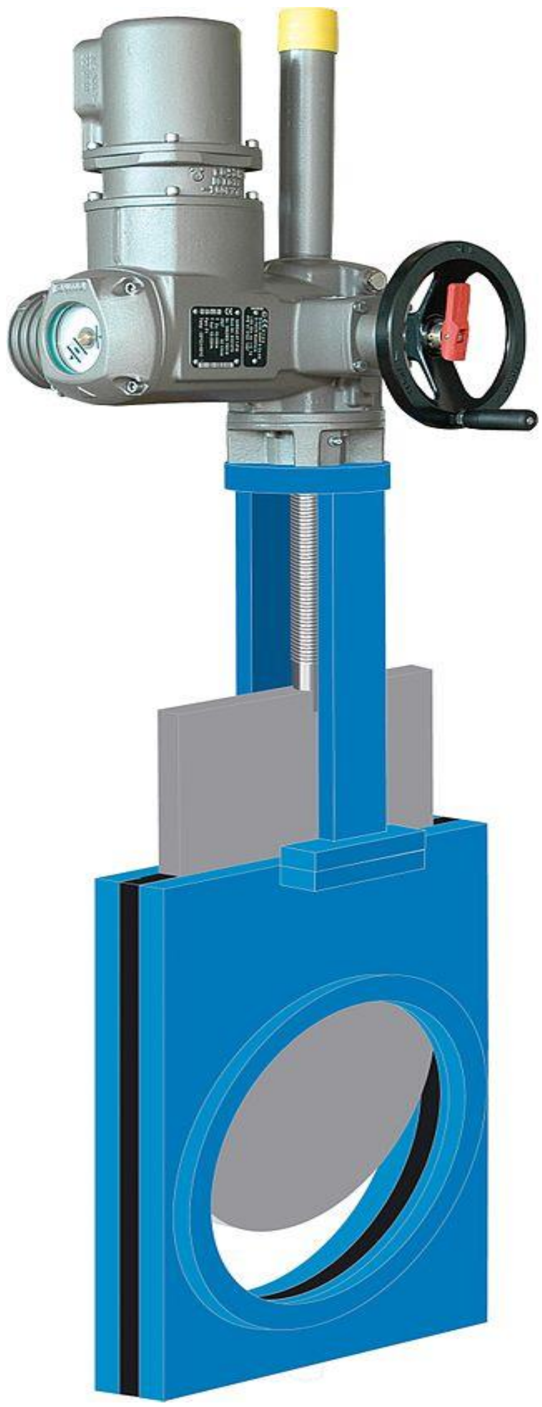


Fig-5: Schematic view of GATE VALVE

CONTROL VALVE SIZING:

- Another important factor associated with all control valves involves corrections to Equation below because of the non-ideal characteristics of the materials that flow.
- A standard nomenclature is used to account for these corrections, depending on the liquid, gas, or steam nature of the fluid.
- These correction factors allow selection of the proper size of valve to accommodate the rate of flow that the system must support.

- The correction factor most commonly used at present is measured as the number of U.S. gallons of water per minute that flow through a fully open valve with a pressure differential of 1 lb per square inch.
- The correction factor is called the valve flow coefficient and is designated as C_v. Using this factor, a liquid flow rate in U.S. gallons per minute is

$$Q = C_v \sqrt{\frac{\Delta p}{S_G}}$$

where Δp = pressure across the valve (psi)
S_G = specific gravity of liquid

Typical values of C_v for different-size valves are shown in Table Similar equations are used for gases and vapors to determine the proper valve size in specific applications.

Control-valve flow coefficients

Valve Size (inches)	C_v
$\frac{1}{4}$	0.3
$\frac{1}{2}$	3
1	14
$1\frac{1}{2}$	35
2	55
3	108
4	174
6	400
8	725

Find (**a**) the proper C_v for a valve that must allow 150 gal of ethyl alcohol per minute with a specific gravity of 0.8 at maximum pressure of 50 psi, and (**b**) the required valve size.

Solution

a. We find the correct sizing factor from

$$Q = C_v\sqrt{\frac{\Delta p}{S_G}}$$

Then

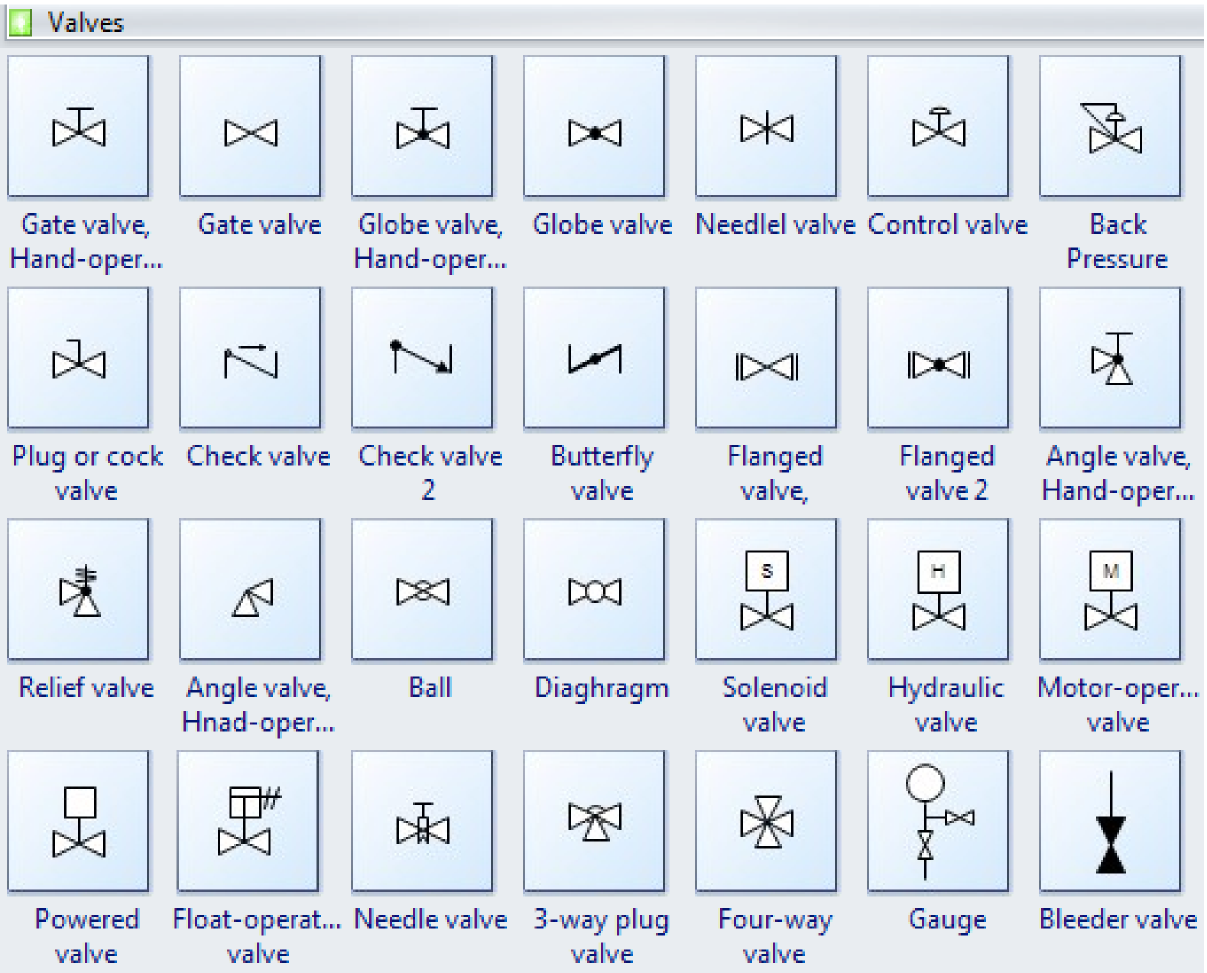
$$C_v = Q\sqrt{\frac{S_G}{\Delta p}}$$

$$C_v = \left(150\,\frac{\text{gal}}{\text{min}}\right)\sqrt{\frac{0.8}{50\ \text{lb/in.}^2}}$$

$$C_v = \mathbf{18.97}$$

b. A $1\frac{1}{2}$-in.-diameter valve (3.8 cm) is selected from Table

Table-1: Control Valve and associated components



Fluid control Example:

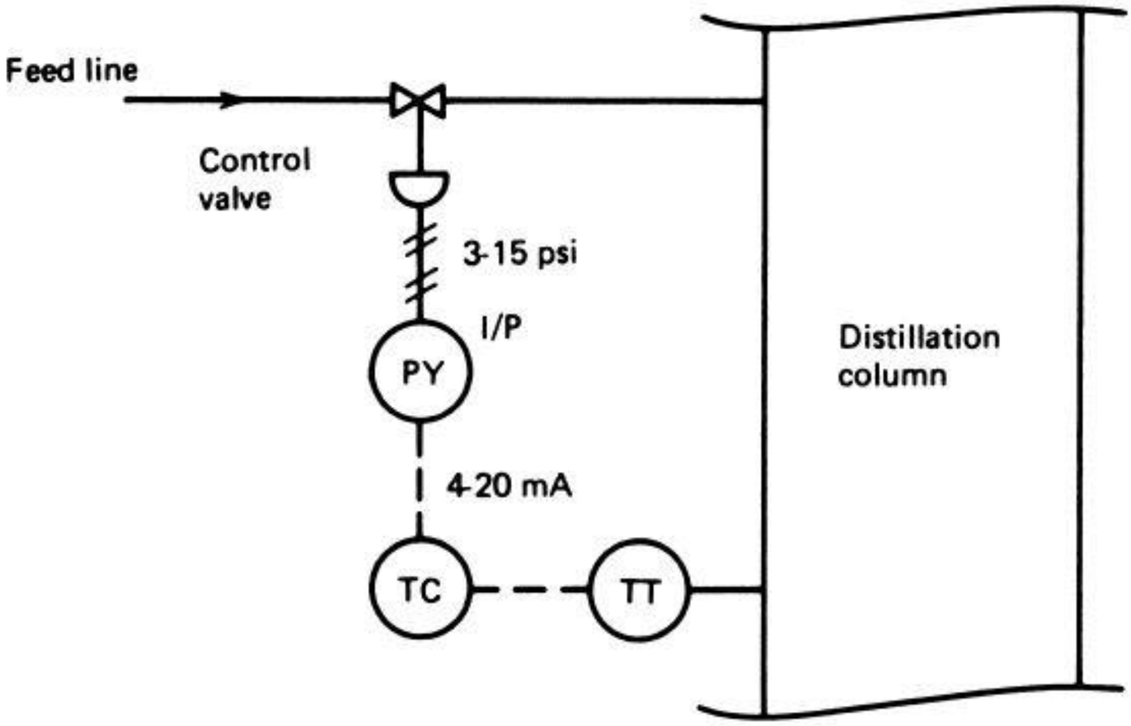


Fig-6: Fluid control example

- The chemical and process-control industry uses fluid control systems extensively. Examples of such applications are many and varied.
- Consider, for example, control of distillation column composition by regulation of a fixed-point column temperature.
- Such regulation is achieved by controlling the feed rate as shown in Figure. A thermocouple measures temperature that is transmitted to the controller as a 4- to 20-mA control signal.
- The controller outputs a 4- to 20-mA signal proportional to proper control-valve position. This is converted to a 3- to 15-psi (20- to 100 kPa) pneumatic signal by an I/P converter that, in turn, operates a pneumatic actuator connected to the control valve.
- The valve size is determined by the characteristics of the gas or vapor that is flowing. The size of the required actuator is determined from the valve size.

CONTROL VALVE SIZING EQUATIONS

In order to determine the correct size of a valve for a specific system, many factors must be considered. The most important factor is the capacity parameter, Cv, or the **flow coefficient**. To determine the valve size needed for your system, you can estimate Cv with the following equations:

Liquids (water, oil, etc.):

Because liquids are incompressible fluids, their flow rate depends only on the difference between the inlet and outlet pressures (ΔP, pressure drop). The flow is the same whether the system pressure is low or high, so long as the difference between the inlet and outlet pressure is the same. The equation below shows the relationship:

$$Cv = Q\sqrt{(S/\Delta P)}$$

Where,

- Cv = Valve flow coefficient, US GPM with P = 1 psi
- Q = Fluid flow, US GPM
- S = Specific gravity of fluid relative to water @ 60F
- ΔP = Pressure drop ($P_1 - P_2$) at maximum flow, psi

Specific gravity correction is negligible for water below 200°F (use S = 1.0). Use actual specific gravity S of other liquids at actual flow temperature. Use the following equation for fluids with viscosity correction factor. Use actual specific gravity S for fluids at actual flow temperature.

$$Cv = K\,Q\,\sqrt{(S/\Delta P)}$$

Where,

- K = Viscosity correction factor for fluids

<u>Estimating diameter of pipe:</u>

Another important piece of information about sizing and specifications is what diameter pipe may be used with a certain flow, seen in the following equation:

$$d = \sqrt{\frac{4\,Q_{max}}{\pi v}}$$

Where:

- d = diameter of pipe (ft.)
- Q_{max} = maximum flow through the valve (ft^3/s)
- v = velocity of flow (ft./s)

Air and Gaseous Flow (natural gas, propane etc.):

Gas flow calculations are slightly more complex because gases are compressible fluids whose density changes with pressure. In addition, there are two conditions that must be considered: low pressure drop flow and high pressure drop flow.

Use the following equation when outlet pressure (P_2) is greater than one half of inlet pressure (P_1).

$$Cv = \frac{Qa\sqrt{G\,(T + 460)}}{1360\sqrt{\Delta P(P_2)}}$$

Use the following equation when outlet pressure (P_2) is less than or equal to ½ of inlet pressure (P_1).

$$Cv = \frac{Qa\sqrt{G\,(T + 460)}}{660\,P_1}$$

Where,

- Cv = Valve flow coefficient, US GPM with P = 1 psi
- Qa = Air or gas flow, standard cubic feet per hour (SCFH) at 14.7 psig and 60F
- T = Flowing air or gas temperature (F)
- ΔP = Pressure drop ($P_1 - P_2$) at maximum flow, psi
- P_2 = Outlet pressure at maximum flow, psia (abs.)
- P_1 = Inlet pressure at maximum flow, psia (abs.)

For Steam (saturated or superheated):

Use the following equation when P2 is greater than ½ P_1

$$Cv = \frac{WK}{2.1\sqrt{\Delta P(P_1 + P_2)}}$$

Use the following equation when P_2 is less than or equal to ½ P_1

$$Cv = \frac{WK}{1.82\,P_1}$$

Where,

- Cv = Valve flow coefficient, US GPM with P = 1 psi

- W = Steam flow, pound per hour (lb. /hr.)
- K = 1 + (0.0007 x F superheat) for steam
- T = Flowing air or gas temperature (F)
- ΔP = Pressure drop ($P_1 - P_2$) at maximum flow, psi
- P_1 = Inlet pressure at maximum flow, psia (abs.)
- P_2 = Outlet pressure at maximum flow, psia (abs.)

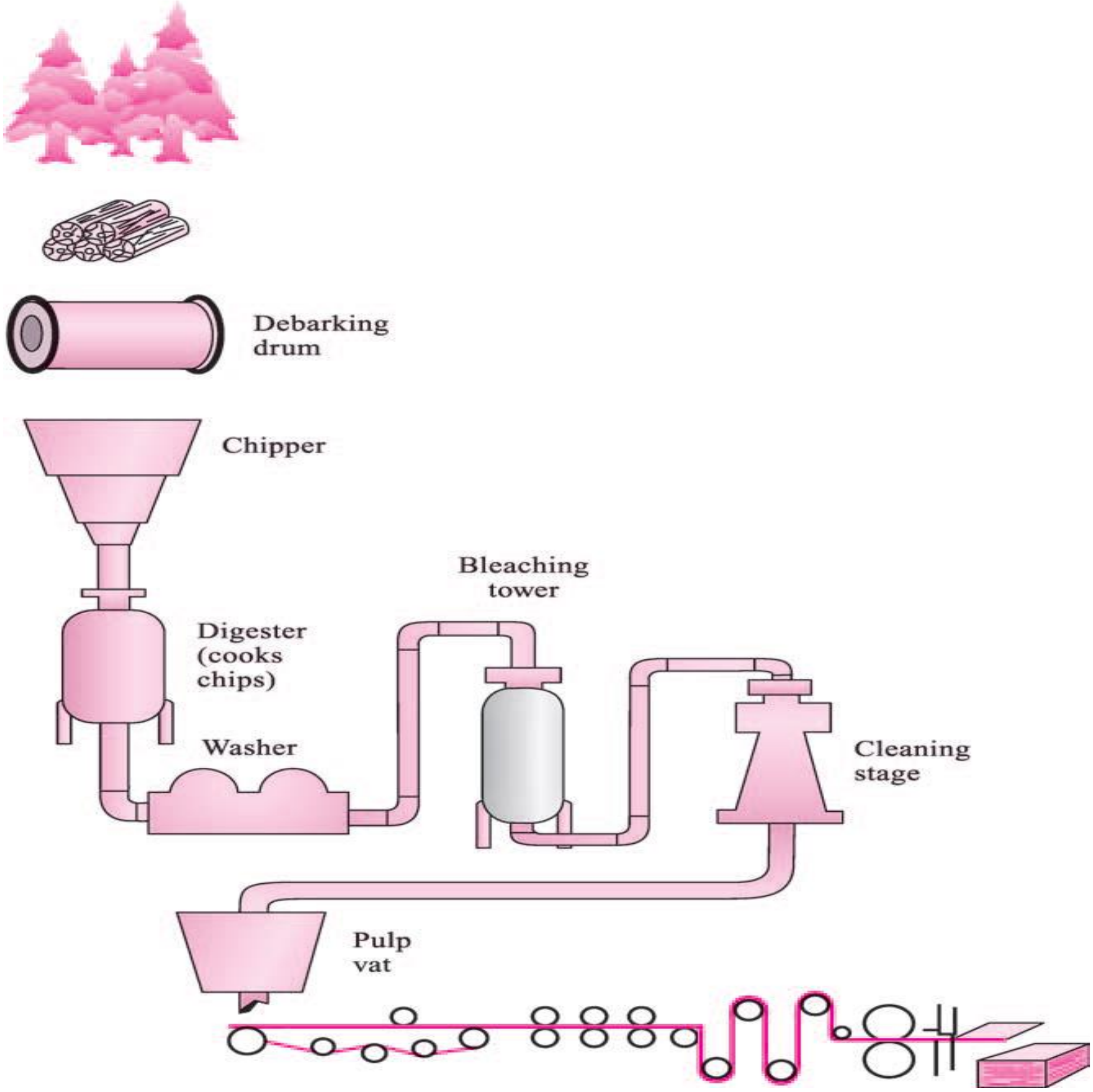


Fig-7: A pulp and paper operation is a process control application

CONTROL VALVE SELECTION CRITERIA:

Frequently several correct choices may be available, thus it is important for customers to provide control valve manufacturers the following information.

- Type of fluid to be controlled.
- Temperature range of fluid.
- Viscosity range of fluid.
- Specific gravity range of fluid.
- Minimum and maximum flow required.
- Minimum and maximum inlet pressure at the control valve.
- Minimum and maximum outlet pressure at the control valve.
- Pressure drop across the valve expected during normal flowing conditions.
- Pressure drop across the valve at zero flow.
- Maximum permissible noise level, if pertinent, and the measurement reference point.
- Degrees of superheat or existence of flashing across the valve, if known.
- Inlet and outlet pipeline size and schedule of pipe.

The following guidelines can be useful in determining if the control valve installed, is suitable for the application.

Flow control processes		
Flow measurement signal to controller	Location of control valve in relation to measuring element	Wide range of flow setpoint
Proportional to flow	In series	Linear
	In bypass	Linear
Proportional to flow squared	In series	Linear
	In bypass	Equal percentage
Small flow range with large changes in pressure drop across the valve	In series	
	In bypass	
Equal percentage characteristics should be used for applications with a small range of flow setpoint, large delta pressure at the valve, and increasing loads. Note: When control valve closes, the flow rate as measured by the sensing element increases.		

Pressure control processes	
Liquid process	Equal percentage
Gas process with small volume and less than 10 ft (3 m) of pipe between control valve and load valve.	Equal percentage
Gas process with large volume (process has a receiver, distribution system, or transmission line exceeding 100 ft (30.5 m) of pipe). As load increases, pressure drop across the valve decreases; and the pressure drop across the valve at maximum load is >20% of the minimum load pressure difference.	Linear
Gas process with large volume. As load increases, pressure drop across the valve decreases; and the pressure drop across the valve at maximum load is &20% of the minimum load pressure difference.	Equal percentage

Level control processes	
Pressure drop across valve increases with load.	Linear
Pressure drop across valve increases greater than 2:1 with load.	Quick opening
Pressure drop across valve decreases with increasing load.	Linear
Pressure drop across valve decreases with increasing load and full load pressure drop is &20% of no-load drop.	Equal percentage

VALVE RANGEABILITY:

VALVE RANGEABILITY

Ratio of the maximum controllable flow to the minimum controllable flow

$$\text{Rangeability} = \frac{\text{Flow at 95\% valve position}}{\text{Flow at 5\% valve position}}$$

Note: 90 & 10 % valve position can be used

If ΔP is independent of flow → Flow proportional to C_v

LINEAR $\text{Rangeability} = 0.95/0.05 = 19$

EQUAL PERCENTAGE $\text{Rangeability} = \alpha^{-0.05}/\alpha^{-0.95}$

QUICK-OPENING $\text{Rangeability} = 3$

VALVE GAIN:

- The gain of a device is defined as the ratio of the change in output to the corresponding change in input.
- In the case of a control valve, the output is the flow in the system (q) and the input is valve position (h).
- A graphical interpretation of the GAIN is the SLOPE of the installed characteristic.

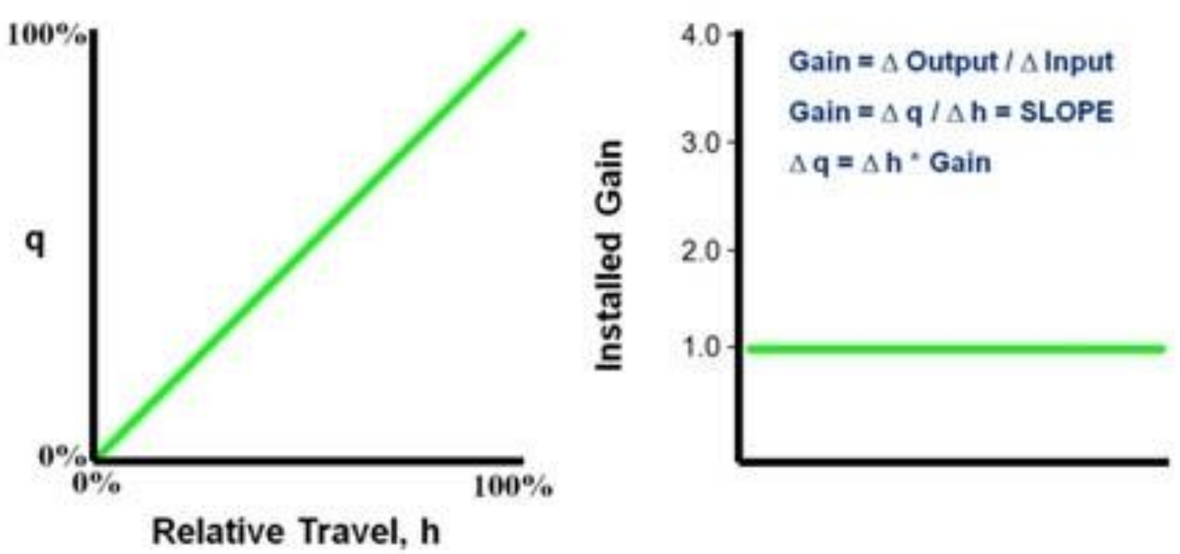


Fig-8: The installed gain of a control valve with an ideal perfectly linear installed characteristic.

- We will never exactly get the ideal installed characteristic and installed gain:
- (1) because real valves do not have exactly linear or equal percentage inherent characteristics, and (2) because the interaction between the equal percentage inherent characteristic and the system characteristic do not exactly cancel each other, but we want to get as close as we can, so the perfectly linear installed characteristic and the constant installed gain of 1.0 are the benchmark we always aim for.

