UNIT-IV

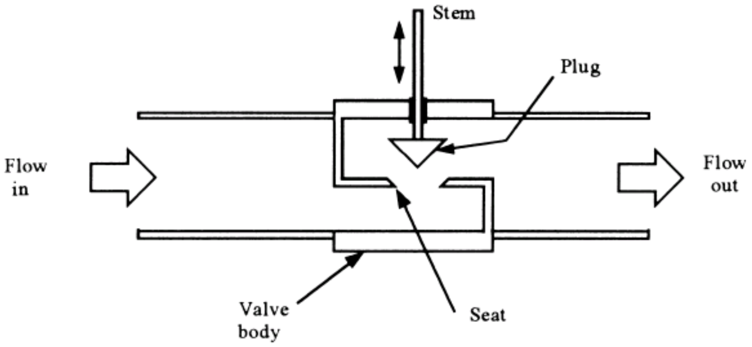
CONTROL VALVES

Many industries involve fluids and the regulation and control of fluid flow. The word fluid represents either gases, liquids, or vapours. In process control system the final control element is mostly the control valve.

Control Valve Principles:

Flow rate in process control is usually expressed as volume per unit time. If mass flow rate is desired, it can be calculated from the fluid density. If a given fluid is delivered through a pipe, then the volume flow rate is, $Q=Av$, Where, Q = flow rate (m^3/s), A = pipe area (m^2) and v = flow velocity (m/s)

The purpose of the control valve is to regulate the flow rate of fluids through pipes in the system. This is accomplished by placing a variable-size restriction in the flow path, as shown in Figure below.



As the stem and plug move up and down, the size of the opening between the plug and the seat changes, thus changing the flow rate. The direction of flow is with respect to the seat and plug. If the flow is reversed, force from the flow would tend to close the valve further at small openings. There will be a drop in pressure across such a restriction, and the flow rate varies with the square root of this pressure drop, with an appropriate constant of proportionality, given by

$$Q = K\sqrt{\Delta p}$$

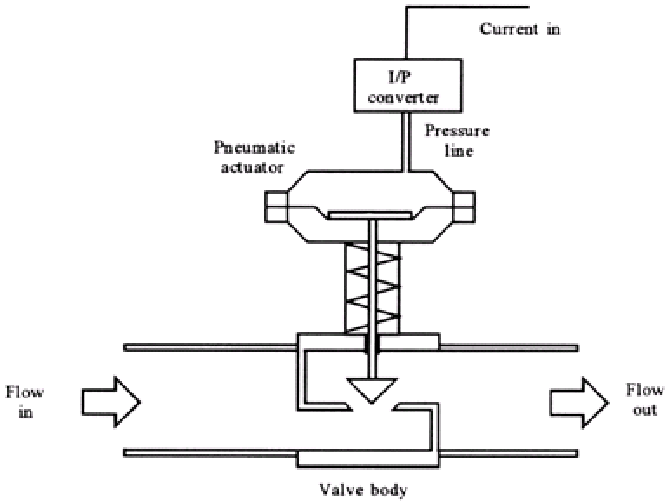
Where K= Proportionality constant,

$\Delta p = p_2 - p_1$ =Pressure difference

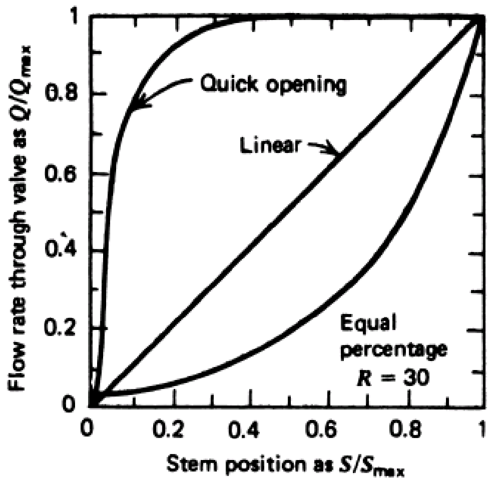
The constant, K, depends on the size of the valve, the geometrical structure of the delivery system, and the material flowing through the valve. change flow rate, it provides a mechanism of flow control.