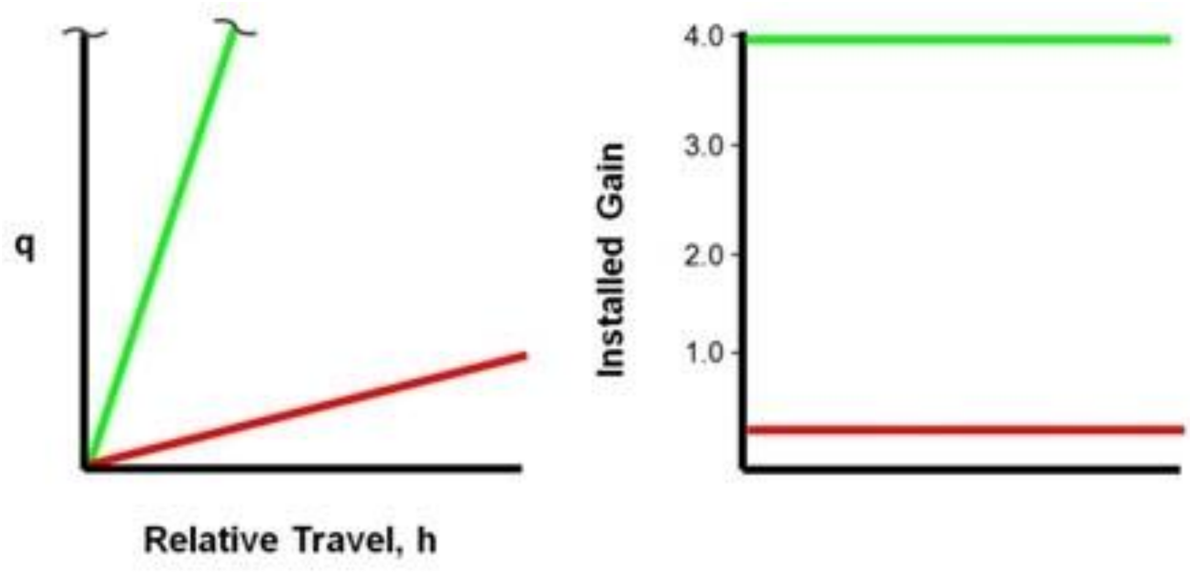


Fig-9: Two valves with straight line installed characteristics. One with a steep slope and a high gain, and one with a shallow slope and a low gain.

CONTROL VALVE POSITIONER:

- Valve positioner is a control device designed to impart sensitivity to the valve and to ensure accurate positioning as dictated by a control signal.
- It receives an electronic or pneumatic signal from a controller and compares that signal to the actuator's position.
- If the signal and the actuator position differ, the positioner sends the necessary power—usually through compressed air—to move the actuator until the correct position is reached.
- A positioner may be used as a signal amplifier or booster.
- It accepts a low pressure air control signal and, by using its own higher pressure input, multiplies this to provide a higher pressure output air signal to the actuator diaphragm, if required, to ensure that the valve reaches the desired position.
- Some positioners incorporate an electro-pneumatic converter so that an electrical input (typically 4 to 20 mA) can be used to control a pneumatic valve.
- Some positioners can also act as basic controllers, accepting input from sensors.

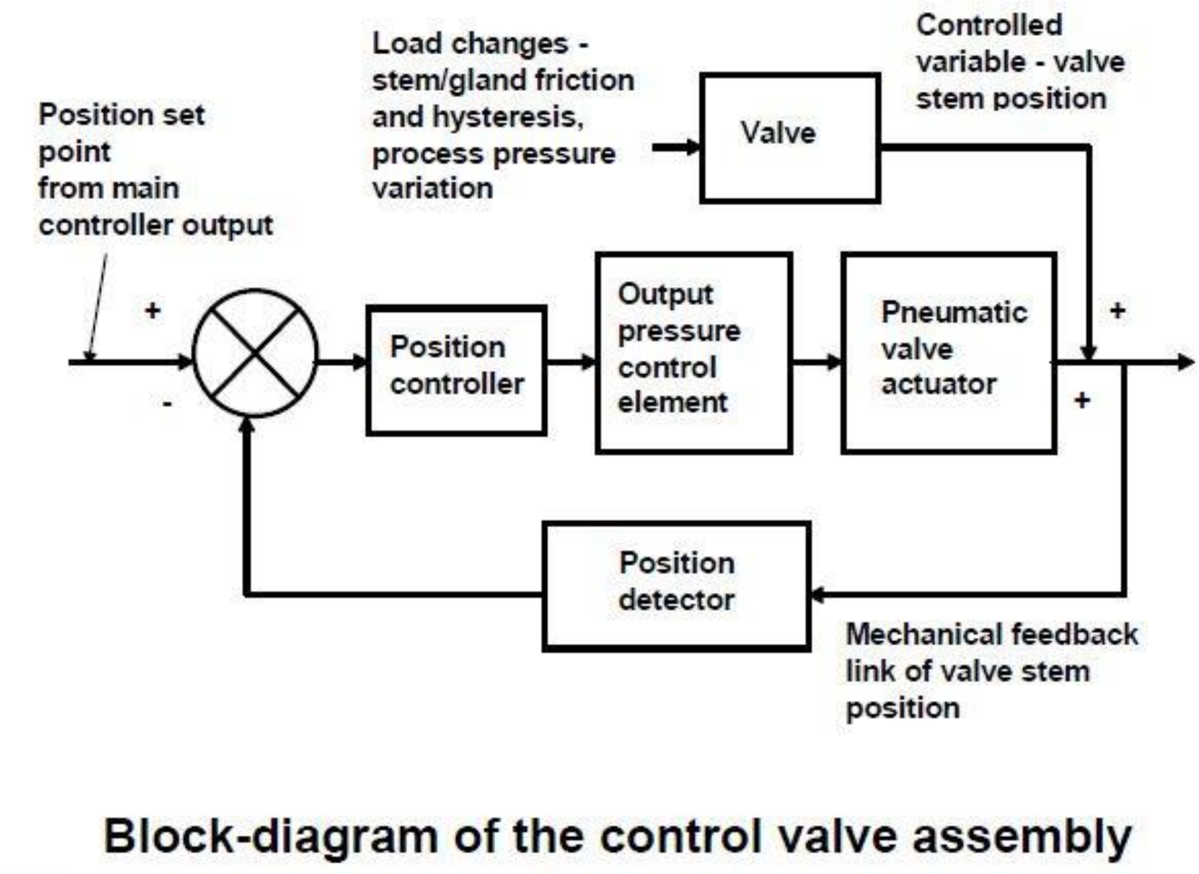


Fig-10:Block diagram of the control valve assembly

A positioner should be considered in the following circumstances:

- When accurate valve positioning is required;
- To speed up the valve response. The positioner uses higher pressure and greater air flow to adjust the valve position;
- To increase the pressure that a particular actuator and valve can close against. (To act as an amplifier);
- When the valve pressure drop at the maximum operating flowrate, exceeds 5 bar for single seated valves or 10 bar for double seated valves;
- To linearize a non-linear actuator;
- Where varying differential pressures within the fluid would cause the plug position to vary;
- When controlling with wide throttling range; and
- When valves are handling sludge or solids in suspension.
- Furnish positioners for all control valves in critical service and where the variable, such as flow, has to be closely controlled.

Controlling the valve:

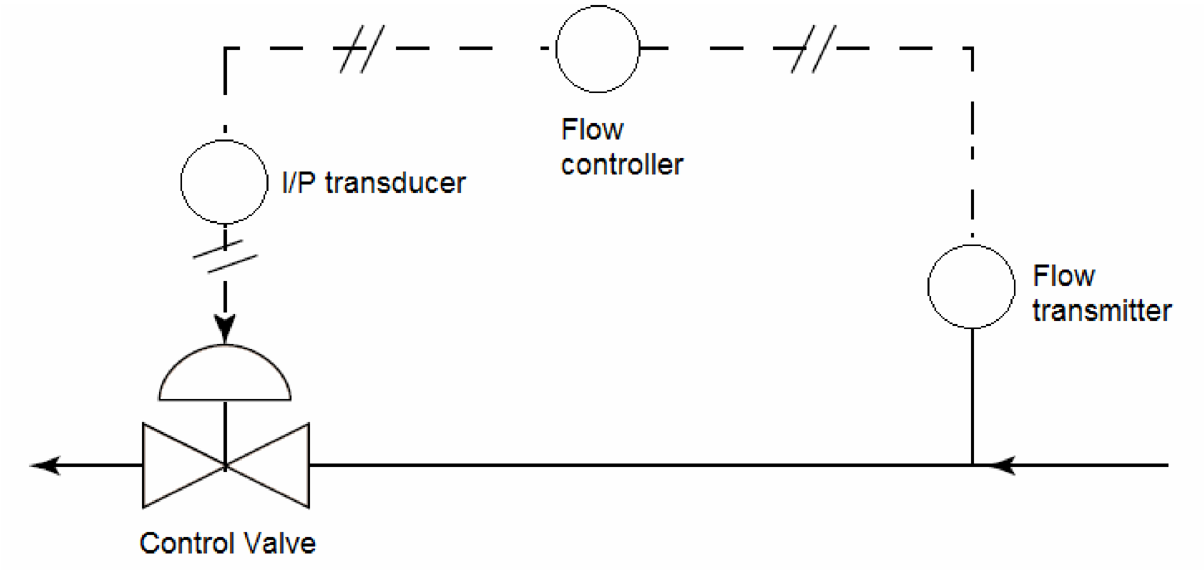


Fig-11: Control valve closed loop

Current to pressure converter:

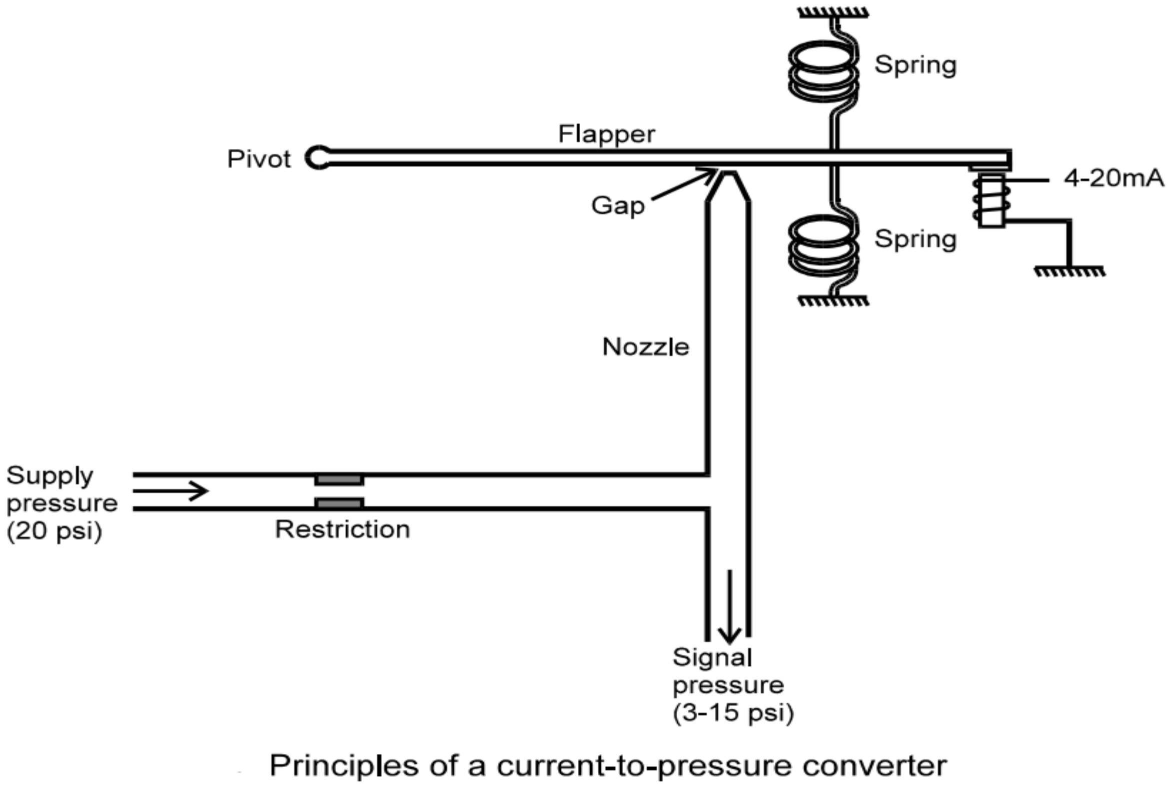


Fig-12: Current to pressure converter.

- In the Current to Pressure converter, we usually give input current signal as 4 – 20 mA. We also give a continuous supply of 20 P.S.I to the Flapper Nozzle assembly.
- As we give input current signal, Electromagnet gets activated.

- If the current is more, then the power of magnet will get increased. The Flapper of the Flapper-Nozzle instrument is connected to Pivot so that it can move up and down and a magnetic material was attached to other end of flapper and it is kept near the electromagnet.
- As the magnet gets activated. the flapper moves towards the electromagnet and the nozzle gets closed to some extent. So the some part of 20 P.S.I supplied will escape through nozzle and remaining pressure will come as output.
- If the current signal is high, then power of the magnet will increase, then flapper will move closer to the nozzle, so less pressure will escape through nozzle and output pressure increases.
- In this way the output pressure will be proportional to the input current.
- For the input current of 4 – 20 mA we can get the output pressure of 3 – 15 P.S.I

Choked Flow:

- Choked flow (otherwise known as critical flow) takes place:

1) When an increase in pressure drop across the valve no longer has any effect on the flow rate through the valve.
2) When the velocity of the gas or vapor reaches sonic velocity at the vena contracta.

- When liquid passes through a restriction, the velocity increases to a maximum and the pressure decreases to a minimum.
- As the flow exits, velocity is restored to its previous value, while the pressure never completely recovers, thus creating a pressure differential across the valve.
- If the pressure differential is sufficiently large, the pressure may, at some point, decrease to less than the vapor pressure of the liquid.
- When this occurs, the liquid partially vaporizes and is no longer incompressible.
- It is necessary to account for choked flow during the sizing process to ensure against undersizing a valve.
- In other words, it is necessary to know the maximum flow rate that a valve can handle under a given set of conditions.
- When selecting a valve, it is important to check the pressure recovery characteristics of valves for the thermodynamic properties of the fluid.
- High recovery valves, such as ball and butterfly, will become choked at lower pressure drops than low recovery valves such as globe which offer a more restricted flow path when fully open.

FLASHING:

- At the point where the fluid's velocity is at its highest, the pressure is at its lowest.
- Assuming the fluid is incompressible (liquid), if the pressure falls below the liquid's vapor pressure, vapor bubbles form within the valve and collapse into themselves as the pressure increases downstream.
- This leads to massive shock waves that are noisy and will certainly ruin the equipment.

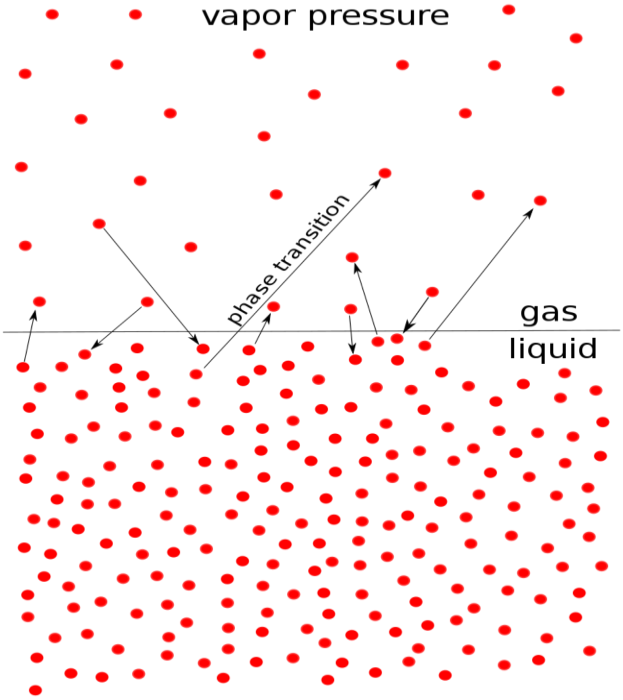


Fig-13: Flashing

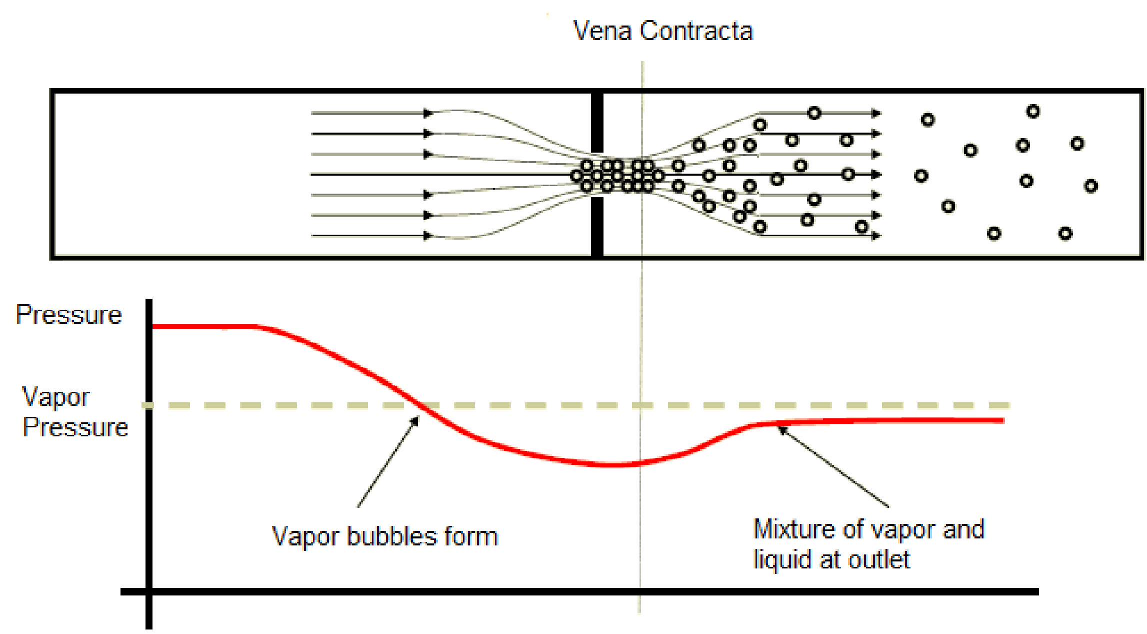


Fig-14: Flashing along with meter

How can flash damage be contained:

- Flashing cannot be eliminated in the valve if the downstream pressure is less than the vapor pressure of liquid.
- However, the damage can be minimized by:

1) Hard face trim (using hard facing materials such as Stellite or Tungsten Carbide), more erosion resistant body material.
2) Increasing size of the valve, therefore reducing the velocity
3) Using angle valve – flow over plug

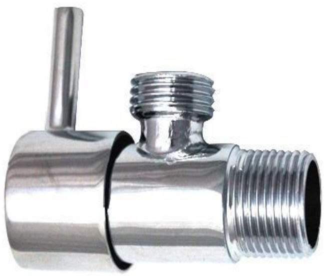


Fig-15: Angle Valve

CAVITATION IN CONTROL VALVES:

- Cavitation is the formation and collapse of vapor bubbles (cavities) in the liquid flowstreams caused by changes in pressure and velocity.
- There are four primary negative side effects of uncontrolled cavitation in control valves:

1) high noise,
2) excessive vibration,
3) material damage, and
4) deterioration of flow effectiveness.
5) Physical damage to valve trim (relation between valve stem position & stem travel) is usually characterized by a pitted, rough appearance.

- The pressure energy in a fluid is converted to kinetic energy due to the contraction at the valve closure member, causing an increase in velocity.
- In addition, as the temperature of the liquid increases, the likelihood of cavitation becomes more likely because of the increased vapor pressure.

- The extent of the cavitation depends mainly on the downstream pressure and the differential pressure across the valve**.**
- Vapor bubbles form if the liquid's pressure falls to near the vapor pressure as the liquid passes through the control valve. Bubbles can suddenly collapse or implode (sudden decline or failing) as the pressure increases down line, producing cavitation.
- Cavitation is one of the results of choked flow. It is the point at which increasing the pressure drop while maintaining a constant inlet pressure yields no further increase in flow rate.

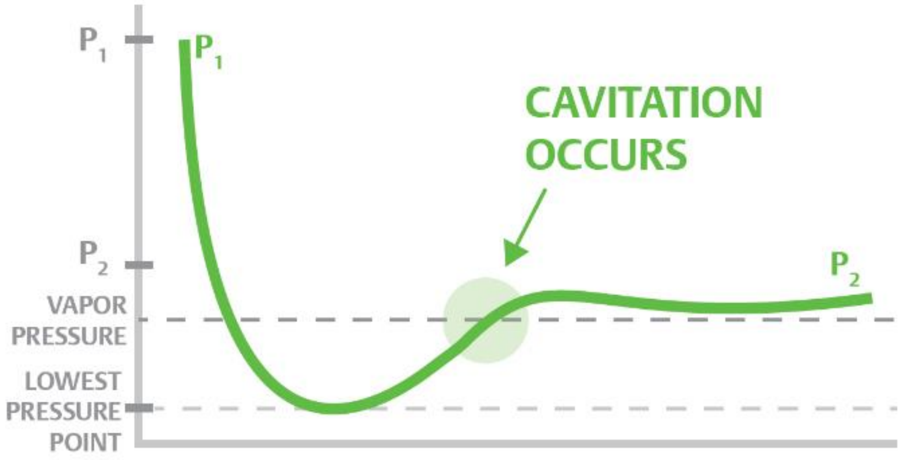


Fig-16: Cavitation occurring spot

DIFFERENCE BETWEEN FLASHING AND CAVITATION (REQUIREMENTS):

Requirements for occurrence of cavitation:	Requirements for occurrence of flashing:
The fluid at both the inlet and outlet must be in all-liquid condition.	The fluid at the inlet must be in all-liquid condition, but some vapor must be present at the valve outlet.
The liquid must be sub-cooled state at the inlet, because if the liquid will be in a saturated state, then any pressure drop across the valve will cause the presence of vapor downstream.	The fluid at the inlet may be in either a saturated or a sub-cooled condition.

The valve outlet pressure must be either at or above the vapor pressure of the liquid.	The valve outlet pressure must be either at or below the vapor pressure of the liquid.

How to avoid Cavitation:

If cavitation is ever encountered, consider the following corrective actions:

1. The first is to equip the control valve with special trim and ensure that the plug and seat are made of a hard facing material that can resist both the onset and effect of cavitation (e.g. stellite hard facing).

2. The second is to use a valve with a low recovery coefficient.

3. The third is to increase the downstream pressure by installing a flow restrictor if possible or reducing the pipe size of a short piece downstream.

Valve Recovery Coefficient:

- Valve recovery refers to the pressure recovery from the low pressure at vena contracta to the valve outlet.
- The term "valve recovery" is usually applied when a valve is employed as a restriction.
- It is a given that any valve could cause cavitation to a differing degree and in different closure positions.
- If using a valve to cause a pressure drop as compared to control the flow of volume, it is safe to say that a low recovery valve will resist causing cavitation more than a high recovery type.
- The valve recovery coefficient is a dimensionless, numerical factor that represents a valve's flow vs. liquid pressure curve, and thus the valve's tendency to cavitate.
- If this factor is higher than desired, cavitation might develop. The valve coefficient is affected by the internal geometry of the valve, valve size, pressure, and the presence or absence of piping reducers adjacent to the valve.

SCHOOL OF ELECTRICAL & ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRONICS & INSTRUMENTATION ENGINEERING

UNIT – IV – Process Control System Components – SIC1406

Pumps are vital equipments used in day today life. In this unit Pumps and the properties, types, configuration are discussed. Its really important to know the difference between pump and motor which is given in the table below:

Table-1: Pump versus Motor

PUMP VERSUS MOTOR

Pump is a hydro-mechanical device used to convert mechanical torque into hydraulic energy.	Motor is an electro-mechanical device used to convert electrical energy into mechanical energy.
It uses mechanical action to move fluids or sometimes slurries from one place to another.	It works on the fundamental principle of Faraday's law of electromagnetic induction.
It transfers its mechanical energy into water, pressurizing it to move.	It uses pressure of flowing water and mechanical energy to produce its rotation.
It receives the source from motor to pump out.	It provides source of mechanical energy to the pump.
It is classified into two basic types – centrifugal and positive displacement pumps.	It is mainly classified into two basic types – Ac and DC motors.

Types of Pumps:

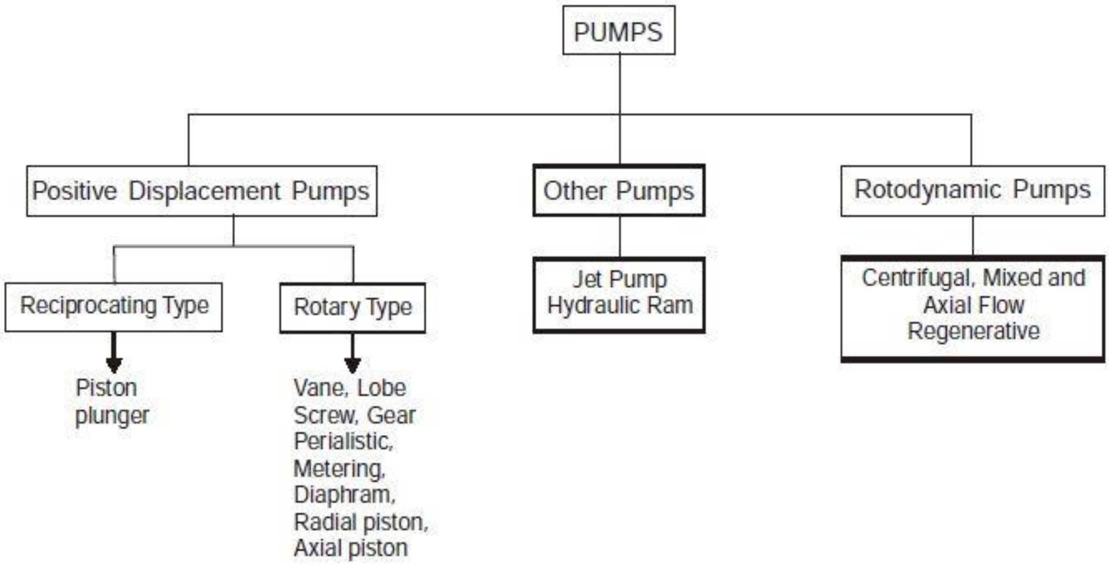


Fig-1: Types of Pumps

Classification according to operating principle:

1) Positive displacement pumps

2) Rotodynamic pumps

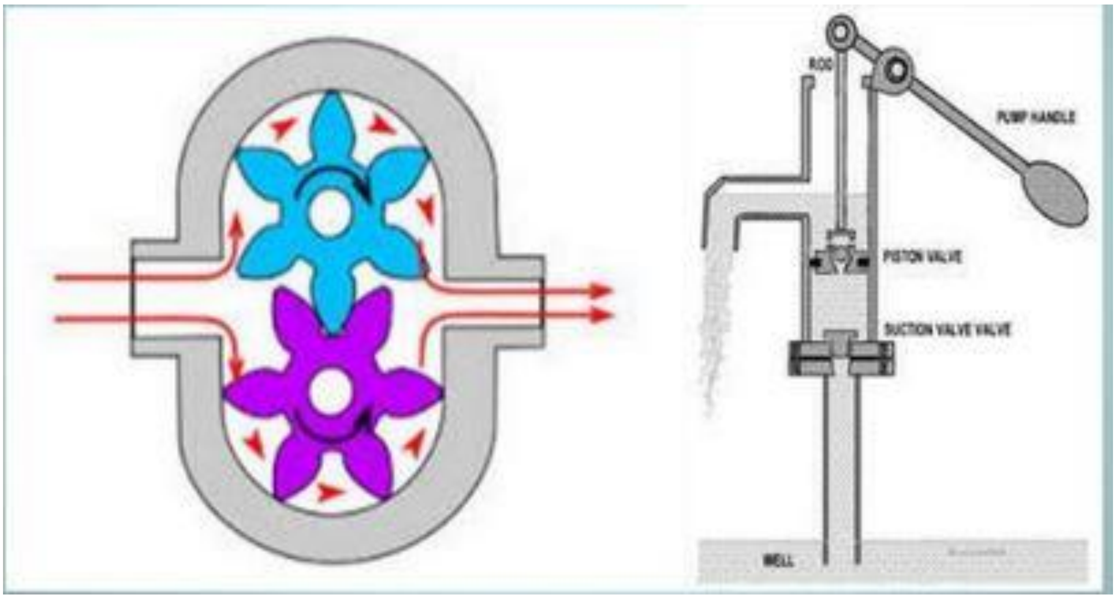


Fig-2: Positive Displacement pumps

POSITIVE DISPLACEMENT PUMPS:

- Positive displacement pump trap liquid at the suction of the pump and pushes that quantity of liquid out to the discharge of the pump.
- The pressure produced by a positive displacement pump depends upon the amount of force exerted on the piston. Positive displacement pump sucks liquid and then pushed liquid forward due to the thrust applied on it by a moving member.
- Discharge of the liquid pumped only depends on the speed of the pump.
- Centrifugal pumps have many operational and maintenance advantages over positive displacement pumps.
- Positive displacement pumps cannot replace with centrifugal pumps. These services involve the requirement for very high pressure, the constant preset delivery which is not affected by system changes, and pumping of various viscous liquids.

Two major categories of positive displacement pumps, reciprocating and rotary

RECIPROCATING

•Has positive pressure characteristics – Creates flow

•Used principally to handle small volumes at relatively high pressures

•Speeds relatively low due to reciprocating motion and inertia effect of parts

•Self-priming and delivered capacity is practically constant regardless of discharge pressure

•Capable of handling practically all types of fluids with uniformly high volumetric efficiency

ROTARY

•Combines the rotary motion of the centrifugal with the positive pressure characteristics of the reciprocating

•Is a positive displacement type as reciprocating and delivers with each revolution a given quantity of fluid

•Self-priming and gives practically constant delivered capacity regardless of pressure

•Speeds are much higher and hence possible to directly connect with driver in most cases

•Can pump practically any fluid that will flow

POSITIVE DISPLACEMENT PUMPS

TYPES:

1. RECIPROCATING

- PISTON
- PLUNGER
- DIAPHRAGM

2. ROTARY

- SCREW (Single, Twin, Triple)
- GEAR
- VANE
- LOBE (Two & Three)

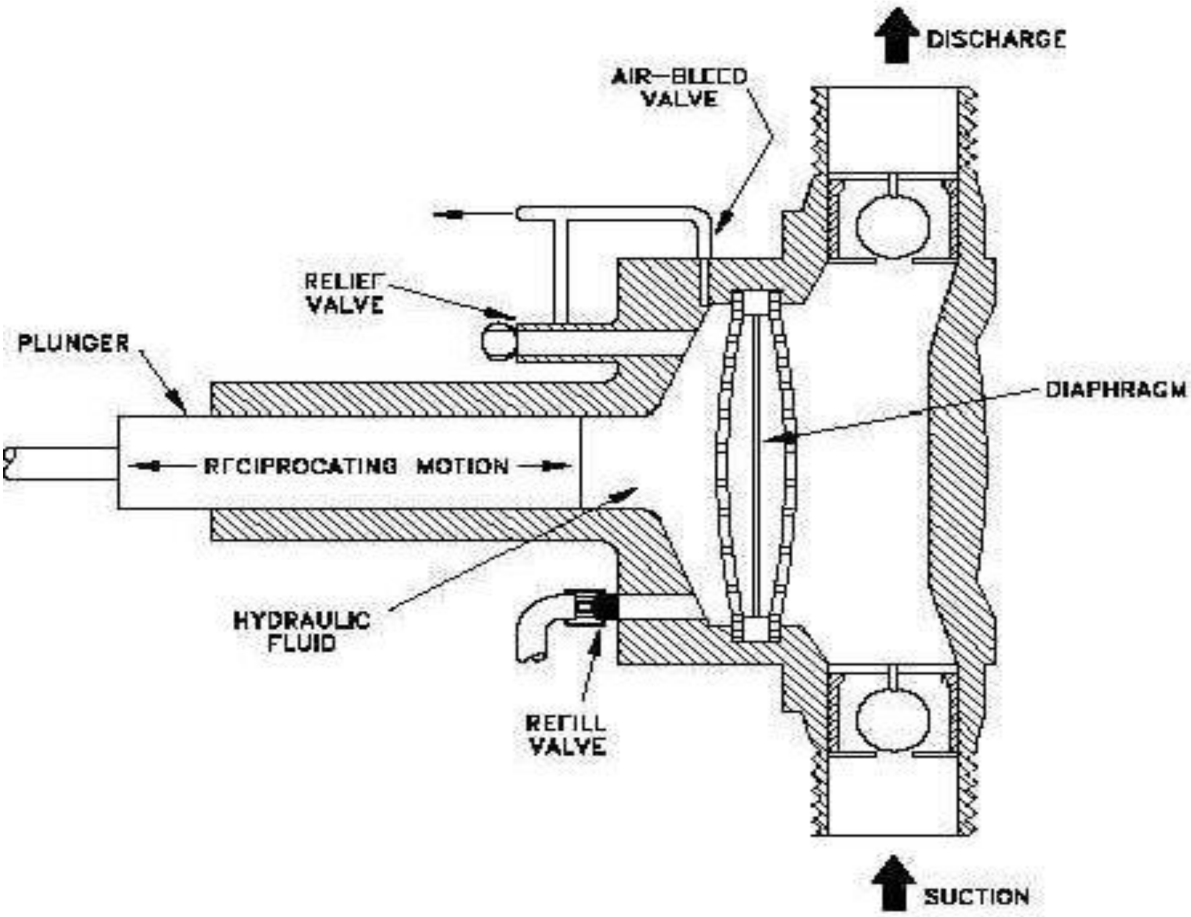


Fig-3: Positive displacement pump

How reciprocating type of positive displacement pump works:

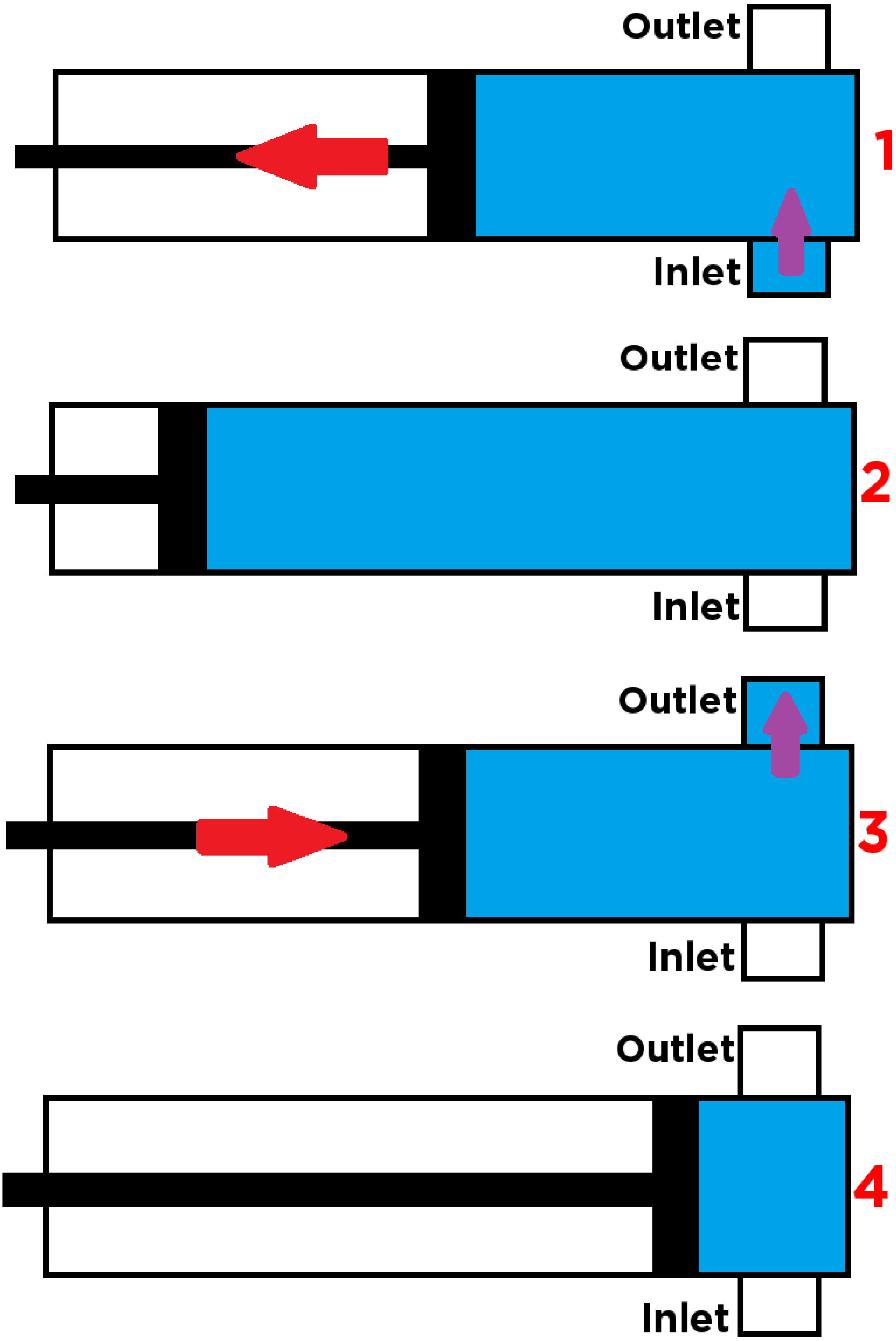


Fig-4: 4 stages explaining the working of the pump

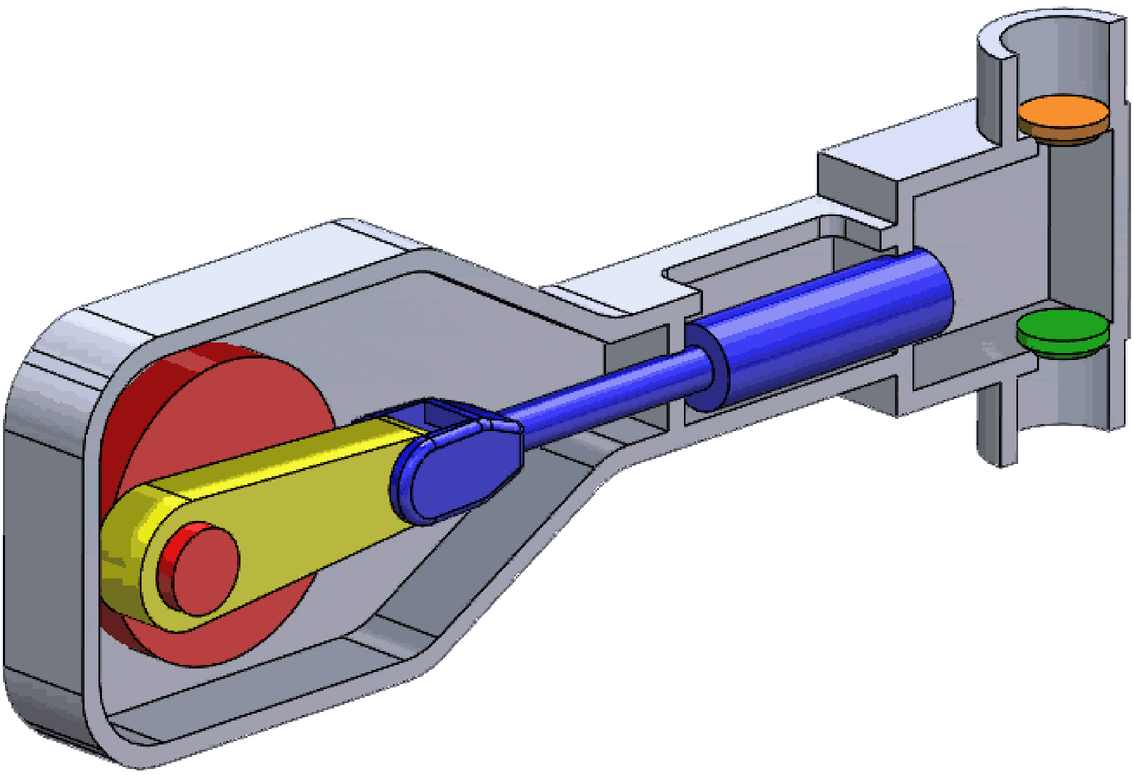


Fig-5: Complete CAD structure of Postive displacement pumps

- Piston, Plunger or a diaphragm: All these parts have the basic functionality of moving the liquid inside the cylinder.

- A)The piston is a lubricated sliding shaft which moves inside the cylinder and pushes the liquid in forward and backward motion, creating a cavity and a high volume pressure at the outlet.

B)In a diaphragm pump, the diaphragm is used to avoid leaking of the liquid since it completely seals the liquid to penetrate outside, and hence they are especially useful when the liquids are dangerous or toxic.

C) In a plunger pump, there is a high-pressure seal which is stationary and a smooth cylindrical plunger slides through the seal.

- **Crank and Connecting rod:** Crank is a circular disk attached to the motor and used to transfer the rotary motion of the motor to the piston. Piston, in turn, moves in a reciprocating motion with help of a connecting rod.
- **Suction pipe:** Liquid flows from this pipe into the cylinder. One side of the pipe is immersed in the liquid and the other end is connected to the cylinder.
- **Delivery pipe:** This can be understood as an outlet pipe. One end is connected to the cylinder while the other is towards the discharge/Outlet.
- **Suction and Delivery valve:** It adjusts the rate of the flow of liquid at the suction and discharge points.

Advantages of Reciprocating Pumps:

- **High Pressure, Low Flow Applications:** Reciprocating pumps are generally designed to pump in low flow, high head applications. One of the most extreme of these applications is water jet cutting, where only a few gallons pass through the pump per minute but exceed pressures of 10,000 PSI.
- **Proven, Common Technology:** Reciprocating pumps are one of the oldest, most proven pump types. Today, a wide variety of reciprocating pumps can be found in many different materials, types, and sizes. Reciprocating pumps range from less than 1 horsepower to over 3,000 horsepower.
- **Durability:** Reciprocating pumps are used in some of the most abrasive and corrosive applications. Fluid ends and fluid end parts can be made of many different materials such as stainless steel, aluminum bronze, tungsten carbide, ceramic, and more. A wide selection of valve types are used in abrasive applications such as pumping cement, sand slurry, mud, etc.
- **Efficiency:** Reciprocating pumps operate at high a higher efficiency compared to other pump designs. In most cases, at any set point, reciprocating pumps operate around 90%.

Factors that determine the efficiency of reciprocating pump:

- **Brake Horsepower (BHP):** How much is the actual power requirement at the input shaft to achieve a desired pressure and flow.
- **Capacity:** It can be defined as the total volume of liquid/flow delivered per unit of time.
- **Slips:** Slip is the capacity loss as a fraction or percentage of the suction capacity.
- **Mechanical efficiency:** Its working at full load pressure and speed is 90% to 95% depending on the size, speed, and construction.
- **Pressure:** Mainly, the suction and the discharge pressure in a pump.
- **Displacement:** Also known as GPM (gallons per minute), it is the calculated capacity of the pump with no slip losses.

Disadvantages of reciprocating pump:

- High Maintenance / Short Life:
- Pulsations

Rotary Positive displacement pumps:

- Rotary positive displacement pumps use the actions of rotating cogs or gears to transfer fluids, rather than the backwards and forwards motion of reciprocating pumps.
- The rotating element develops a liquid seal with the pump casing and creates suction at the pump inlet.

- Fluid, drawn into the pump, is enclosed within the teeth of its rotating cogs or gears and transferred to the discharge.
- The simplest example of a rotary positive displacement pump is the gear pump. There are two basic designs of gear pump: external and internal

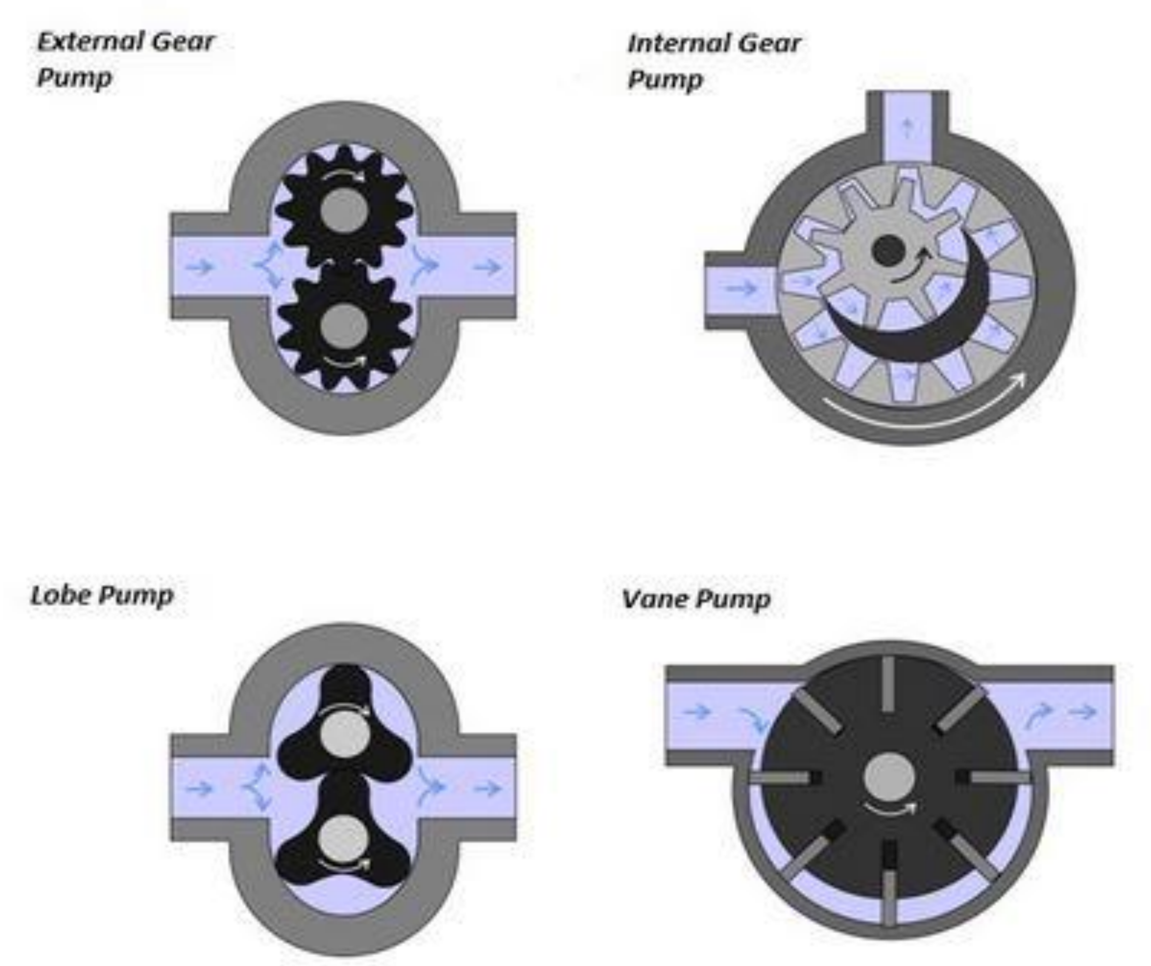


Fig-6: Different structures of the impellar of the pump

Flexible vane pump:

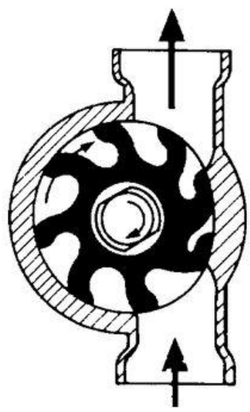


Fig-7: Flexible vane pump

ROTODYNAMIC PUMPS:

•A rotodynamic pump is a kinetic machine in which energy is continuously imparted to the pumped fluid by means of a rotating impeller, propeller, or rotor, in contrast to a positive displacement pump in which a fluid is moved by trapping a fixed amount of fluid and forcing the trapped volume into the pump's discharge.