Control Valve Types:

The control valves are classified by a relationship between the valve stem position and the flow rate through the valve. Figure given below shows a typical control valve using a pneumatic actuator attached to drive the stem and hence open and close the valve.



There are three basic types of control valves, whose relationship between stem position (as a percentage of full range) and flow rate (as a percentage of maximum) is shown in Figure shown below.



(i). Quick Opening :

This type of valve is used predominantly for full ON/full OFF control applications. Such a valve, may allow 90% of maximum flow rate with only a 30% travel of the stem.

(ii). Linear:

This type of valve, has a flow rate that varies linearly with the stem position. It represents the ideal situation where the valve alone determines the pressure drop. The relationship is expressed as

$$\frac{Q}{Q_{\max}} = \frac{S}{S_{\max}}$$

Where,

S_{max} = maximum stem position (m)

S = stem position (m)

Q_{max} = maximum flow rate (m^3/s)

Q = flow rate (m^3/s)

(iii). **Equal Percentage:**

This has a characteristic such that a given percentage change in stem position produces an equivalent percentage change in flow. Generally, this type of valve does not shut off the flow completely in its limit of stem travel. Thus, represents the minimum flow when the stem is at one limit of its travel. At the other extreme, the valve allows a flow as its maximum.

For this type, we can define rangeability, (R),

$$R = \frac{Q_{\max}}{Q_{\min}}$$

Where,

R=Rangeability

Q_{min} = minimum flow rate (m^3/s)

Q_{max} = maximum flow rate (m^3/s)

And

$$Q = Q_{\min} R^{S/S_{\max}}$$

Types of valve bodies:

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.

(i) Ball Valves:

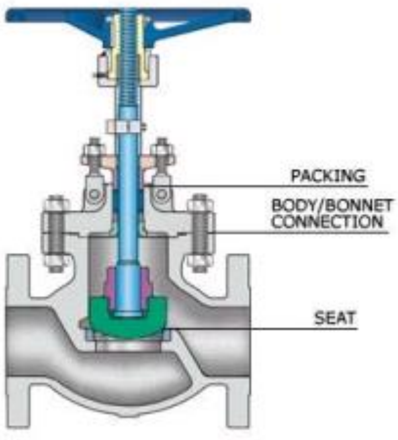
Ball valves are quick opening valves that give a tight shutoff. When fully open, a ball valve creates little turbulence or resistance to flow. The valve stem rotates a ball which contains an opening. The ball opening can be positioned in the fully open or fully closed position but must not be used to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

(ii) 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.

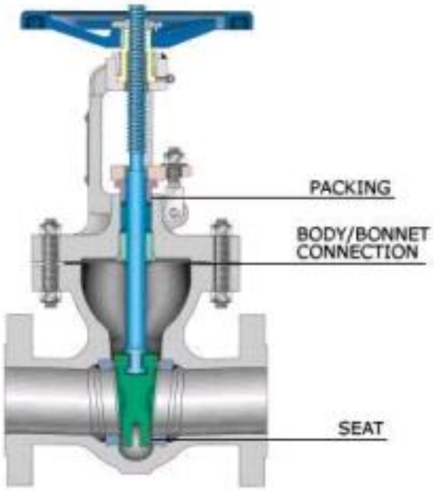
(iii)Globe Valves:

Globe valves consist of a movable disk-type element and a stationary ring seat in a generally spherical body. The valve stem moves a globe plug relative to the valve seat. The globe plug can be at any position between fully opened and fully closed to control flow through the valve. The globe and seat construction gives the valve good flow regulation characteristics. Turbulent flow past the seat and plug, when the valve is open, results in a relatively high pressure drop, limited flow capacity, and low recovery.



(iv). Gate Valves:

Gate valves use linear type of stem motion for opening and closing of a valve. These valves use parallel or wedge shaped discs as closure members that provide tight sealing.