•The impeller is the key component of a centrifugal pump. It consists of a series of curved vanes. These are normally sandwiched between two discs (an enclosed impeller). For fluids with entrained solids, an open or semi-open impeller (backed by a single disc) is preferred

Fig-8: Impellar types

- Fluid enters the impeller at its axis (the 'eye') and exits along the circumference between the vanes.
- The impeller, on the opposite side to the eye, is connected through a drive shaft to a motor and rotated at high speed (typically 500-5000rpm).
- The rotational motion of the impeller accelerates the fluid out through the impeller vanes into the pump casing.
- There are two basic designs of pump casing: volute and diffuser. The purpose in both designs is to translate the fluid flow into a controlled discharge at pressure.

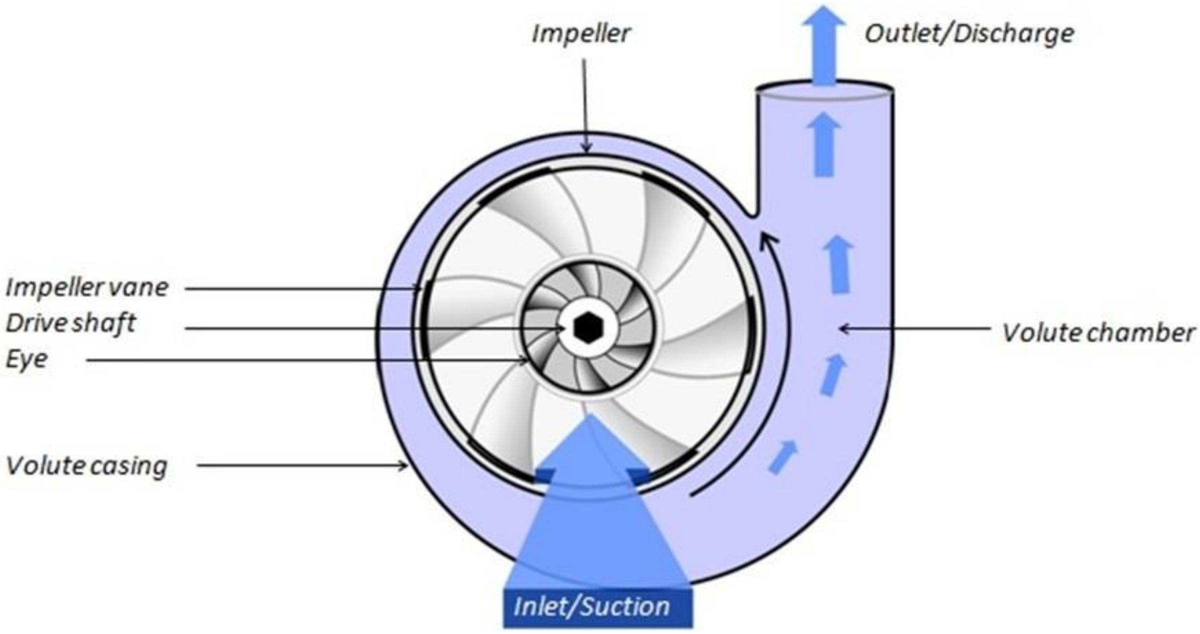


Fig-9: Volute Design type of Impellar

The same basic principle applies to diffuser designs. In this case, the fluid pressure increases as fluid is expelled between a set of stationary vanes surrounding the impeller.

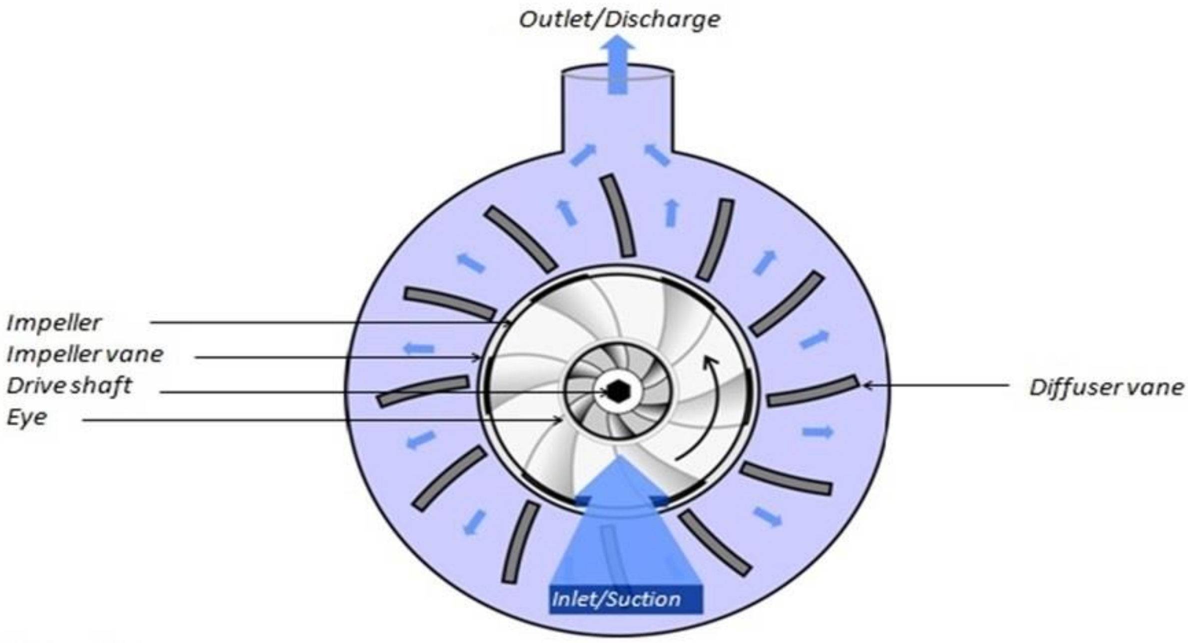


Fig-10: Diffuser case design

Fig-11: 3D CAD model of diffuser pump

Features different from positive displacement pumps:

- In comparison to the latter, centrifugal pumps are usually specified for higher flows and for pumping lower viscosity liquids, down to 0.1 cP.

In some chemical plants, 90% of the pumps in use will be centrifugal pumps.

Property	**Centrifugal**	**Positive Displacement**
Effective Viscosity Range	Efficiency decreases with increasing viscosity (max. 200 Cp)	Efficiency increases with increasing viscosity
Pressure tolerance	Flow varies with changing pressure	Flow insensitive to changing pressure
	Efficiency decreases at both higher and lower pressures	Efficiency increases with increasing pressure
Priming	Required	Not required
Flow (at constant pressure)	Constant	Pulsing
Shearing (separation of emulsions, slurries, biological fluids, food stuffs)	High speed damages shear-sensitive mediums	Low internal velocity. Ideal for pumping shear sensitive fluids

Factors affecting performance of centrifugal pump:

- Working fluid viscosity
- Specific density and gravity of working fluid
- Operating temperature and pressure
- Net Positive Suction Head (NPSH) and Cavitation
- Vapour pressure of the working fluid

Applications of Centrifugal pumps:

- Oil & Energy
- Waste Management, Agriculture & Manufacturing
- Pharmaceutical, Chemical & Food Industries
- Various industries (Manufacturing, Industrial, Chemicals, Pharmaceutical, Food Production, Aerospace etc.) -

Axial Flow pump:

- An axial-flow pump, or AFP, is a common type of pump that essentially consists of a propeller (an axial impeller) in a pipe.
- The propeller can be driven directly by a sealed motor in the pipe or by electric motor or petrol/diesel engines mounted to the pipe from the outside or by a right-angle drive shaft that pierces the pipe.

Fig-12: Axial flow pumps impellar

- Axial pumps are used for the promotion of incompressible fluids and are employed for large volume flows at relatively low delivery heads.
- As with all types of centrifugal pumps, the energy transmission in axial flow pumps is carried out exclusively through flow-related processes.

- The pump usually consists of an impeller with a few number of vanes, typically only three or four vanes. The vanes are oriented in such a way that the pumped fluid exits axially (i.e., in the same direction as the shaft), rather than radially (90 degrees from the shaft).
- The impeller is normally driven by an electric motor. The axial orientation of the impeller vanes produces very low head as the liquid is pumped.
- An axial flow pump may generate only 10 to 20 feet of head, much lower than most other types of centrifugal pumps. They are capable of producing very high flow rates – as high as several hundred thousand gallons per minute, the highest flow rates of any type of centrifugal pump.
- They're sometimes called propeller pumps, because the axial flow impeller looks similar to a boat propeller. Some configurations can have their flow and head adjusted by altering the pitch of the impeller vanes.
- Axial flow pumps have performance characteristics that are quite different from other pump types.
- The shut-off (zero flow) head may be as much as three times the head at the pump's best efficiency point. Also, the required horsepower increases as flow is decreased, with the highest horsepower draw being at shut off (zero flow).

PUMP PERFORMANCE:

- The pump converts electrical power into fluid motion.
- Engineers have a common language and analytical models to describe pump performance.
- In any one application these parameters may be more or less important.

❑ Flow rate, Q

❑ Head, h

❑ Efficiency, η

- Note that Q is also used as the symbol for heat transfer.

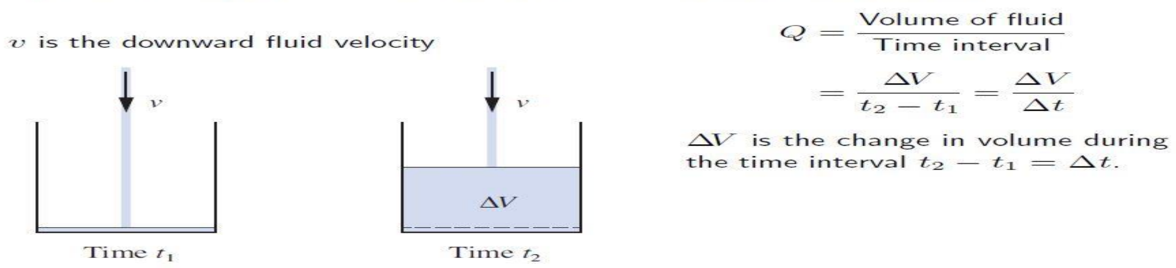


Fig-13: Interpretation of filling from a faucet

Mass flow rate

$$\dot{m} = \frac{\text{Mass of fluid}}{\text{Time interval}} = \frac{\Delta m}{\Delta t}$$

Mass and volume are related by the fluid density, ρ

$$\text{density } \rho = \frac{\text{mass}}{\text{volume}} \implies \Delta m = \rho\,\Delta V$$

Therefore

$$\dot{m} = \rho Q$$

Flow rate in a tube:

Consider flow from a faucet into a bucket.
The average fluid velocity is v.

In time Δt, the fluid slug moves $L = v\,\Delta t$.
Therefore, the volume passing an arbitrary reference point is

$$\Delta V = LA = v\,\Delta t\,A$$

where A is the cross-sectional area of the pipe.

Therefore, the volumetric flow rate is

$$Q = \frac{\Delta V}{\Delta t} = \frac{v\,\Delta t\,A}{\Delta t} = vA$$

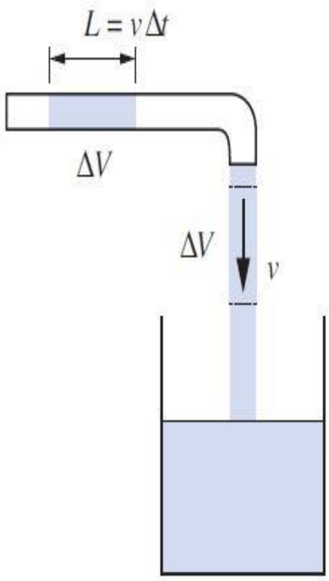


Fig-14: Flow rate in a tube calculation

Flow rate formulas:

Volumetric Flow Rate

$$Q = vA$$

where v is the average fluid velocity in the tube, and A is the cross-sectional area of the tube.

Mass flow rate

$$\dot{m} = \rho Q = \rho v A$$

where ρ is the fluid density.

If $\dot{m}$ is known, then the average velocity is

$$v = \frac{Q}{A} = \frac{\dot{m}}{\rho A}$$

Head is a measure of how high the pump can push the fluid.

If the friction losses in the inlet and outlet tubes can be neglected, the head produced by the pump is equal to h, the height of the free end of the hose above the free surface of the supply reservoir.

Each pump has a characteristic relationship between head and flow rate.

- An increase in head causes a decrease in Q
- There is a maximum h for which $Q = 0$
- At $h = 0$ (no uphill) then Q is a maximum

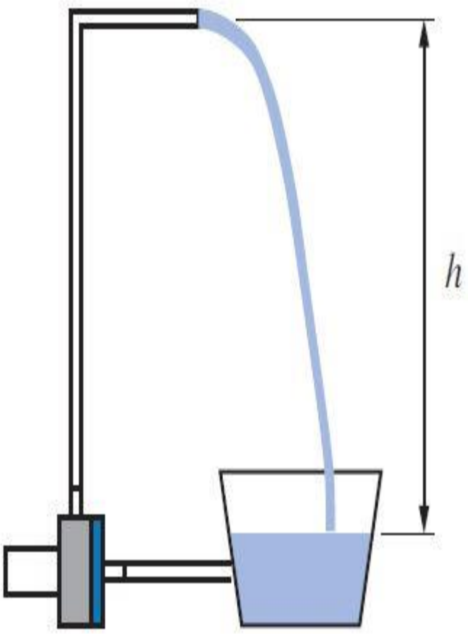


Fig-15: Head measurement in a pump

Pump Curve:

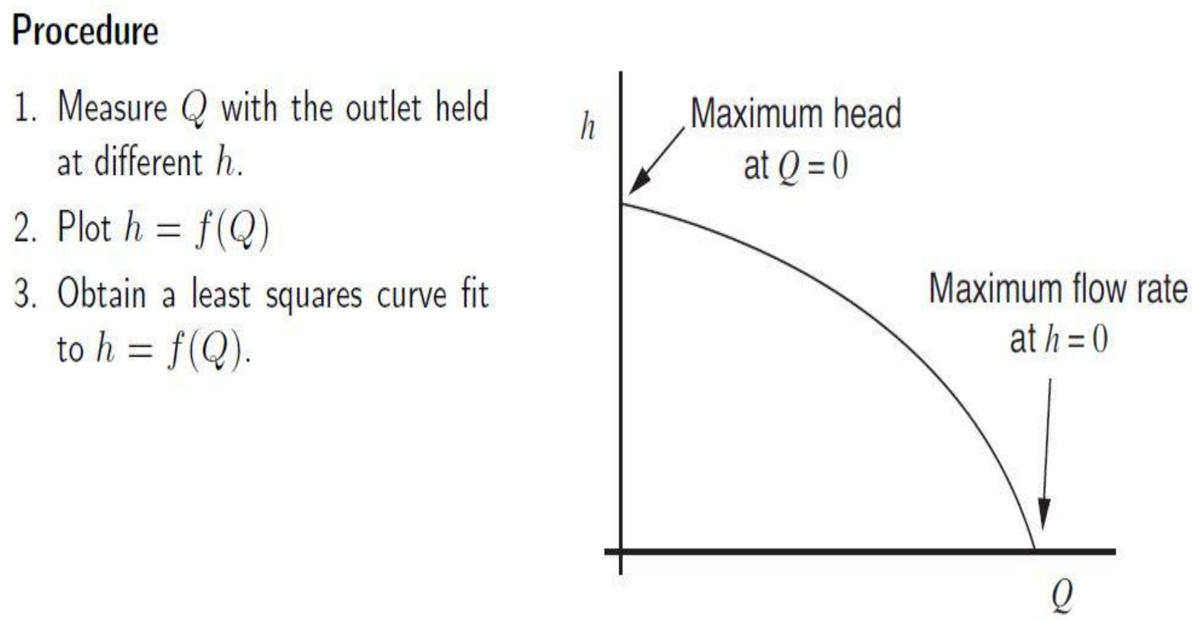


Fig-16: Head versus Flow rate graph

Pump Efficiency:

- Each pump has an optimal operating point, i.e., an optimal (Q, h) that yields maximum efficiency.
- In most engineering applications, there are several pumps that can supply the desired flow rate at the necessary head.
- Given a choice of pumps that can meet the Q and h requirements, one should choose the pump that operates at the maximum efficiency.
- What is efficiency?

$$\eta = \text{Output}/\text{Input}$$

Pump Efficiency

$$\eta = \text{Output}/\text{Input}$$

$$= \frac{\text{Desired outcome}}{\text{Cost of obtaining the outcome}}$$

For a pump:

Output = is the power delivered to the fluid

Input = is the power consumed by the motor

- The units of Output and Input must be the same because efficiency is dimensionless.
- Output and Input could be defined in terms of energy instead of power as long as the units are consistent.

Output is rate at which usable energy is transferred to the fluid

$$\begin{aligned} \text{Output} &= \textit{Rate} \text{ at which fluid is elevated} + \textit{flow} \text{ of kinetic energy in output stream} \\ &= \dot{m}gh + \tfrac{1}{2}\dot{m}v^2 \end{aligned}$$

where

$$\begin{aligned} \dot{m} &= \text{mass flow rate (kg/s)} \\ g &= \text{acceleration of gravity } (\mathrm{m/s^2}) \\ h &= \text{pump head (m)} \\ v &= \text{velocity of the water leaving the tube (m/s)} \end{aligned}$$

Characteristics of different pumps:

- Creating a resistance to the flow controls the kinetic energy (movement) of a liquid coming out of an impeller.
- The first resistance is created by the pump volute (casing), which catches the liquid and slows it down.
- When the liquid slows down in the pump casing, some of the kinetic energy is converted to pressure energy.
- It is the resistance to the pump’s flow that is read on a pressure gauge attached to the discharge line.
- A pump does not create pressure, it only creates flow. Pressure is a measurement of the resistance to flow.

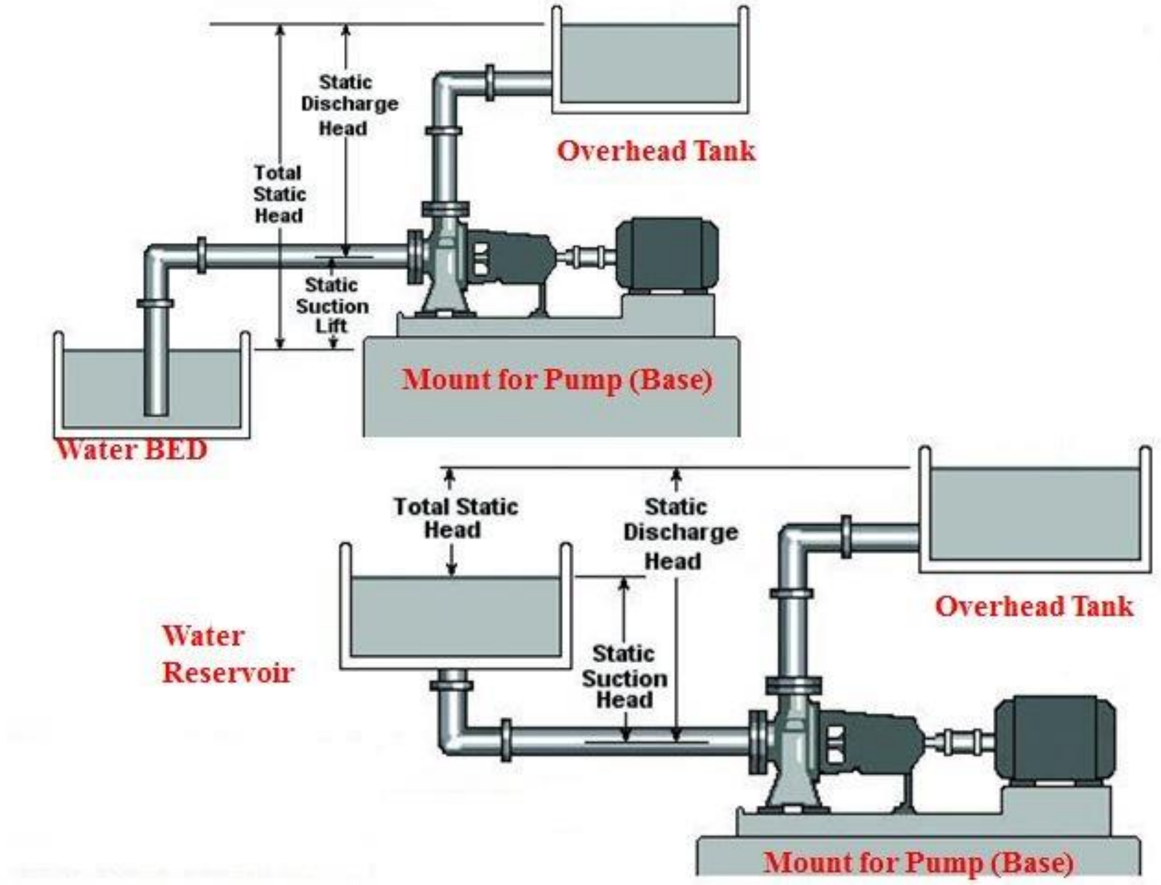


Fig-17: Representation of static discharge head, static suction lift and total static head

❖ **Head—Resistance to Flow:**

- In Newtonian (true) fluids (non-viscous liquids, such as water or gasoline), the term head is the measurement of the kinetic energy that a centrifugal pump creates.
- Imagine a pipe shooting a jet of water straight into the air. The height that the water reaches is the head.

❖ **Friction Head (h_f):**

- Friction head is the head required to overcome the resistance to flow in the pipe and fittings. It depends on the size, condition and type of pipe; the number and type of pipe fittings; flow rate; and nature of the liquid.

❖ **Velocity Head (h_v):**

- Velocity head is the energy of a liquid as a result of its motion at some velocity (V).
- It is the equivalent head in feet through which the water would have to fall to acquire the same velocity or, in other words, the head necessary to accelerate the water.
- Velocity head can be calculated using the following formula:

$$h_v = \frac{V^2}{2_g}$$

Where:
g = 32.2 ft./sec.^{2}
V = liquid velocity in ft./sec.

❖ **Pressure Head:**

- Pressure head must be considered when a pumping system either begins from or empties into a tank that is under some pressure other than atmospheric.
- The pressure in such a tank must first be converted to feet of liquid.
- A vacuum in the suction tank or a positive pressure in the discharge tank must be added to the system head, whereas a positive pressure in the suction tank or vacuum in the discharge tank would be subtracted.

$$\text{Vacuum, feet of liquid} = \frac{\text{Vacuum, in. of hg} \times 1.13}{\text{Specific Gravity}}$$

❖ **Total Dynamic Suction Lift (h_s):**

- Total dynamic suction lift is the static suction lift minus the velocity head at the pump suction flange plus the total friction head in the suction line.
- The total dynamic suction lift, as determined on a pump test, is the reading of a gauge on the suction flange, converted to feet of liquid and corrected to the pump centerline, minus the velocity head at the point of gauge attachment.
- **PUMP TERMS:**
- **Suction lift** exists when the source of supply is below the centerline of the pump. Therefore, the **static suction lift** is the vertical distance in feet from the centerline of the pump to the free level of the liquid to be pumped.
- **Suction head** exists when the source of supply is above the centerline of the pump. Therefore, the **static suction head** is the vertical distance in feet from the centerline of the pump to the free level of the liquid to be pumped.
- **Static discharge head** is the vertical distance in feet between the pump centerline and the point of free discharge or the surface of the liquid in the discharge tank.
- **Total static head** is the vertical distance in feet between the free level of the source of supply and the point of free discharge or the free surface of the discharge liquid.

- **Total Head or Total Dynamic Head**

  Total head (H), or total dynamic head (TDH), is the total dynamic discharge head minus the total dynamic suction head:

$TDH = h_d + h_s$ (with suction lift)

$TDH = h_d - h_s$ (with suction head)

- **Power:**

Pump input or brake horsepower (BHP) is the actual horsepower delivered to the pump shaft. Pump output or water horsepower (WHP) is the liquid horsepower delivered by the pump. These two terms are defined by the following formulas:

$$\text{Water HP} = \frac{\text{GPM x Head x Specific Gravity}}{3960}$$

$$\text{Brake HP} = \frac{\text{GPM x Head x Specific Gravity}}{\text{3960 x Pump Efficiency}} \; OR \; \frac{\text{Water HP}}{\text{Pump Efficiency}}$$

Sample Pump Performance Curve:

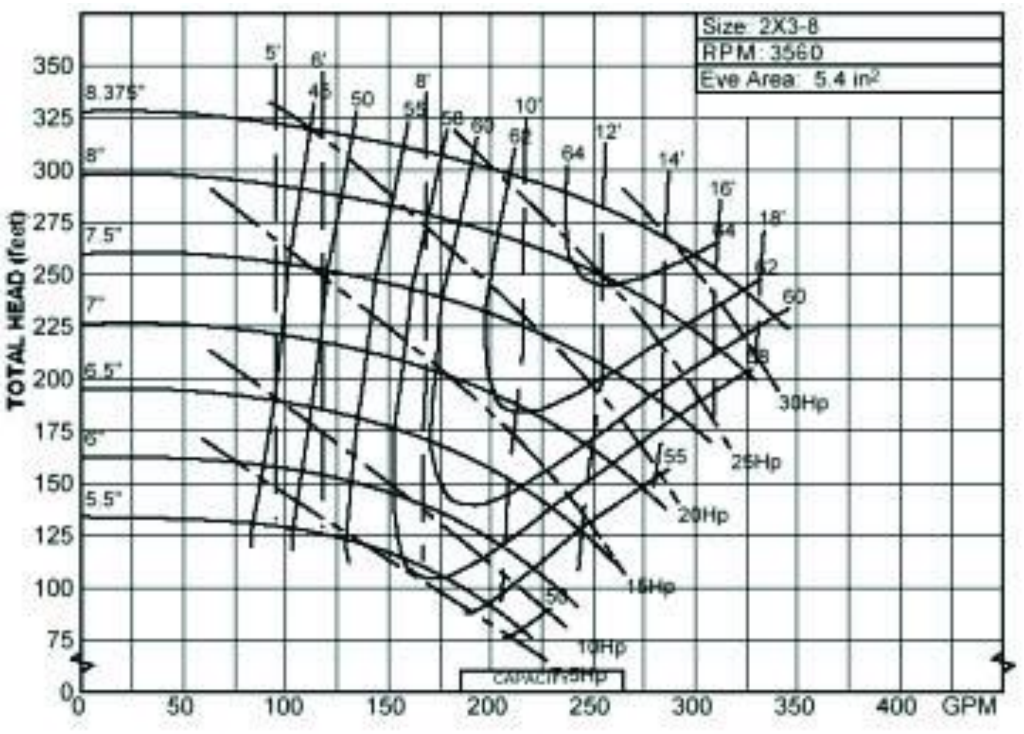


Fig-18: Flow rate versus Total Head

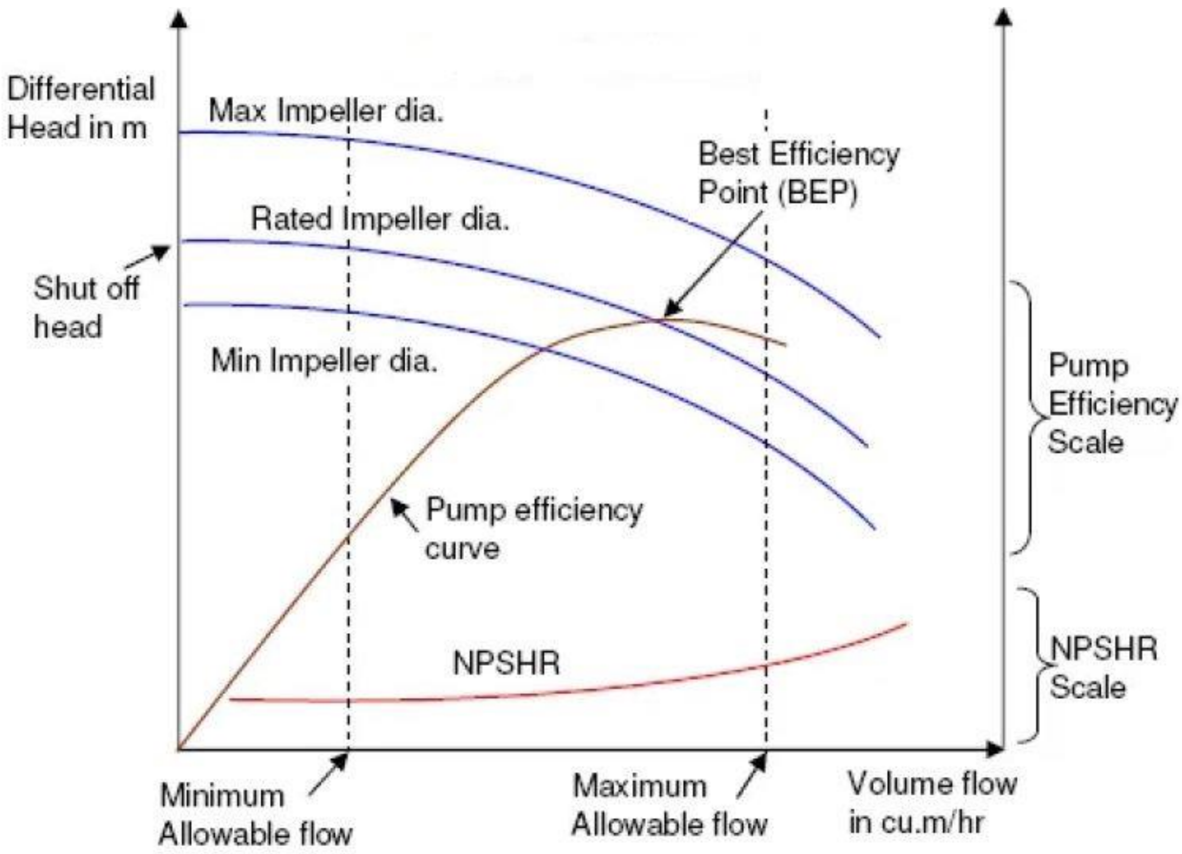


Fig-19: Volume flow versus Differential head graph

PIPE WORK CALCULATION:

- Design of piping system incorporates all major disciplines of engineering like chemical engineering, mechanical engineering, civil engineering, instrumentation and control engineering, electrical engineering, etc.
- Process design of pipe is a balance between size or diameter of pipe and pressure drop in the pipe.
- For a given flow rate of fluid if larger size of pipe is selected then it gives lesser pressure drop
- Larger size of pipe increases the fixed cost of pipe and lesser pressure drop means lesser power consumption or lesser operating cost of pipe.

Optimum Pipe Size:

- Several equations and nomographs are available in literature to estimate the optimum pipe diameter.
- But these equations or nomographs are not reliable as optimum pipe diameter depends on the current cost of material, cost of power, rate of interest at particular place and at particular time.

- It changes with place and time. For example, optimum pipe diameter equation, derived in USA, cannot be used to find the same in India.
- One such equation derived for carbon steel pipe and turbulent flow of an incompressible fluid is

$$d_{opt} = 293\, \dot{m}^{0.53}\, \rho^{-0.37}$$

where, d_{opt} = Optimum pipe size, mm

$\dot{m}$ = Flow rate, kg/s

ρ = Density of fluid, kg/m^3

Table-2: Recommended Fluid Velocities

Fluid		Recommended velocity, m/s
Water	Pump suction line	0.3 to 1.5
	Pump discharge line	2 to 3
	Average service	1 to 2.5
	Gravity flow	0.5 to 1
Steam	0 to 2 atm g, saturated	20 to 30
	2 to 10 atm g, saturated	30 to 50
	Superheated below 10 atm g	20 to 50
	Superheated above 10 atm g	30 to 75
	Vacuum lines	100 to 125
Air	0 to 2 atm g	20
	> 2 atm g	30
Ammonia/ refrigerant	Liquid	1.8
	Gas	30

Pressure drop in a pipe:

Relation between pressure drop and pipe diameter is given by Fanning or Darcy equation. It is derived for steady flow in uniform circular pipes running full of liquid under isothermal conditions.

$$\frac{\Delta p}{L} = \frac{2f\ v^2 \rho}{g_c \cdot D_i} = \frac{32 f\ \dot{m}^2}{\pi^2 \rho\ g_c D_i^5}$$

For SI units, g_c = Newton's law conversion factor = 1

where, Δp = Pressure drop, Pa

L = Length of pipe, m

$\dot{m}$ = Mass flow rate of fluid, kg/s

ρ = Density of fluid, kg/m^3

D_i = Pipe inside diameter, m

v = Velocity of fluid, m/s

f = Fanning friction factor

Pump Selection:

- The factors that should be considered in selecting pumps for construction in selecting pumps for construction applications
- 1. Dependability.
- 2. Availability of repair parts.
- 3. Simplicity to permit easy repairs.
- 4. Economical installation and operation.
- 5. Operating power requirements.

Energy required to operate the pump:

The energy (ft-lb/min) required to operate a pump is given by the following equation:

$$W = \frac{wQh}{e}$$

where

W = energy, ft-lb per min

w = weight of one gallon of water, lb

h = total pumping head (ft), including friction loss in pipe

e = efficiency of the pump, expressed decimally

Horsepower required for pump:

The horsepower (hp) required by a pump is given by the following equation:

$$P = \frac{W}{33{,}000} = \frac{wQh}{33{,}000e}$$

where

P = power, hp

W = energy, ft-lb per min

w = weight of one gallon of water, lb

h = total pumping head (ft), including friction loss in pipe

e = efficiency of the pump, expressed decimally

33,000 = ft-lb per minute for 1 hp

PUMP OPERATION MAINTENANCE:

Pumps are the cogs in the wheel that keep your facility functioning efficiently, whether they are used for manufacturing processes, HVAC, or water treatment. To keep pumps running properly, a regular maintenance schedule should be implemented and followed.

- 1) DETERMINE MAINTENANCE FREQUENCY
- 2) OBSERVATION IS KEY
- 3) SAFETY FIRST
- 4) MECHANICAL INSPECTION
- 5) LUBRICATION
- 6) ELECTRICAL/MOTOR INSPECTION
- 7) REPLACE DAMAGED SEALS AND HOSES

Table-3: Characteristics of different lubricants used in a Pump

	P-80®	Solvents	Soaps & Detergents	Petroleum Distillates
Reduces Friction by	70%	30%	30%	60%
Characteristics	• Provides superior temporary lubrication • Environmentally friendly • Safe for workers • Comes in many biodegradable formulas	• Provides poor lubrication • Contains high VOCs, may be flammable • Poses possible health risks	• Provides inconsistent, nominal lubrication • May reactivate when wet	• Provides sustained lubrication • Often incompatible with materials • Leaves a heavy residue

PUMP NOISES AND VIBRATION:

- The noise emitted by pumps and systems is caused by vibrations in the piping and the pump casing.
- These vibrations interact with the surrounding air and are perceived as airborne sound.
- Transient flow and the pressure fluctuations associated with it produce this effect.
- The fluctuations occur when energy is transferred via the impeller vanes to the fluid handled.
- The finite number of vanes leads to periodic pressure fluctuations with amplitudes of varying intensity.
- Since the flow encounters continually increasing static pressure, the boundary layers are at great risk of separating.
- The flow pattern of the fluid flowing around the vanes as well as flow separation make the flow in a centrifugal pump transient.
- For single-stage volute casing pumps comprising a few basic components, these transient flows are the main source of noise apart from that generated by the drive of the centrifugal pump.
- Multistage pumps with balancing devices also produce substantial turbulence noise resulting from the characteristically high delivery heads of the individual stages, as can higher pressures when they are relieved in balancing devices.
- The aforementioned sources of noise relate to pumps and systems operated in the absence of cavitation. When cavitation occurs in a pump or valve, the level of noise produced is considerably high.

- Cavitation noise typically sounds like a high-pitched crackling and transitions to an intense rattling sound when the effect intensifies
- The trend toward higher rotational speeds exacerbates the problem of noise in centrifugal pumps, which leads to smaller, more powerful machines (increased power density).
- Adding to this is the fact that better use is being made of materials to reduce wall thickness.

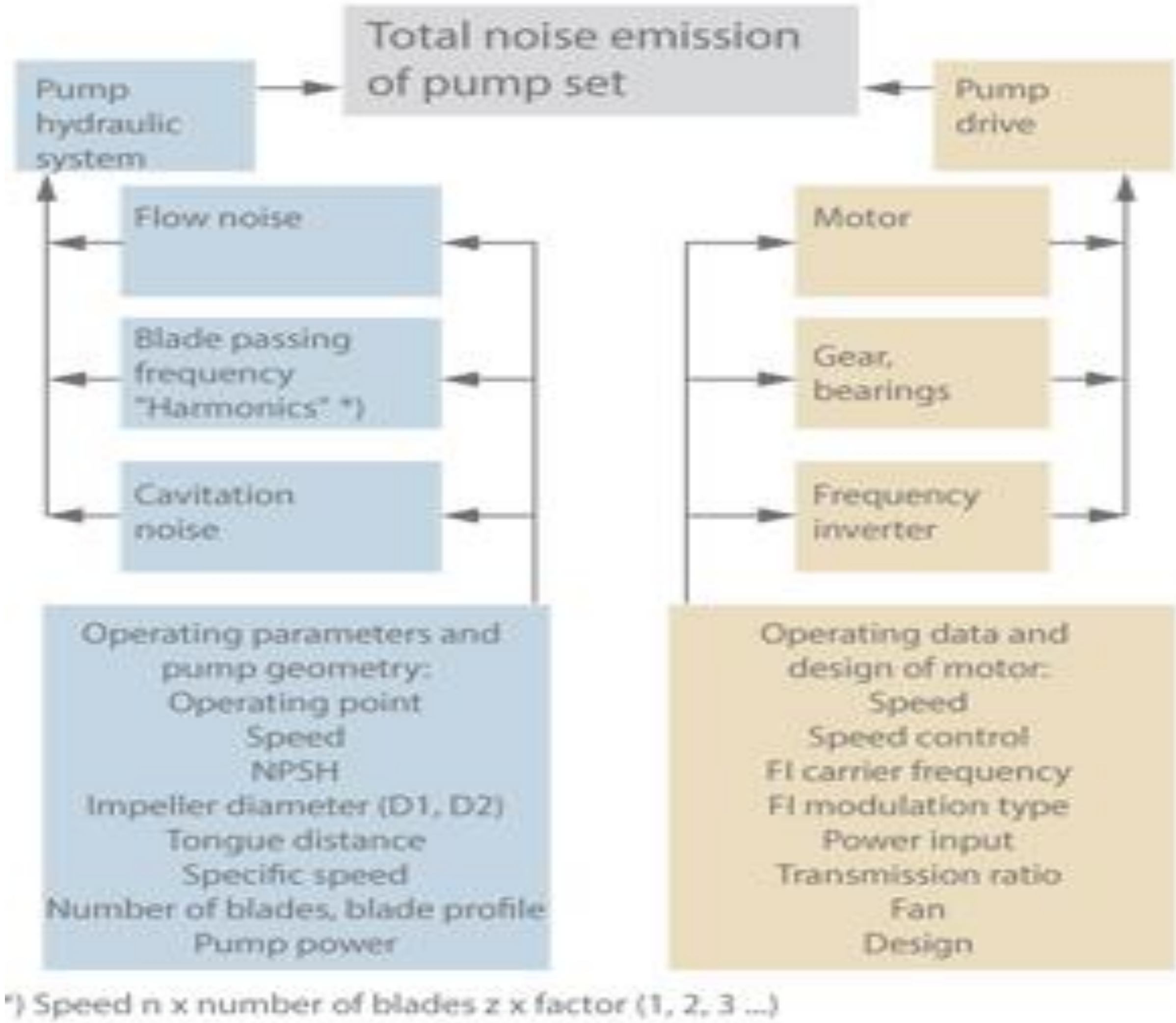


Fig- 20: Noise in pumps and systems: Factors influencing total noise emissions of the pump

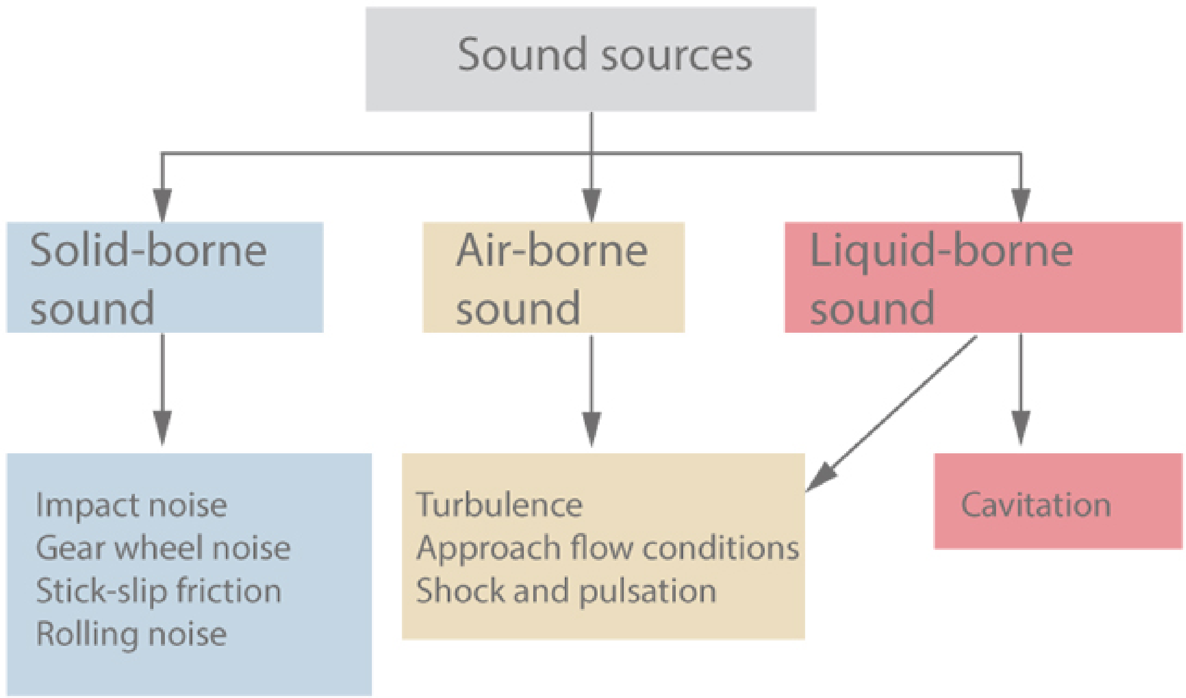


Fig-21: Noise in pumps and systems: Centrifugal pump sound sources

NOISE CONTROL:

- The most critical active sound-absorbing measure for noise control is the correct selection of the pump itself, which must be designed for the task in question and have the correct size.
- The sound of a centrifugal pump varies in intensity along its H/Q curve depending on the operating point.
- To conserve energy and minimise noise, pumps should generally be run at the operating point that provides optimum pump efficiency. Noise is usually lowest when the pumps are operated at a speed near BEP.
- Passive sound-absorbing measures are a necessity when centrifugal pumps are used in applications with stringent noise restrictions, and include expansion joints in the piping, installation of the pump set on rubber-metal or spring mounts, in sound enclosures and insulated rooms in which pump sets are operated with special sound-proofing or sound-dampening panels.

Selection of Pumps:

1. Process Liquid Properties:

- What type of liquid is the pump intended for? Below are process liquid properties that must be considered before selecting a pump.
- Liquid viscosity
- Temperature
- Specific gravity
- Vapor pressure
- Solids present & concentration
- Shear sensitive
- Abrasive or Non-abrasive

2. Materials of Construction:

- What materials of construction are compatible with the process liquid or any other liquids the pump might come into contact with.
- Chemical compatibility charts are available to help you identify the most appropriate materials of construction for the pump.

3. Is the Pump Critical to Plant Operation?

- In critical applications, where downtime is NOT an option, more expensive, heavy-duty pumps with special features can be chosen. If pumps can be removed from service for maintenance, less expensive options could be considered.

4. Pump Inlet Conditions

- We don't want to starve a pump. System Net Positive Suction Head (NPSH) available is calculated by knowing pump inlet pressure and liquid vapor pressure. Always make sure NPSHA exceeds pump Net Positive Suction Head (NPSH) required.

5. Pump Environment

- If your pump will be outside, special construction or installation considerations may need to be made for freezing temperatures. If the environment is hazardous, contains explosive vapors or dust, special motor features will be required. These are just a few examples of environmental conditions to consider.

6. Power Source Availability

- The most common power source in India is 230 V and 50 Hz (single & 3 phase system) & in the United States is 115-230 Volts/60 Hertz/1-phase or 230-460 Volts, 60 Hertz/3-phase.
- Special motors can be specified for operation or by using DC batteries. Compressed air or pressurized hydraulic oil can also be used for power.

7. Flow Rate and Pressure

- Your total volume and knowing how much time you have to move the fluid will determine flow rate. Pump differential pressure can be calculated by knowing pipe size (length & fittings), static lifts, and system equipment (filters, valves, etc.) friction losses

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UNIT – V – Process Control System Components – SIC1406

ANNUNCIATOR ALARM CIRCUITS:

The purpose of an alarm system (annunciator) is to bring attention to an abnormal or unsafe operating condition in the plant. Traditional annunciators used discrete alarm modules for this purpose. These dedicated hardware units are diminishing in numbers yet are still used in installations where simplicity is desired or where separation from the basic process control system is required for safety reasons. In some installations where traditional units have been replaced by PLC- or DCS-based annunciators, the recognition of and response to alarm conditions have deteriorated because on computer screens they are not very visible and can go unnoticed. In addition, because of the low incremental cost of adding new alarm points, excessive numbers of alarms been configured. Because of the floods of alarms, an important new component of safety system design is alarm rationalization and alarm management.

It is possible to connect conventional annunciators as frontend devices to DCS systems through various communication links. There is a wide variety of such links available, ranging from serial links employing MODBUS protocol to Ethernet links utilizing Object Linking and Embedding (OLE) for Process Control (OPC). This hybrid solution adds the visibility, reliability, and built-in redundancy of dedicated annunciators to the flexibility and record-keeping convenience of DCS based systems.

More sophisticated annunciator designs can incorporate bar graph-type displays, color computer graphics, and event recording or data-logging systems. Much of the new development in annunciator system designs involves enhanced methods of communication and reporting. As a consequence, annunciator status can be logged and used for tasks such as alarm management and abnormal event analysis. Graphic displays can be dynamic, where flow in pipes is shown by actual movement, and CRT displays can concentrate large amounts of information into a single display. Figure 1 illustrates such a display, where the CRT displays the plot plan of the plant as the background. Such a plot plan can be separated into small square segments, so that if an unsafe condition is detected in a particular segment, the corresponding square can start flashing in the color that corresponds to the type of safety problem detected. This type of annunciator display is easily and quickly comprehended and can provide a summary report on a large number of safety conditions in an efficient manner.

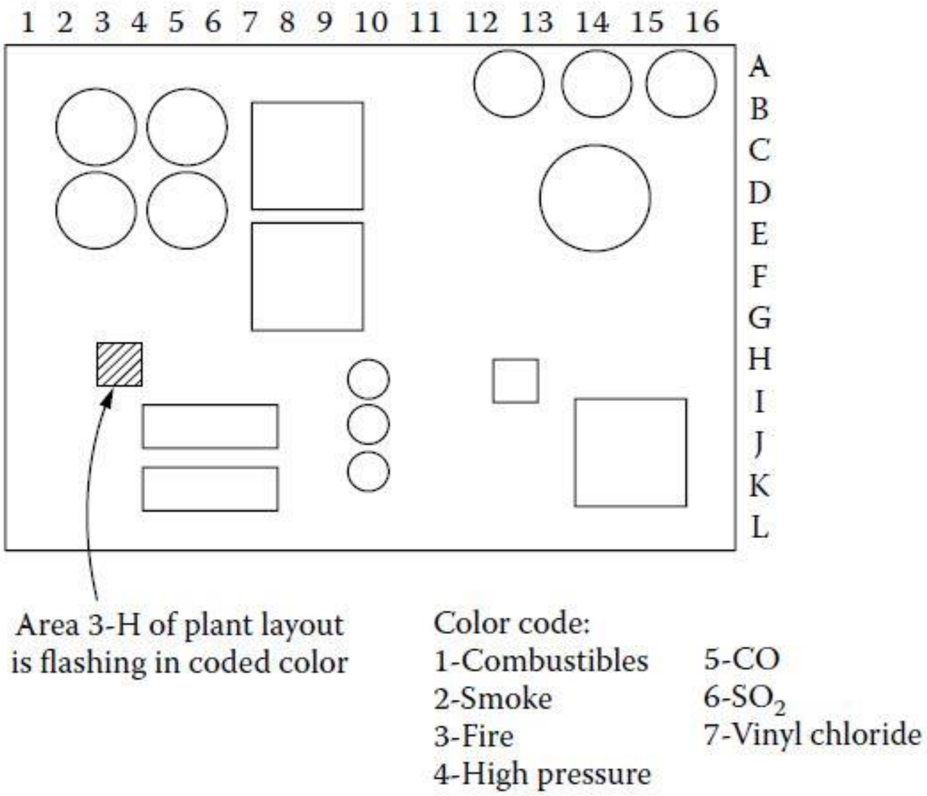

Fig-1: The overall safety status of the plant can be displayed on a single CRT.