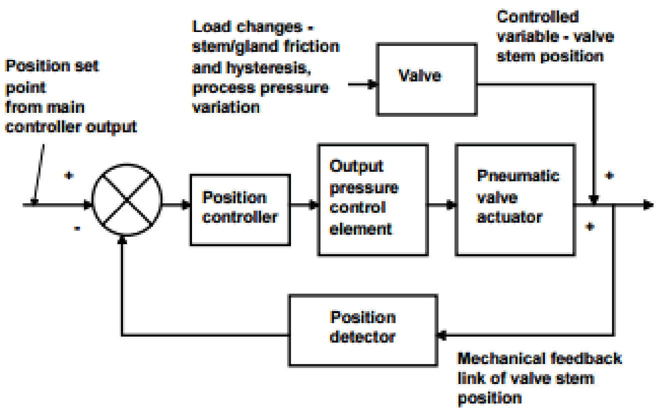


ACTUATORS

A valve actuator is a device that produces force to open or close the valve utilizing a power source. This source of power can be manual (hand, gear, chain-wheel, lever, etc.) or can be electric, hydraulic or pneumatic. Basic actuators turn valves to either fully opened or fully closed positions. But modern actuators have much more advanced capabilities. They not only act as devices for opening and closing valves, but also provide intermediate position with high degree of accuracy. The valve actuator can be packaged together with logic control and digital communication ability to allow remote operation as well as allowing predictive maintenance data.

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.



Control Valve Sizing:

An important factor associated with all control valves is correction factors

The correction factor is called the valve flow coefficient and is designated as C_v.

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

Where, Δp = pressure across the valve in psi and

SG = the specific gravity

Typical values of C_v for different-size valves are shown in Table. Similar equations are used for gases and vapours 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

Selection of body materials and characteristics of control valves for typical applications

1. Give careful consideration to selecting the correct materials of construction. Take into consideration the components of the valve that come in to contact with the process fluid such as the valve body, the valve seat or any other valve components exposed to the process fluid.
2. Consider the operating temperature and pressure the control valve will be exposed to. Consider the local ambient atmosphere and any corrosives that can occur which may affect the exterior of the valve.
3. Consider the degree of control you require and ensure the selected valve is mechanically capable of achieving the desired operating conditions.
4. Consider the inherent flow characteristic of the control valve you are selecting. Different valve types have different flow characteristics. The flow characteristic can be generally thought of as the change in rate of flow in relationship to a change in valve position. This item is discussed in a little more detail later.
5. Aim for optimal valve travel. When a valve is sized correctly, the range of operation will correspond well to the control range of the valve.
6. Avoid oversizing a control valve. If the control valve is too large for the required application, then percentage of travel is less.

Problems:

1. **Alcohol is pumped through a pipe of 10 cm diameter at 2 m/s flow velocity. Find the volume flow rate.**

Solution:

A pipe of 10 cm diameter has a cross-sectional area of

$A = \pi D^2/4$

$D = 10\text{cm} = 10/100\text{m} = 10^{-1}$ m

$A = 7.85\text{x}10^{-3}\ \text{m}^2$

Flow rate $Q = Av = 7.85\text{x}10^{-3}\ \text{m}^2 \text{ X } 2 \text{ m/s} = 0.0157 \text{ m}^3/\text{s}$

2. **A pressure difference of 1.1 psi occurs across a constriction in a 5-cm-diameter pipe. The constriction constant is 0.009 m^3/s per $kPa^{1/2}$. Find**

(a) the flow rate in m^3/s and (b) the flow velocity in m/s.