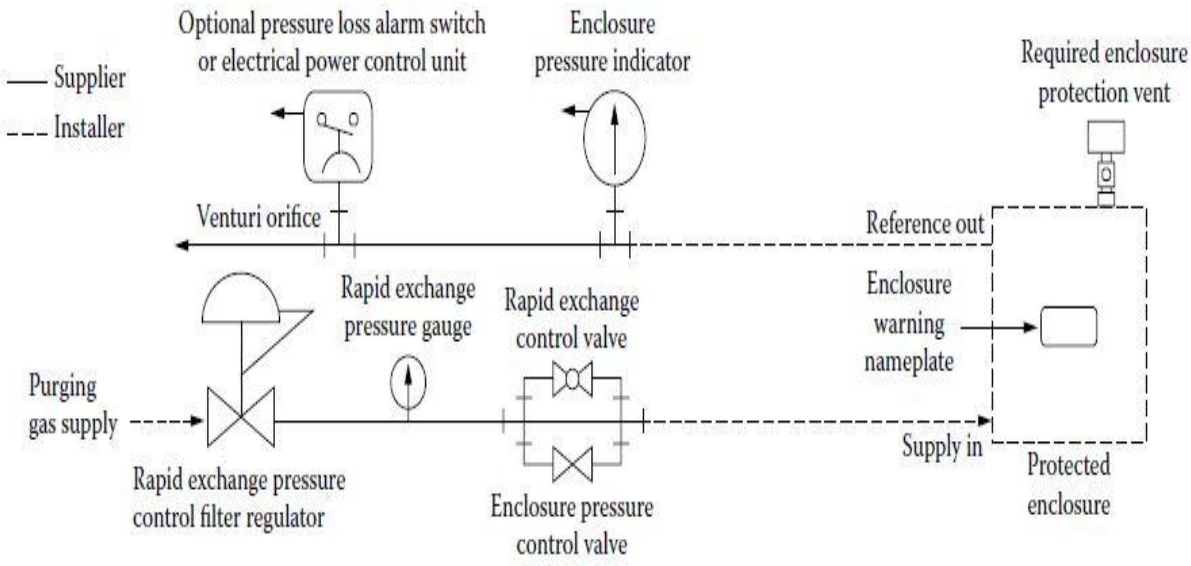

Fig-2: Local annunciators were available in explosion-proof designs or were mounted in air-purged enclosures when mounted in Class 1 areas.(from Bebco Industries)

The annunciators were compact, reliable, and because of the hermetically sealed relay logic modules, they could also be mounted in certain hazardous areas in addition to the general-purpose control rooms. In order to be mounted in Class 1 explosion-proof areas, they required purging (Figure 2). Miniaturization of instruments and the use of graphic control panels initiated the development of remote annunciator systems, consisting of a remotely mounted relay cabinet connected to alarm lights installed at appropriate points in the graphic or semigraphic diagram.

Principle of operation:

The annunciator system consists of multiple alarm points. Each alarm circuit includes a trouble contact (alarm switch), a logic module, and a visual indicator (Figure 3). The individual alarm points are operated from a common power supply and share a number of annunciator system components, including an audible signal generator (horn), a flasher, and acknowledge and test pushbuttons. In normal operation the annunciator system and individual alarm points are quiescent. The trouble contact is an alarm switch that monitors a particular process variable and is actuated when the variable exceeds preset limits. In electrical annunciator systems it is normally a switch contact that closes (makes) or opens (breaks) the electrical circuit to the logic module and thereby initiates the alarm condition. In the alert state, the annunciator turns on the visual indicator of the particular alarm point, the audible signal, and the flasher for the system. The visual indicator is usually a backlighted nameplate engraved with an inscription to identify the variable and the abnormal condition, but it can also be a bull's-eye light with a nameplate.

The audible signal can be a horn, a buzzer, or a bell. The flasher is common to all individual alarm points and interrupts the circuit to the visual indicator as that point goes into the alert condition. This causes the light to continue to flash intermittently until either the abnormal condition returns to normal or is acknowledged by the operator. The horn acknowledgment pushbutton is provided with a momentary contact: when it is operated, it changes the logic module circuit to silence the audible signal, stop the flasher, and turn the visual indicator on "steady." When the abnormal condition is corrected, the trouble contact returns to normal, and the visual indicator is automatically turned off. The lamp test pushbutton with its momentary contact tests for burned-out lamps in the visual indicators. When activated, the pushbutton closes a common circuit (bus) to each visual indicator in the annunciator system, turning on those lamps that are not already on as result of an abnormal operating condition.

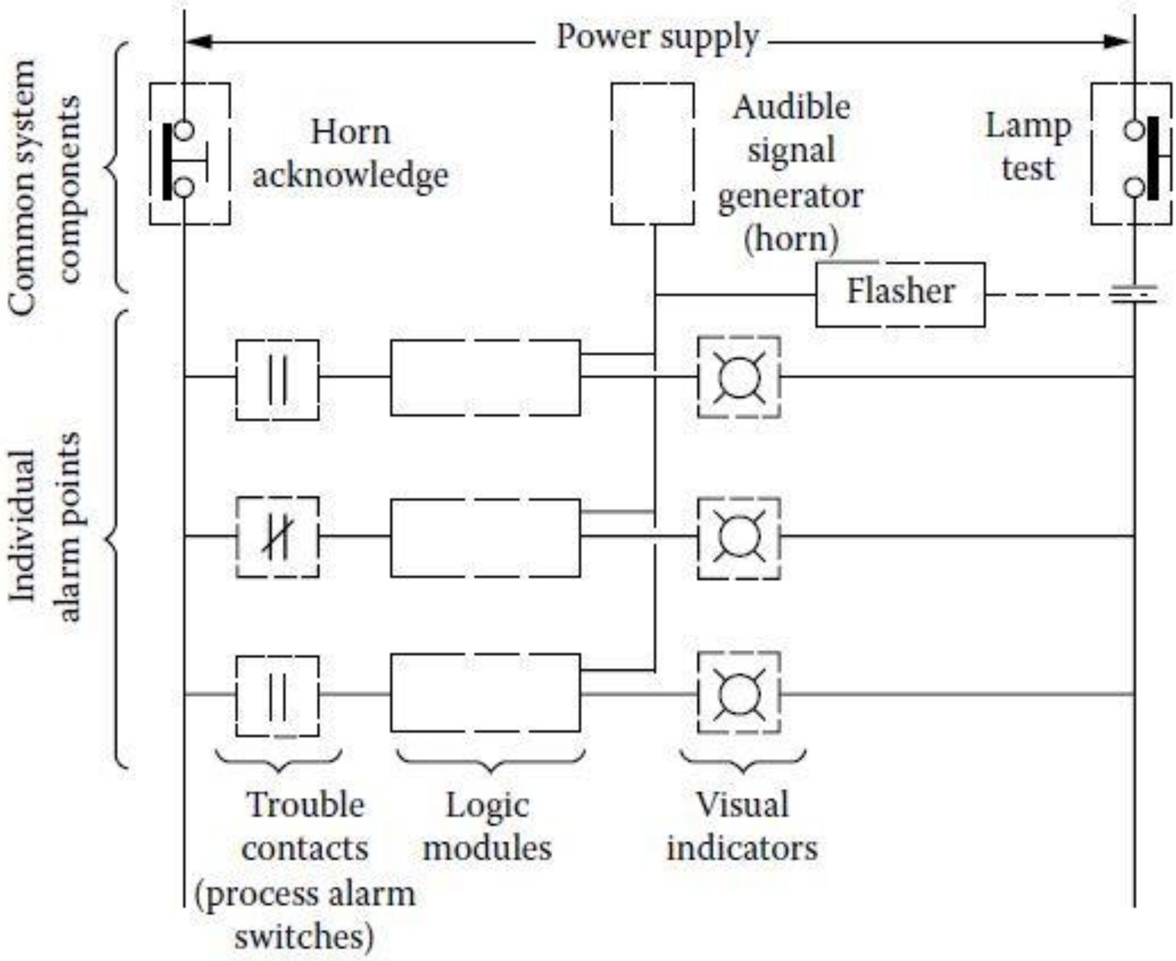

Fig-3: The main components of a traditional annunciator system.

A wide variety of sequences are available to define the operation of an individual alarm point in the normal, alert, acknowledged, and return-to-normal stages in the annunciator sequence. The five most commonly used annunciator sequences are shown in Table 1, identified by the original code designation of the Instrumentation, Systems, and Automation Society (ISA). These sequences were specified by the ISA-recommended practice RP-18.1, which has since been revised and updated into standard ISA 18.1. Because the old sequence designations are still used in some plants, some of their more common versions are listed in Table 1 and also described below. The sequence designations of the present standard ISA 18.1 will also be discussed below.

Table-1: The Old ISA Designations of Annunciator Sequences

The Old ISA Designations of Annunciator Sequences

ISA Code for the Sequence	*Annunciator Condition*	*Process Variable Condition (Trouble Contact)*	*Visual Indicator*	*Audible Signal*	*Use Frequency*
IB	Normal	Normal	Off	Off	55%
	Alert	Abnormal	Flashing	On	
	Acknowledged	Abnormal	On	Off	
	Normal again	Normal	Off	Off	
	Test	Normal	On	Off	
ID	Normal	Normal	Dim	Off	1%
	Alert	Abnormal	Flashing	On	
	Acknowledged	Abnormal	On	Off	
	Normal again	Normal	Dim	Off	
2A	Normal	Normal	Off	Off	4%
	Alert	Abnormal	Flashing	On	
	Acknowledged	Abnormal	On	Off	
	Return to normal	Normal	Dim flashing	On	
	Reset	Normal	Off	Off	
	Test	Normal	On	Off	
2C	Normal	Normal	Off	Off	5%
	Alert	Abnormal	Flashing	On	
	Acknowledged	Abnormal	On	Off	
	Return to normal	Normal	On	Off	
	Reset	Normal	Off	Off	
	Test	Normal	On	Off	
4A	Normal	Normal	Off	Off	28%
	Alert	Abnormal			
	Initial		Flashing	On	
	Subsequent		On	Off	
	Acknowledged	Abnormal			
	Initial		On	Off	
	Subsequent		On	Off	
	Normal again	Normal	Off	Off	
	Test	Normal	On	Off	
All others					7%

ISA Sequence 1B, also referred to as flashing sequence A, is the one most frequently used. The alert condition of an alarm point results in a flashing visual indication and an audible signal. The visual indication turns off automatically when the monitored process variable returns to normal.

The New ISA Designations of Annunciator Sequences as Defined by ISA Standard ISA 18.1

Sequence	Signal Device	Normal	Alert	Condition-sensing Returns to Normal Before Acknowledge	Acknowledge	Condition-sensing Returns to Normal	Return to Normal Reset	Remarks
A	Visual	Off	Flash	Flash	On	Off	—	Flasher memory
	Audible	Off	On	On	Off	Off	—	
A-5	Visual	Off	On	On	On	Off	—	Memory
	Audible	Off	On	On	Off	Off	—	
A-4	Visual	Off	Flash	Off	On	Off	—	Flasher
	Audible	Off	On	Off	Off	Off	—	
A-4-5	Visual	Off	On	Off	On	Off	—	
	Audible	Off	On	Off	Off	Off	—	
A-13	Visual	Dim	Flash	Flash	On	Dim	—	Memory—flasher
	Audible	Off	On	On	Off	Off	—	Continuous lamp test

ISA Sequence 1D (often referred to as a dim sequence) is identical to Sequence 1B except that ordinarily the visual indicator is dim rather than off. A dimmer unit, common to the system, is required. Because all visual indicators are always turned on—for dim (normal), flashing (alert), or
steady (acknowledged)—the feature for detecting lamp failure is unnecessary.

ISA Sequence 2A (commonly referred to as a ring-back sequence) differs from Sequence 1B in that following acknowledgment the return-to-normal condition produces a dim flashing and an audible signal. An additional momentary contact reset pushbutton is required for this sequence. Pushing the reset button after the monitored variable has returned to normal turns off the dim flashing light and silences the audible signal. This sequence is applied when the operator must know if normal operating conditions have been restored. ISA Sequence 2C is like Sequence 1B except that the system must be reset manually after operation has returned to normal in order to turn off the visual indicator. This sequence is also referred to as a manual reset sequence and, like Sequence 2A, requires an additional momentary contact reset pushbutton. Sequence 2C is used when it is desirable to keep the visual indicator on (after the horn has been silenced by the acknowledgment pushbutton) even though the trouble contact has returned to normal. ISA Sequence 4A, also known as the first-out sequence, is designed to identify the first of a number of interrelated variables that have exceeded normal operating limits. An off-normal condition in any one of a group of process variables will cause some or all of the remaining conditions in the group to become abnormal. The first alarm causes flashing, and all subsequent points in the group turn on the steady light only. This sequence monitors interrelated variables. The visual indication is turned off automatically when conditions return to normal after acknowledgment.

New ISA Sequences:

In the updated annunciator standard ISA 18.1, the sequence designations are different, as shown in Table above. The most widely used sequence, the basic flashing sequence, is now designated as sequence A. The sequence designations in ISA 18.1 use the following letter codes:

A = Automatic Reset

M = Manual Reset

R =Ringback

F = First-out

Therefore, using the ISA 18.1 sequence designations A-13 means that the annunciator has automatic reset and is provided with Option 13, which suggests the presence of a dim lamp monitor. For definitions of less frequently used
sequences, refer to ISA 18.1.

Optional Operating Features:

Annunciator sequences may be initiated by alarm switch trouble contacts that are either open or closed during normal operations. These are referred to as normally open (NO) and normally closed (NC) sequences, respectively, and the ability to use the same logic module for either type of trouble contact is called an *NO-NC option.*

It is important because some alarm switches are available with either an NO or an NC contact but not with both, and therefore without the NO-NC option in the logic module two types of logic modules would be required. The logic module is converted for use with either form of contact by a switch or wire jumper connection. The relationship between the NO and NC sequences required in the logic module to match the various trouble contacts and analog measurement signal actions is shown in Figure 4.

A high alarm in a normally closed annunciator system requires a normally closed trouble contact operated by a direct-acting analog input. If an increase in the measured variable results in an increased output signal, the detector is direct acting; if the output signal is reduced, it is a reverse-acting sensor. If the trouble contacts in all alarm switches in the plant are standardized such that normal operating conditions will cause all trouble contacts to be NC (or NO), the required annunciator sequence is also NC (or NO), and Figure 3.1f need not be consulted. Annunciator systems are fail safe or self-policing if they initiate an alarm when the logic module fails because of relay coil burnout. The feature is standard for most NO and NC annunciator sequences; annunciators using NC trouble contacts are also fail safe against failures in the trouble contact circuit. The lock-in option locks in the alert condition initiated by a momentary alarm until the horn acknowledgment button is pushed, preventing loss of a transient alarm condition until the operator can identify it. The logic module is usually changed from lock-in to non lock-in operation by either addition of a wire jumper or operation of a switch. The lock-in feature is useful for monitoring unstable or fluctuating process variables.

ANNUNCIATOR TYPES:

The audiovisual annunciator can be packaged as an integral, remote, or semigraphic annunciator.

Integral Annunciator:

The integral annunciator, a cabinet containing a group of individual annunciator points wired to terminal blocks for connection to external trouble contacts, power supply, horn and acknowledge and test pushbuttons, is the most economical of the various packaging methods available in terms of cost per point. It is also the simplest and cheapest to install. Two methods of packaging integral annunciators are illustrated in Figure below. In the nonmodular type, plug-in logic modules are installed inside the cabinet and connected to alarm windows on the cabinet door through an interconnecting wiring harness; in the modular type, individual plug-in alarm point assemblies of logic module and visual indicator are grouped together. The nonmodular and modular cabinet styles are both designed for flush panel mounting with the logic modules and visual indicators accessible from the front. Electrical terminals for the external circuitry are located in the rear of the cabinet and are accessible from the back. Integral annunciators are used on nongraphic and on semigraphic control panels in which physical association of the visual indicators with a specific location in the graphic process flow diagram is not required. Integral annunciator cabinets occupy more front but less rear panel space than the equivalent remote designs. The electrical terminals are in a general-purpose enclosure at the rear of the cabinet, and trouble contacts can be wired directly to them, thus eliminating the need for and resultant costs of intermediate terminal blocks for trouble contact wiring.

An advantage of the modular-type cabinet is that it can be expanded by enlargement of the panel cutout and by the addition of modular alarm point assemblies. Nonmodular cabinets cannot be expanded, and new cabinets must be installed to house additional alarm points. Consequently, one should include more spare points when specifying the cabinet size for a nonmodular system. The modular cabinet is also more compact, takes up less panel space, and has a greater visual display area per point than the nonmodular design. Figure 5 illustrates various configurations of visual indicators that can be supplied with integral annunciator cabinets. Many of these groupings are also available in single unit assemblies for remote annunciator systems.

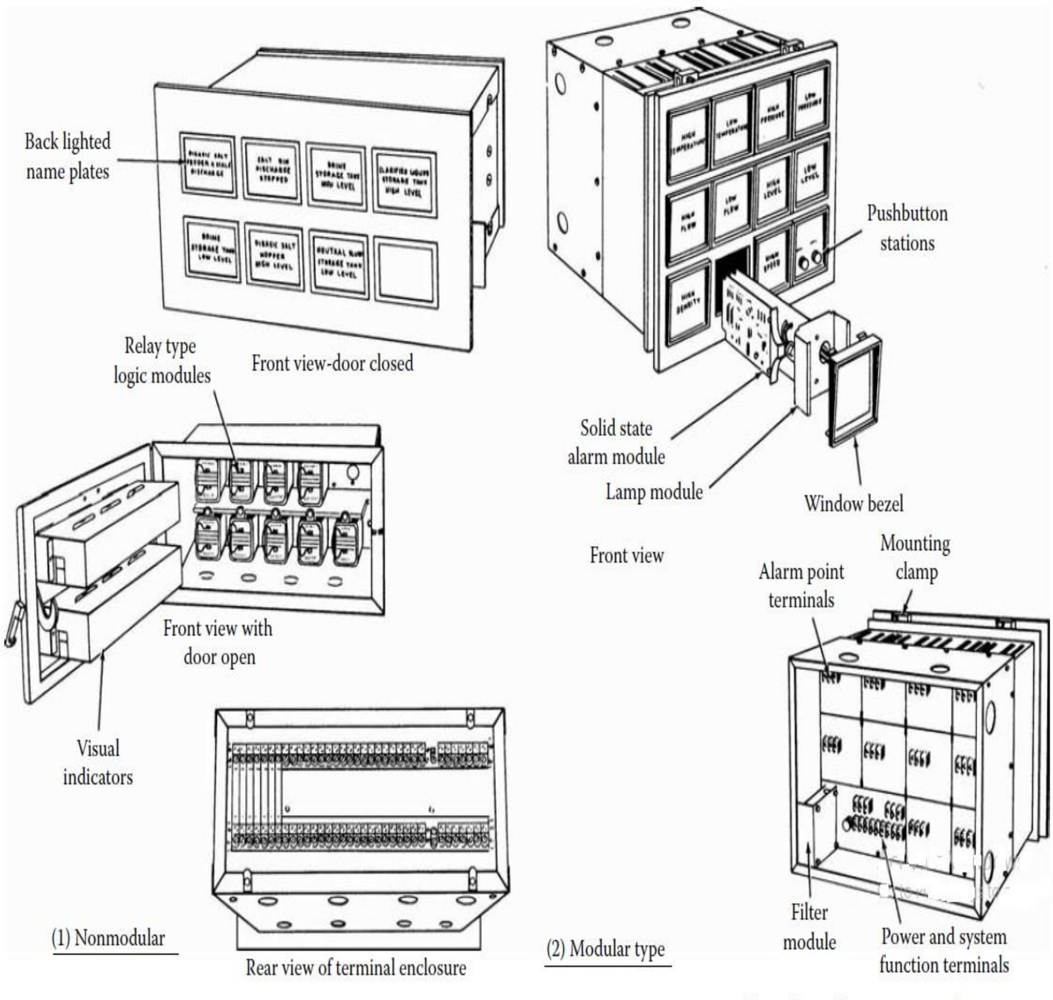

Fig-4: Integral annunciator cabinets are available in modular (right) and nonmodular (left) construction.

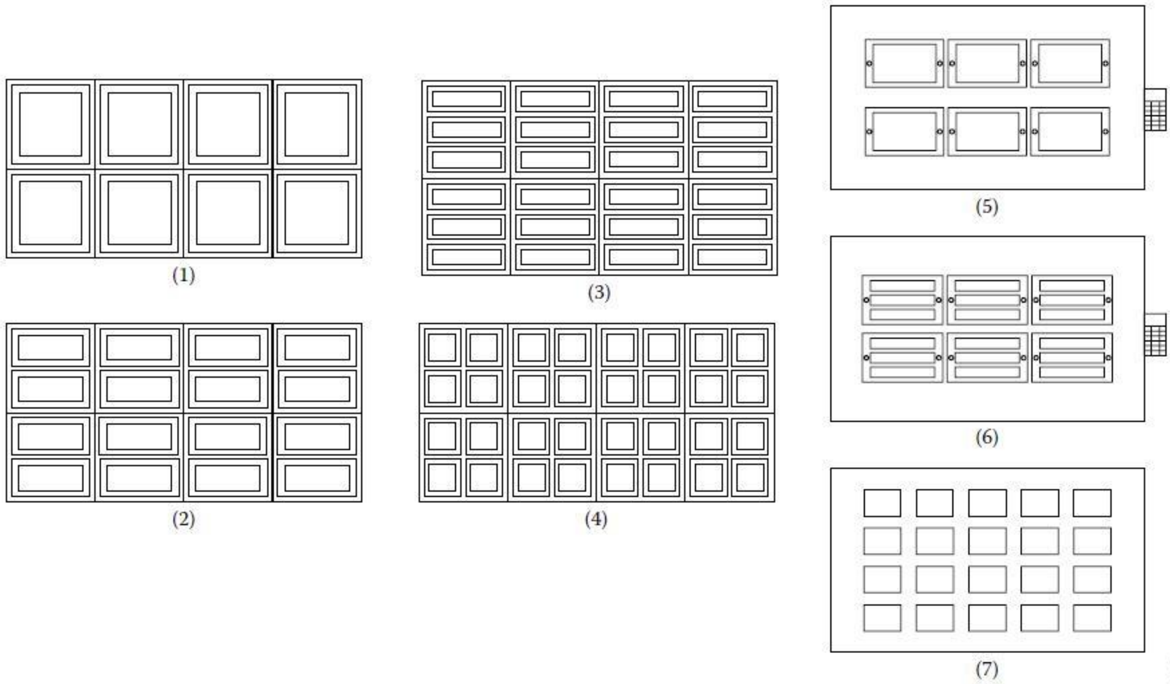

Fig-5: Integral annunciator window configurations. 1. Modular single-point annunciator. 2. Modular double-point annunciator. 3. Modular triple point annunciator. 4. Modular quadruple-point annunciator. 5. Nonmodular single-point. 6. Nonmodular triple-point. 7. Nonmodular singlepoint with small nameplate.

RECORDING ANNUNCIATOR:

Solid-state, high-speed, recording annunciators are available to amend or substitute a printed record of abnormal eventsfor only visual and/or audible alarms. These systems print out a record of the events and identify the variable, the time at which the alarm occurs, and the time at which the system returns to normal. They can also discriminate among a number of almost simultaneous events and print them out in the time sequence in which they occurred. A number of optional features, including secondary printers at remote locations, supplementary visual indication, and computer interfacing, are also available. The typical unit consists of logic, control, and printer sections.

The input status is continuously scanned. If a change in the trouble contacts has occurred since the preceding scan cycle, the central control places the exact time, the alarm point identification, and the new status of the trouble contact (normal or abnormal) into the memory and initiates the operation of the output control unit (Figure 6).

The output control unit accepts the stored information and transfers it to the printer, which logs the event. Following this, the memory is automatically cleared of the data and is ready to accept new information. In addition to or in place of the printer (if a permanent record is not required), a CRT display can serve as the event readout. Trouble contacts are connected to terminal points in the logic cabinet, and a cable connects the cabinet and the printer.

A recording annunciator can perform more sophisticated monitoring than an audiovisual annunciator and is correspondingly more expensive on a per-point basis. System cost per point decreases as the system size increases. Higher equipment cost, however, is offset in part by savings in control panel space and in installation costs. Recording annunciators are frequently used by the electrical power generating industry but may be applied to advantage in any industrial process that must monitor large numbers of operating variables and analyze abnormal events efficiently.

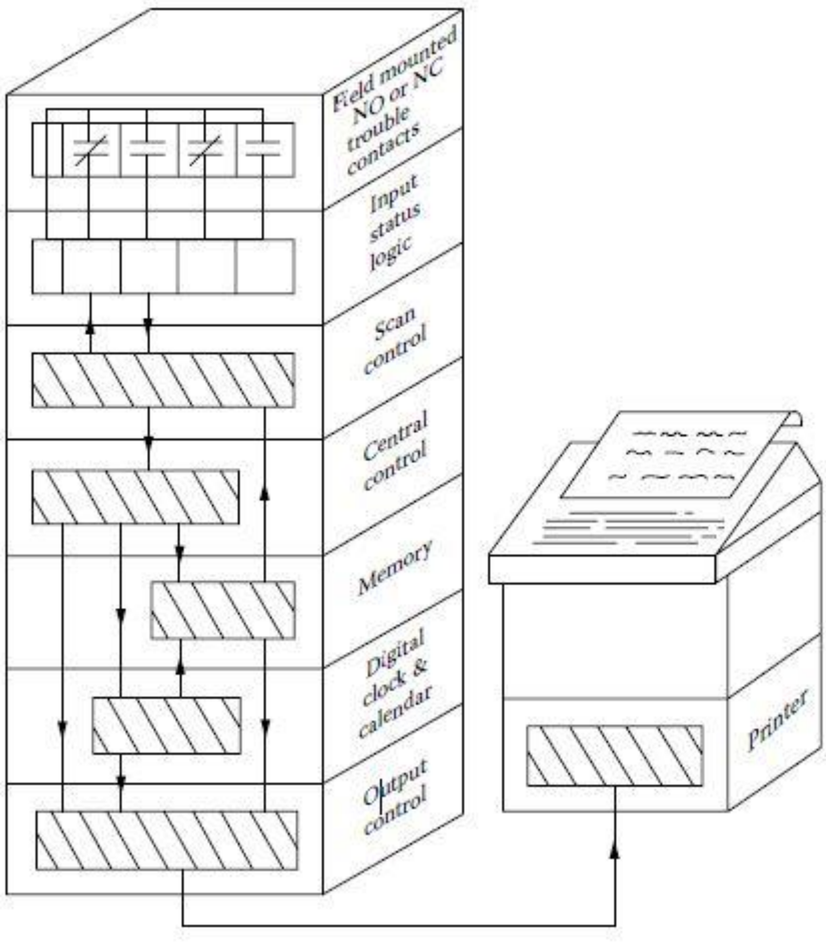

Fig-6: Recording annunciator.

Vocal Annunciators:

Vocal annunciators are unique in the type of abnormal audible message they produce. The audible output is a verbal message identifying and describing the abnormal condition when it occurs and repeating the message until the operator acknowledges the difficulty. The system continuously scans the trouble contacts, and when an abnormality is found, it turns on a flashing visual indicator and selects the optional proper verbal message for broadcast.

The visual indicator is turned off by the system when the point returns to normal. The control unit also arranges the messages to be broadcast in the order in which the difficulties occur. In the event of multiple alarms, the second message is played only after the first has been acknowledged. The flashing visual indicator for each point, however, turns on when the point becomes abnormal. The verbal message may be broadcast simultaneously in the control room and related operating areas, thus permitting personnel at the operating unit to correct the problem immediately.

Relay-Type Annunciators:

The basic element of this annunciator is an electrical relay wired to provide the logic functions required to operate a particular sequence. Figure 7 illustrates some of the basic relay designs. At least two relays per logic module are necessary for most sequences. The relays are installed and wired in a plugin assembly, which is the logic module for a single alarm point. The plug-in module assembly is usually hermetically sealed in an inert atmosphere to prolong the life of the relaymcontact. The sealing also makes the logic module acceptable in certain hazardous electrical areas. Figure 7 .1n is a semischematic electrical circuit for a remote system with sequence operation according to old ISA Sequence 1B (new Sequence A): Two logic modules are shown; one is in normally closed operation and the other is in normally open operation. The remote visual indicators for each alarm point, the horn, the flasher, and the acknowledge and test pushbuttons common to the system are also shown. Each logic module has two relays, A and B, shown in their de-energized state according to normal electrical convention.

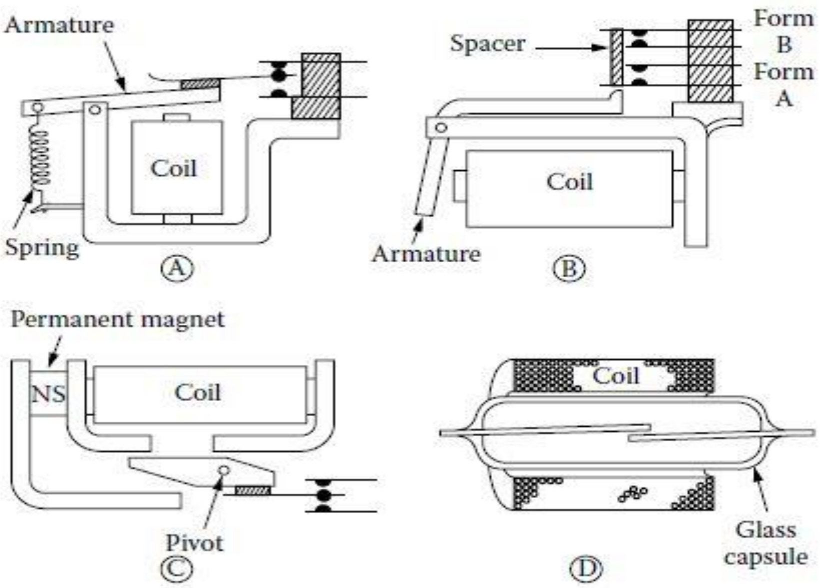

Fig-7: Standard electro-mechanical relay structures include: A) the clappertype, B) the phone-type, C) the balanced-force, and D) the Reed relay.

Semigraphic Annunciator:

The semigraphic annunciator developed in the late 1960s combines some of the advantages of the integral annunciator with the flexibility to locate visual indicators at appropriate points in a graphic flow diagram. Figure 8 illustrates a semigraphic annunciator.

It consists of a cabinet containing annunciator logic modules wired to visual indicators placed in a 3/4-inch (18.75-mm) lamp insertion matrix grid forming the cabinet front. The semigraphic display is placed between the lamp grid and a transparent protective cover plate, and the visual indicators are positioned to backlight alarm name plates located in the graphic display. The protective cover and lamp grid are either hinged or removable to provide access to the logic module and lamp assemblies.

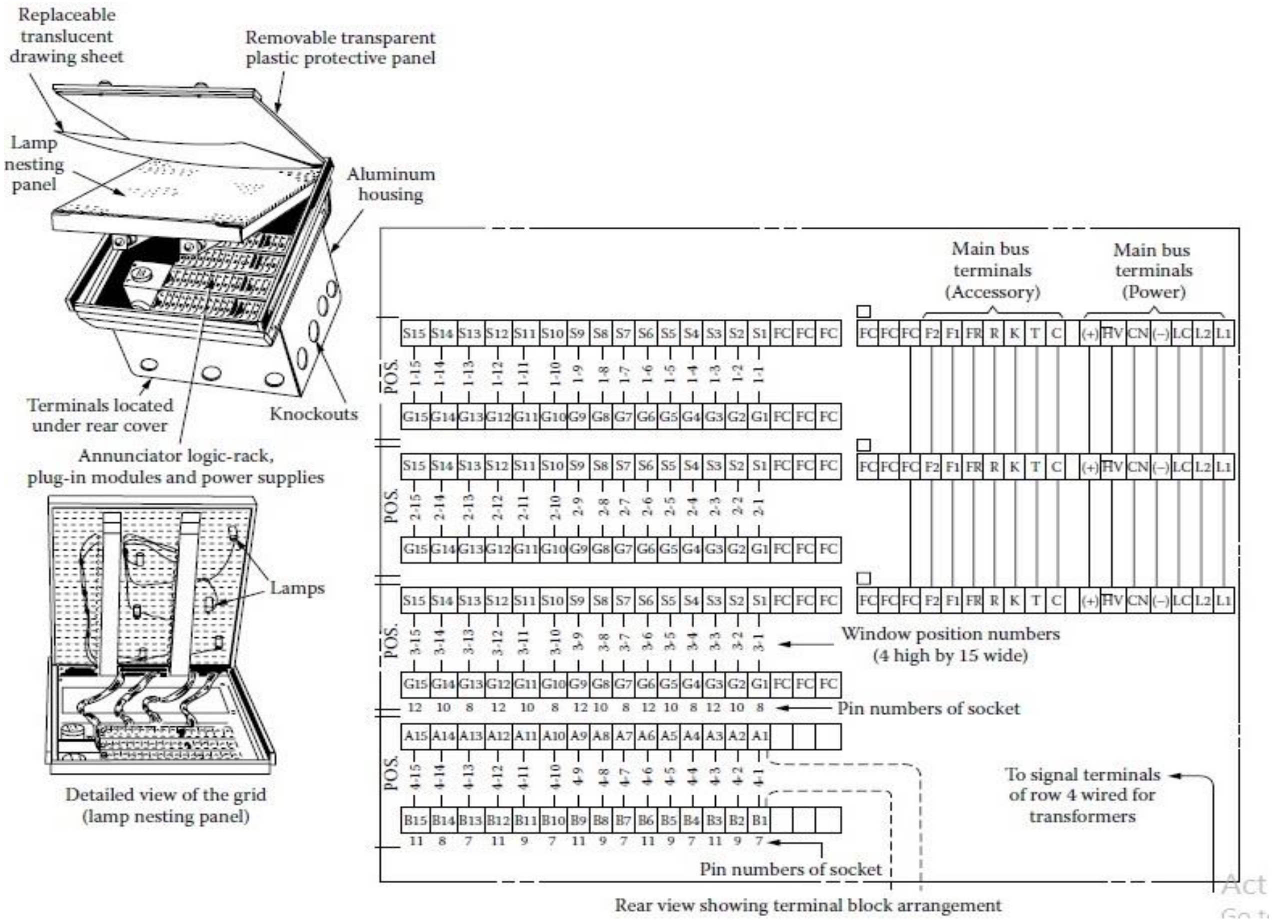

Fig-8: Construction of a typical semigraphic annunciator, showing the plug-in modules,the lamp nesting panel, and the arrangement of the terminal blocks on the rear of the unit.

The lamp assemblies are connected to intermediate terminals located behind the lamp grid, and the terminals in turn are connected to the logic modules. Terminal points for trouble contact wiring are in the back of the cabinet. The semigraphic annunciator is flexible, and changes in the annunciator system, graphic display, and related panel modifications can be made easily and cheaply. It is practical to prepare the graphic displays in the drafting room or model shop, thus protecting proprietary process information of a confidential nature. The graphic display has little or no effect on completing either the annunciator or the control panel because it can be installed on site or at any time.

The semigraphic annunciator has a high density of 40 alarm points per linear foot (0.3m) and a solid state rather than relay-type logic design. Power supplies are self-contained in the semigraphic annunciator cabinet. Front panel layouts illustrating integral, remote, and semigraphic annunciators are shown in Figure 9. Integral systems similar to the one shown at the left in the figure are normally specified on nongraphic control panels. The graphic panel in the center contains a remote annunciator with backlighted nameplates (shaded rectangles) and pilot lights (shaded circles) for visual indication. The remote system may also be used with miniature lamps in a semigraphic display similar to the one shown at the right.

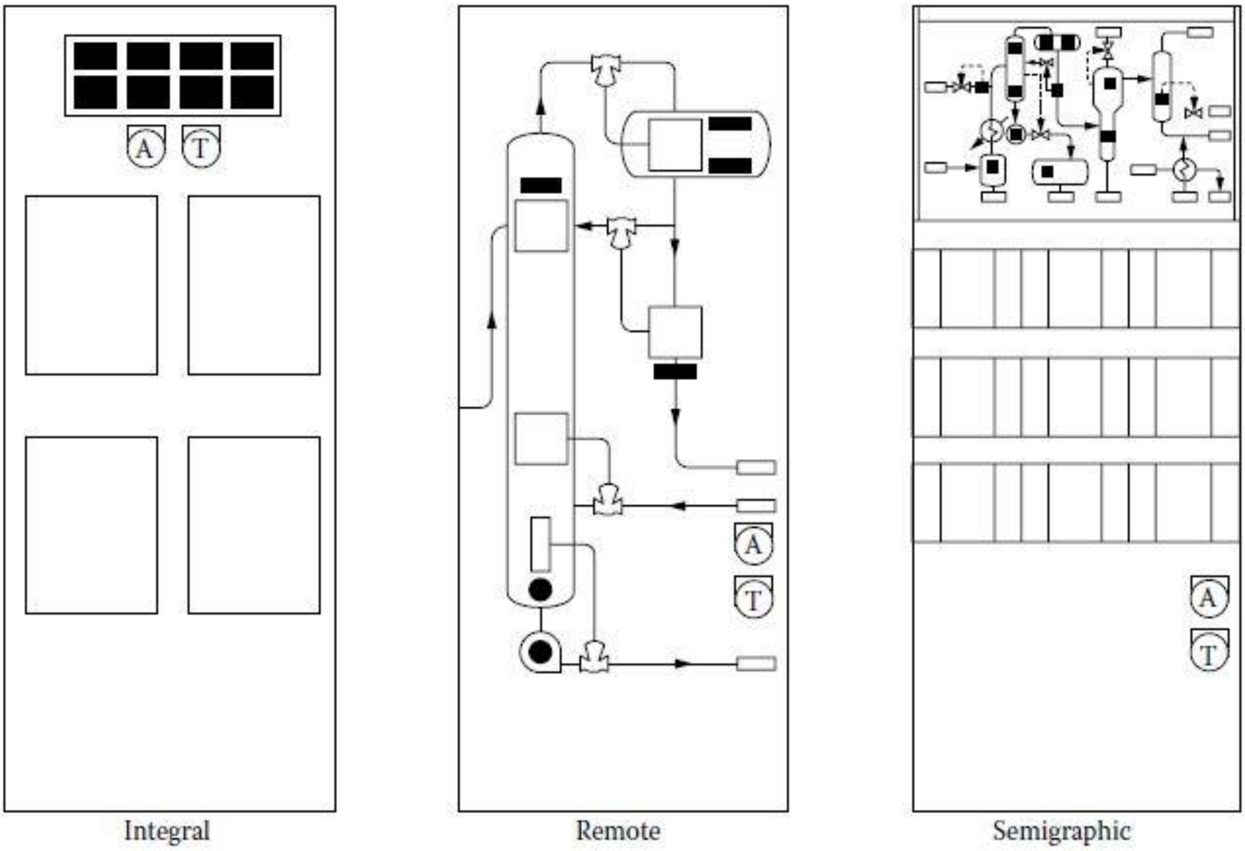

Fig-9: Control panels with integral, remote, and semigraphic annunciators.

INTERLOCKS:

An interlock is a feature that makes the state of two mechanisms or functions mutually dependent. It may be used to prevent undesired states in a finite-state machine, and may consist of any electrical, electronic, or mechanical devices or systems. In most applications, an interlock is used to help prevent a machine from harming its operator or damaging itself by preventing one element from changing state due to the state of another element, and vice versa. Elevators are equipped with an interlock that prevents the moving elevator from opening its doors, and prevents the stationary elevator (with open doors) from moving.

Safety systems and safety interlocks must be integrated into the overall process controls of the plant. Safety interlocks serve the protection and safety of operators, equipment, and the environment. Two major types of interlocks are used:

Failure interlocks:

—which are continuously active and usually serve to initiate equipment shutdowns

Permissive interlocks:

—which evaluate conditions in order to allow the starting or the continuation of actions. Several control languages have been used to implement safety instrumented control strategies. The most often used languages used are ladder logic, SFCs, and function blocks. More recently there has been a move to embed safety features inside the DCS. Doing so leverages the configuration, diagnostics, alarming, history collection, and control capabilities of the DCS.

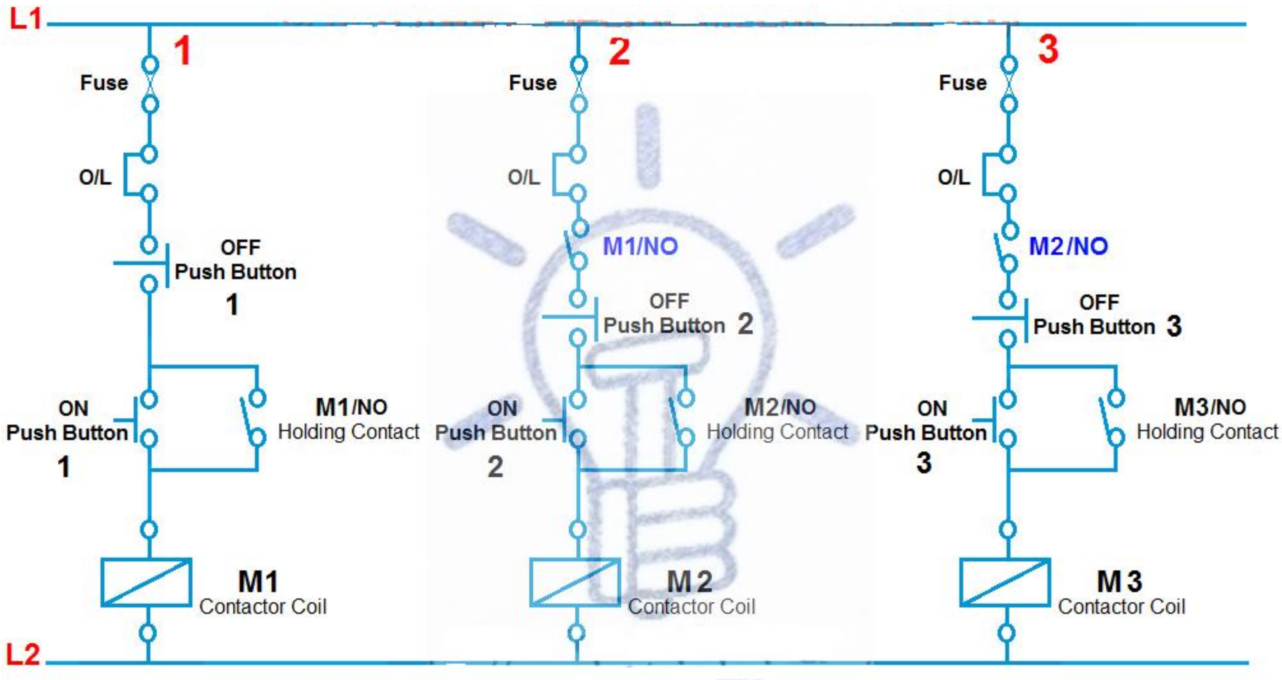

Fig-10: Electrical Interlocks.

To interconnect the motor circuit in such a way, in which the second motor will not start until the first one run likewise the third one motor will not run unless the second one run and so on. This kind of motor circuit connection is called interlocking.

A simple electrical interlocking control diagram is shown above in figure 10.

Working of Electrical Interlocking

When we push the ON-1 button to energies the M1 Contactor (or starts M1 Motor), then circuit complete through Fuse, Overload relay’s trip link, OFF Push -1 and ON Push 1. And motor M1 Starts to run. As Contactor M1 energies, it’s all normally Close (NC) links open and the other normally open (NO) links used in the circuit close.

When m1 energies, the normally open (NO) link will be closed immediately, which is in parallel with ON-Push 1. This is called Holding link i.e. it holds the motor in start condition. Now, Motor will still run even we leave (disconnect to stop) the ON-Push 1.

A normally open (NO) link is also used in line 2. When M1 energizes, this link (NO M1 in line 2) will be also closed, therefore, M1 Motor will start to run, this way, supply also will reach to ON Push 2. Now, if we press ON-Push 2, then second motor M2 will be also started to run, in addition, the normally open (NO) links of the connected contactor M2 in the circuit would be also closed immediately.

And Holding would be occurred through M2 link which is in parallel with ON-Push 2. This way, Motor 2 will start to run. Note that Motor 2 will not start to run until Motor 1 runs, i.e. unless Motor 1 link M1 close. Likewise, Motor 3 will not start until motor 2 runs, i.e. motor 3 will start (by pressing the On-Push of Motor 3 =M3) to run after start the motor 2.

In each control circuit, control fuse, and overload relays are connected for short circuit and overload protection respectively.

VALVE INTERLOCKS:

A valve interlock is a trapped key lock assembly which locks the valve in one or two positions - open and/or closed - with one key trapped within the lock assembly and one key free. It's about controlling the sequence of events, conducting different valve process activities.

To change the valve position (open-to-close or close-to-open), two keys need to be inserted into the lock assembly. The free key can only be released when the valve is in the open or closed position. Alternatively a 'single keyed interlock' only allows removal of the locked open or closed key when the valve is in the correct locking position.

Objective of the valve interlock system

What is a key interlock?

The types of interlock systems are based on the principle of key exchange or a key transfer principle. Valves can only be operated in a predetermined sequence which is designed to maintain production, availability and the safety of systems.

Integral-fit mechanical locking devices:

Key interlocks are integral-fit mechanical locking devices, attached to the host equipment. Typical interlock systems are applied to valves, closure doors, rotary switches or any form of equipment operated by human intervention. In addition, keys can be customized to intelligent format: electronic tagging of individual keys and managed by system software. The lock mechanism is designed to ensure that valves are always either fully open or fully closed. Generally, the system is based on the operating principle of one key free when the valve is locked closed and the other key free when the valve is locked open.

Valve Interlock system sample:

The type of interlock system below in figure 11 is designed to mechanically interlock two pressure safety valves having two upstream block valves and two downstream block valves to prevent isolation of both the relief valves at the same time and allow safe isolation of the safety valve for maintenance.

Operating condition of the valve interlock:

Note here PSV stands for “Pressure safety valve”

- One PSV (PSV-A) is operational and other PSV (PSV-B) is standby
- Key B is taken from the control room

To put PSV-B into maintenance:

- Insert key B into valve #4 and close by releasing key A
- Key A can be taken to the control room to keep PSV-B isolated for maintenance

To change-over putting PSV-A into operation and PSV-B into operation:

- Insert key B into valve #1 and open by releasing key C (both safeties are online)
- Insert key C into valve #2 and close by releasing key D, which can be taken to the control room

PSV-B is now in operation and PSV-A is in standby.

To further isolate PSV-A for maintenance:

- Insert key D into valve #3 and close releasing key E
- Key E can be taken to the control room to keep PSV-A isolated for maintenance

Both PSVs will never be closed simultaneously, ensuring that at least one PSV is always available for equipment protection.

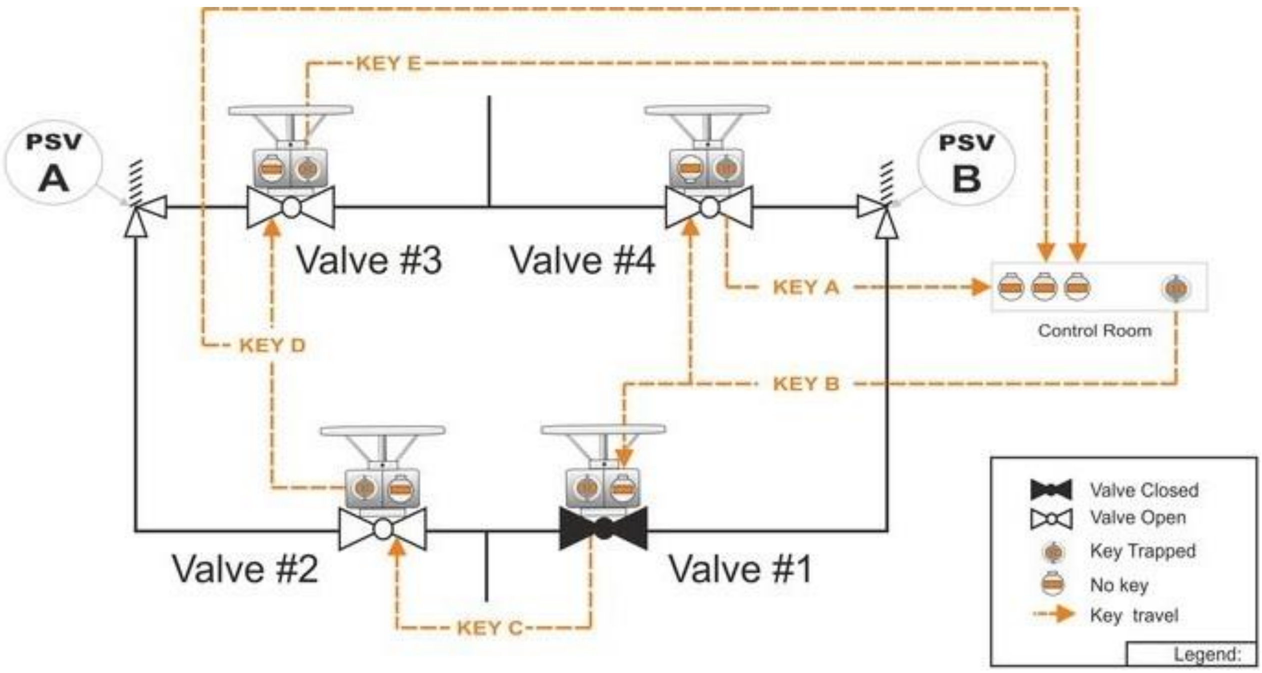

Fig-11: Sample Valve interlock system

DESIGN OF MICROPROCESSOR BASED PID CONTROLLER:

There are two approaches to general-purpose PID control systems: the analog approach and the digital approach. Conventional analog controllers use primarily RC circuits, transistors and operational amplifiers as computing elements. The hardware is simple, inexpensive and reliable; it is easy to operate and easy to service. However, the applications of such controllers are limited to the control of relatively simple loops. Analog controllers are not so suitable for systems with complicated loops or for large systems - it is easier to use a supervisory computer and CRT overview display than a large control panel. With analog controllers, flexibility and expandabilityare also lacking. DDC systems - using a large computer to supervise many loops - have progressed to distributed systems using microprocessor-based controllers which each handle eight or sixteen loops: such systems allow sophisticated analog control algorithms to be combined with sequential control. However, since each microprocessor handles severalloops, to protect against microprocessor failure the reliability has to be high - and backup analog controllers are required in some applications. The advent of one-chip microprocessors has made single loop controllers possible. The microprocessor based PID controller can have the features like:

(1) If possible, a combined A/D, D/ A converter rather than separate (costly) preCision *AID*, D/ A converters should be used.

(2) The converter needs high resolution and moderate speed.

(3) The microprocessor should incorporate PID control algorithms.

(4) A wide variety of controller variations should be possible.

(5) New controllers should resemble conventional analog controllers and be at least as easy to use.

(6) The controllers should be easy to interface to supervisory computer systems.

HARDWARE:

A/*D*, D/A Conversion Principles and Characteristics. Typical microprocessor-based systems scan analog inputs, convert them to digital signals using one or more dedicated or multiplexed A/D converters, process the digital signals in the microprocessor, and finally output the results via one or more dedicated or multiplexed D/A converters. Inputs and outputs are not simultaneous or continuous, but the input scan rate is fast enough for the input to appear continuous, and the output is held constant between updates - for example, by using sample and- hold networks. Disadvantages of systems with conventional A/D, D/A converters are that

(a) Using both *A/D* and D/A converters with high accuracy and high speed is quite expensive (such conversion is not needed in conventional controllers) and

(b) Unless an A/D, D/A converter is multiplexed, if more inputs and outputs are required, more microprocessor I/O ports and converters must be added. As explained below, our multiplexed A/D, D/ A conversion system "ADA" does not have these disadvantages.

Figure 12 explains the basic converter principles. A single D/ A coriverter is used for both A/D and D/ A conversion. (Using separate A/D and D/ A converters would cause span errors). A comparator compares the output from the D/ A converter with an input from the field. The microprocessor adjusts the converter output to equal the input Ei, thus eliminating A/D, D/ A converter span errors. The D/ A converter output is updated periodically; sample and hold circuitry is used so that the output appears (stepwise) continuous.

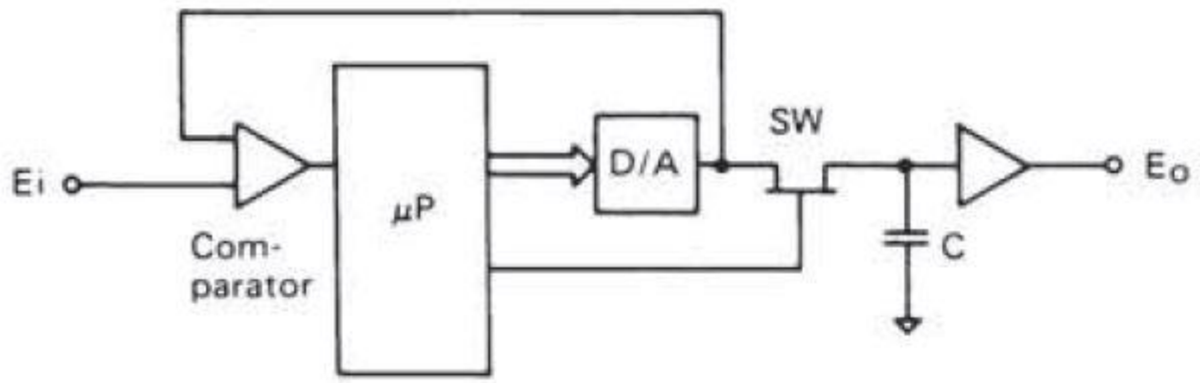

Fig-12: "ADC" Converter prinicples

Figure 13 shows the circuit of Fig. 12 extended using a multiplexer to provide for multiple inputs - e.g. measured variable, set point and parameter settings. If standard voltages are applied to two of the multiplexer inputs, the microprocessor can automatically perform periodic calibration of this converter - and update span and offset constants stored in RAM. For multiple analog outputs, identical sample and hold networks can be added. As shown by the dotted line in Fig. 13, the output from the first sample-and-hold network is fed back to the multiplexer input, so the microprocessor can automatically adjust the converter constants to compensate for sample-and-hold network characteristics.

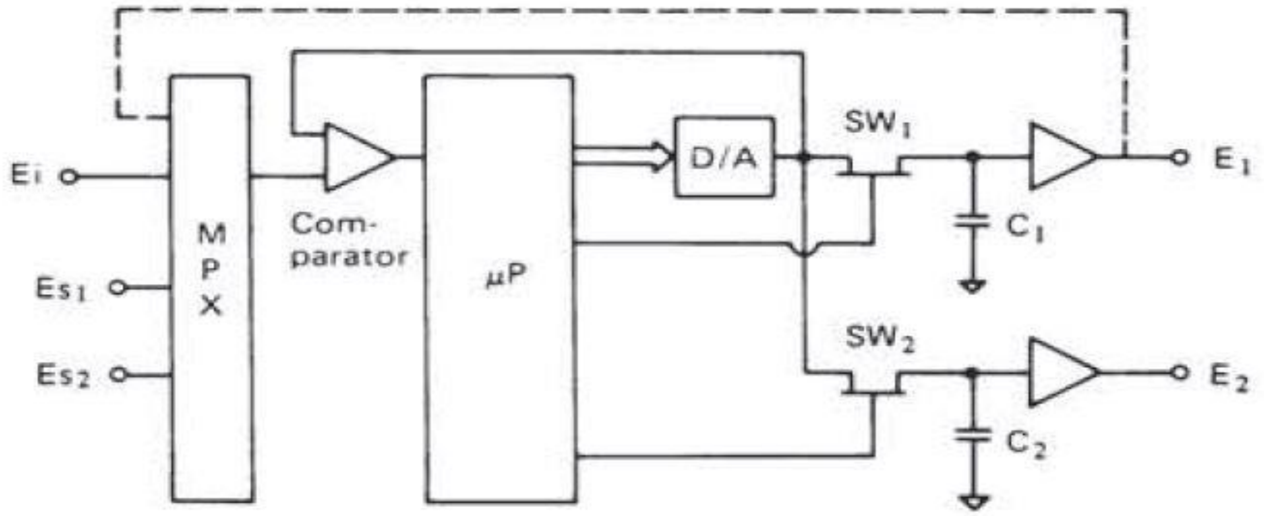

Fig-13: Multiplexed ADA converter

Because all inputs and outputs use the same D/ A converter, and because this autocalibration method is used, zero offset and span errors are virtually eliminated.

Application of this "ADA" Technology to a Basic PID Controller:

Figure 14 illustrates the basic principles. As well as the measurement value PV, inputs to the controller include the setpoint SV and the PID controller parameters.

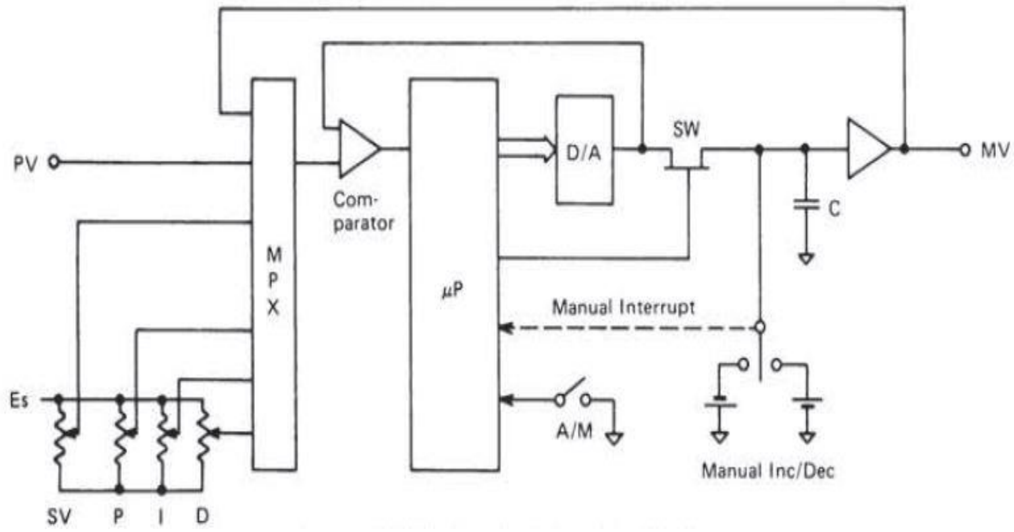

Fig-14: PID Controller Schematic Diagram.

The setpoint and parameters could be set digitally, but in this controller they are set using potentiometers as in conventional analog controllers. The controller outputs include the manipulated variable MV. A transfer circuit is required so that the controller can be used in manual mode. One input is provided for output tracking. The controller reads the process variable and the setpoint/parameter settings and performs PID control. PV and SV must be read accurately. The output signal (D/ A converter) update period is 0.1 second, and the sample and hold circuit holds the output signal.

PID Computation:

The PID computation is performed by microprocessor software. There is no interference between P, I and D settings. Conventional analog controllers require special low-leakage high-precision capacitors, high-value potentiometers (and semiconductor circuitry) with accurate non-linear characteristics. In this controller, non-linear para meter-setting potentiometer characteristics and derivative action ahead of PI action can be easily realized using software.

Auto/Manual transfer:

When the controller is switched from auto to manual mode, the previous output (charge on output capacitor) is maintained, so transfers between auto and manual modes are bumpless. When the manual lever is operated, the micro-processor opens FET switch SW. The manual lever is then used to adjust the output (voltage on the output capacitor) directly. The microprocessor then reads this value and periodically refreshes it via the D/ A converter - the output in manual mode is drift free. When the controller is switched from manual mode to auto, the PID controller is initialized so that the preceding manual output is its initial output.

Thus, even if there is a deviation between process variable and set point when the controller is transferred from manual to auto mode, transfer is bumpless and balanceless.

Backup Against Power Failure:

The setpoint SV and PID parameters are set by potentiometers, so the settings are retained even if power fails. The output MV is held by a sample and hold circuit, so if power to the circuit is lost, the output is held - an output drift in this case of 1% or less per ten minutes can be achieved. When power is reapplied, the voltage across the sample and hold circuit output capacitor is read and the controller is initialized so that the initial output equals the previous output.

Self-diagnostic features:

To check the A/D converter, one method is to convert a standard voltage, another is to apply the PV value to a potentiometer divider of known ratio and compare the two voltages. To check the D/ A converter, two standard voltages are used. Reading in a standard voltage via the A/D converter to RAM, outputting this voltage via the D/ A converter to the sample and hold network capacitor, and comparing this output with the standard input, checks A/D, D/ A and sample and hold circuits.

A watchdog timer is used for microprocessor diagnostics. If the normal strobe signals from the microprocessor to the watchdog timer are missing during a given time interval, the microprocessor is reset and restarted.

High resolution A/D converter:

When microprocessors are incorporated in an analog system, A/D converters are required at the interface, and so their characteristics affect the whole system.

Where moderate speed is required, successive approximation type A/D converters are common; for high resolution, linear-slope dual-slope type A/D converters are common. A new converter which combines successive approximation and dual slope converters - in order to realize the advantages of both - is described below. Its dual-slope converter performs interpolation to improve the resolution of the successive approximation converter.

Principles:

Figure 15 explains the basic principles.

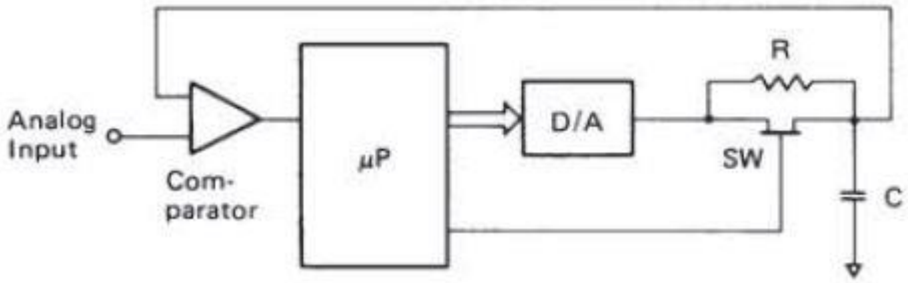

Fig:15: Principles of A/D converter configuration

Suppose that the analog input is between output steps n and n+ 1 of the D/ A converter). First, the micro-processor turns the FET ON and operates the successive approximation A/D converter (D/ A converter plus comparator) to measure the input with 8-bit resolution. With the output stable at step n (the voltage step just below the analog input), the microprocessor then turns the FET OFF and applies a D/ A converter output corresponding to step n+2. A timer interpolates between steps n and n+1- while the RC circuit charges until the voltage across the capacitor equals the analog input voltage - measuring time interval ta. The D/ A converter output is then set to correspond to step n+1, and the FET is turned ON to charge the capacitor.

The FET is turned OFF and the D/A converter output set to correspond to step n-l. The timer measures the time interval tb for the voltage across the capacitor to decay to equal the analog input. When (as shown in Fig. 16) a voltage differential corresponding to two steps is used to charge and discharge the RC time constant over an interval corresponding to one voltage step, the charge/discharge characteristic is relatively linear (nonlinearity 0.01 % of full span).

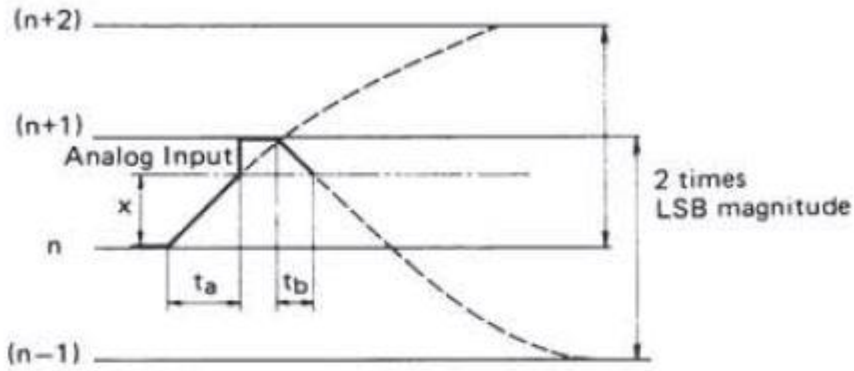

Fig-16: Converter waveforms

Experimental Results:

Figure 17 shows the experimental results. A ramp analog input was applied to our A/D converter, the result was digitally multiplied by 64 and applied to a separate high resolution D/ A converter. The 14-bit resolution of our A/D converter is seen to give a characteristic that is very close to linear. An 8085A microprocessor was used, and the A/D conversion time was 4 ms.

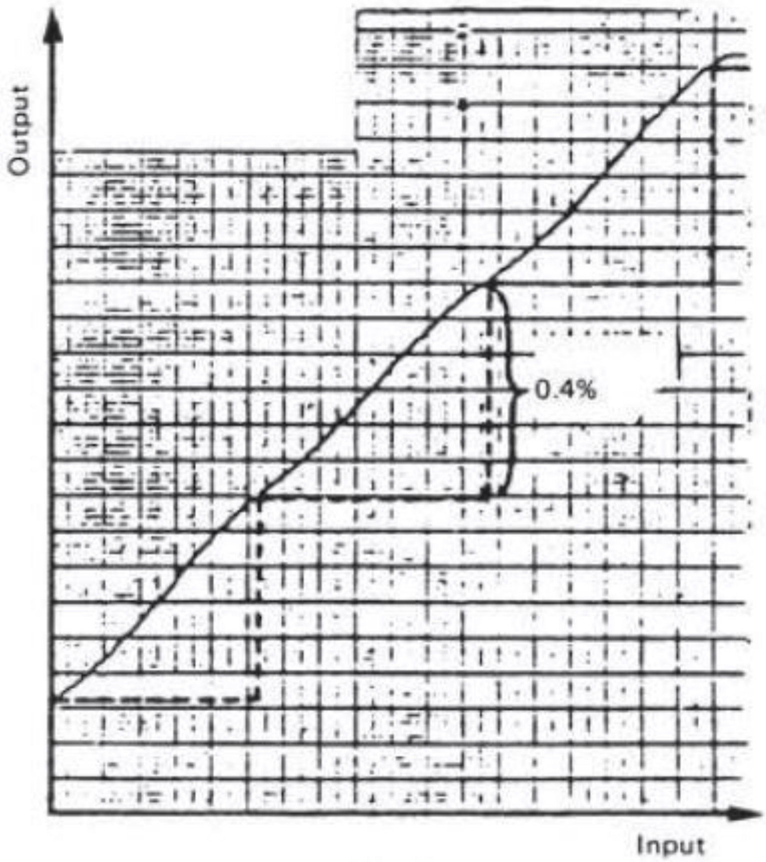

Fig-17: Experimental results

Software:

Most analog PID controllers give positional-type outputs, however many DDC systems have velocity-type outputs. Velocity type outputs are used because the output is unchanged if the system CPU fails. With velocity-type outputs it is easier to achieve bumpless transfer. However, from a control accuracy point of view, positional control - as used in this system - is preferable. Positional PID algorithm.

This algorithm meets the requirements that:

(1) There is no interference between the integral time setting *TI* and the derivative time setting *TD* .

(2) For noise reduction, derivative gain ‘m’ is finite.

(3) Derivative ahead of PI characteristic (derivative of process variable, not deviation) is possible.

$$Y_n = K_P\,[e_n + \frac{\Delta t}{T_I}\sum e_n + m(M_n - \widetilde{M}_{n-1})] \qquad (1)$$

Where $\widetilde{M}_{n-1} = \frac{\Delta t}{T_D/m} M_{n-1} + (1 - \frac{\Delta t}{T_D/m})\widetilde{M}_{n-2}$

M_n : Input

e_n : Deviation

K_P : Proportional gain

m : Derivative gain

Δt : Sampling period

Bumpless and Balanceless Transfer.

Auto/Manual transfer:

When transferring from manual to auto mode, it is required that - even if there is an input deviation - the output should not change. This is satisfied by - in auto mode - setting *Bn* = *Yn Kp en* , *M";, - J* = *Mn* . Thus, when we switch to auto mode we have *YA* = *YM* • When transferring from auto mode to manual, we must initialize *YM* to *YA* and change the velocity action of manual mode to the positional action of auto mode. For other types of control - when there is external feedback, feedforward, changes in proportional gain *Kp*, or when there is autoselector control with external reset signal, this can be handled in the same way as auto/manual transfer. For P/PD control, manual reset can be handled by setting *Rn* = *YM Kpe" MR*, and slewing *R n* at a constant rate towards 0.

Some problems with output saturation:

The outputs of conventional controllers are normally restricted to the range 4 to 20 mA. Hence, the output may saturate at the high or low limit. The effects of reset windup and output saturation are not taken into account in equation (1) above, so it is important to consider how to prevent such effects and the following one.

Precession:

If the output contains enough noise to cause output saturation, noise pulses into the proportional or derivative term in the velocity type controller may cause the output to fluctuate widely. We call this "precession"; this phenomena is the most serious defect of the velocity-action controller, but does not occur in positional-action controllers.

Prevention of Reset Windup:

For batch processes - where a large deviation may continue for some time - the integral part R_n may grow very large, resulting in reset windup. When the deviation decreases, the output does not change - even after the sign of the deviation changes in sign, it takes a long time for the reset part to decrease enough for the output to decrease below the limit value. In this controller, output limiting is achieved by limiting the integral part - resetting it to zero when the output reaches an output limit, so that immediately the deviation decreases the output will also change.

The equations become:

When the output is not in saturation: $L < Y_n < H$

$$R_n = R_{n-1} + K_p \frac{\Delta t}{T_I} e_n \qquad (3)$$

When the output is saturated: $Y_n \geqslant H, \quad Y_n \leqslant L$

$$R_n = \frac{\Delta t}{T_I} (H \text{ or } L - K_p e_n) + (1 - \frac{\Delta t}{T_I}) R_{n-1} \qquad (4)$$

Simple PID controllers and their expandability:

It is possible to design "universal controllers" - with functions, including data communication functions, to meet every need - if there is no need to minimize system cost. On the other hand, the majority of users today require only simple PID controllers. It is thus important for manufacturers to continue to supply controllers which will compete in such a cost-sensitive market. It is convenient and economical to expand controller functions not with special hardware (as in conventional analog controllers) but with specialpurpose modular firmware - software modules in semiconductor memory and associated I/O expansion hardware. Based on the market demand and economic considerations, certain often-used function modules can be equipped as standard - selectable using switches on the unit - and other functions for system expansion and upgrading can be offered as plug-in (retrofit) options. Available firm ware modules include the following functions :

Alarm module. There are many demands for – in addition to providing controller action – monitoring the measurement input (PV). This alarm module indicates the preset alarm setpoint and outputs a contact signal to an external device.

Expanded PID module:

This module contains various PID controller options, as follows, so the user can select the functions it requires:

- External A/M and Cascade/Local transfer
- External feedback
- Non-linear gain characteristic
- P/PD control
- PI/PID control with reset bias setpoint and so on.

Communications module:

A serial communication line is used to communicate with external computers and the like, and provide SPC, DDC and overview functions. This makes it easy to configure or reconfigure an instrumentation system.

Firmware and User-Programmable Functions:

There are two categories of firmware: manufacturer-provided firmware and user provided firmware.

The manufacturer can provide programs in accordance with the user's specifications. However, if changes are required, the manufacturer must revise the programs, which can be costly. Hence, it is useful if manufacturers can supply controllers which use field programmable ROMs for program storage and can be programmed by the user using a simple dedicated or general-purpose language.

A general-purpose PlO controller should be appli cable to both small and large scale processes, and should offer optimum cost performance. To realize this ideal, a simple basic controller was designed; it can be easily expanded using add-in modules and it is computer compatible for upwards expandability.