Solution:

$\Delta p = (1.1 \text{ psi})(6.895 \text{ kPa/psi}) = 7.5845\text{kPa}$

(a). **The flow rate** is

$$Q = K\sqrt{\Delta p}$$

$$Q = 0.009\sqrt{7.5845}$$

$$= 0.025\text{m}^3/\text{s}$$

(b). **The flow velocity** is found from $Q=Av$

$$A = \frac{\pi D^2}{4} = \frac{\pi(5\text{X}10^{-2})^2}{4} = 0.0019625m^2$$

$$v = \frac{Q}{A} = 12.7m/s$$

3. **An equal percentage valve has a maximum flow of 50cm^3/s and a minimum of 2 cm^3/s. If the full travel is 3 cm, find the flow at a 1cm opening.**

Solution:

The rangeability R is

$$R = \frac{Q_{\max}}{Q_{\min}}$$

$$= \frac{50}{2} = 25$$

The flow at a 1 cm opening is

$$Q = Q_{\min}R^{S/S_{\max}} = 2\text{X}25^{1/3} = 5.85 \text{ cm}^3/\text{s}$$

4. **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. Sizing factor can be found from

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

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

$$C_v = 150 \sqrt{\frac{0.8}{50}} = 18.97$$

b. From the table we can select $1\frac{1}{2}$ inch diameter valve

CAVITATION:

Cavitation occurs in control valves in liquid media applications. It happens when localized low pressure causes bubbles to form and then suddenly collapse.

FLASHING:

Flashing occurs in control valves during liquid flow. When the internal pressure of the liquid falls below the vapour pressure and remains below it flashing happens. During this phase vapour bubbles form and flow with the liquid downstream at increased velocities causing erosion to valves.

PUMPS

A pump is a machine used to move liquid through a piping system and to raise the pressure of the liquid. It is a hydraulic machine which converts mechanical energy into hydraulic energy. Pump can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement and gravity pump. Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid.

Pump can be classified into two categories:

1. Positive displacement pumps and
2. Non-positive displacement pumps

POSITIVE DISPLACEMENT PUMP

Positive-displacement pump operate by forcing a fixed volume of fluid from inlet to the discharge zone of the pump. It can be classified into two types:

1. **Rotary-type positive displacement pump:**

   Rotary-Type Positive displacement pump can move the fluid by using rotating mechanism that creates a vacuum that captures and draws in the liquid. Rotary positive displacement pump can be classified into two main types:

   Gear pumps - a simple type of rotary pump where the liquid is pushed between two gears.

   Rotary vane pumps - similar to scroll compressors, these pump have a cylindrical rotor encased in a similar shaped housing. As the rotor orbits, the vanes trap fluid between the rotor and the casing, drawing the fluid through the pump.

2. **Reciprocating-type positive displacement pump:**

   Reciprocating pump move the fluid using one or more oscillating pistons, plungers or membranes (diaphragms), while valves restrict fluid motion to the desired direction. Pump in this category are simple with one cylinder or more.

   Typical reciprocating pumps are:

   Plunger pumps- a reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back.

   Diaphragm pumps-similar to plunger pumps, where the plunger pressurizes hydraulic oil which is used to flex a diaphragm in the pumping cylinder. Diaphragm valves are used to pump hazardous and toxic fluids.

Piston displacement pumps - usually simple devices for pumping small amounts of liquid or gel manually.

NON - POSITIVE DISPLACEMENT PUMP

With this pump, the volume of the liquid delivered for each cycle depends on the resistance offered to flow. A pump produces a force on the liquid that is constant for each particular speed of the pump. Resistance in a discharge line produces a force in the opposite direction. When these forces are equal, a liquid is in a state of equilibrium and does not flow. If the outlet of a non positive-displacement pump is completely closed, the discharge pressure will rise to maximum for a pump operating at a maximum speed.

Centrifugal Pump:

A centrifugal pump uses a rotating impeller to increase the pressure and flow rate of a fluid. Centrifugal pump are most common type of pump used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and it is accelerated by the impeller, flowing radially outward. Centrifugal pumps are typically used for large discharge through smaller heads.

SELECTION OF PUMPS

1. Select the pump based on rated conditions as per the data sheet.

2. Ideally the pump should have a suction specific speed of less than 11,000.

3. The BEP (Best Efficiency Point) should be between the rated point and the normal operating point.

4. The hydraulic efficiency should be high. Higher efficiency means less vibration and noise.

5. The pump should not have maximum diameter impeller.

6. The pump should be capable of a head increase at rated conditions by installing a larger impeller.

7. The head/capacity characteristic-curve should continuously rise to shut-off.

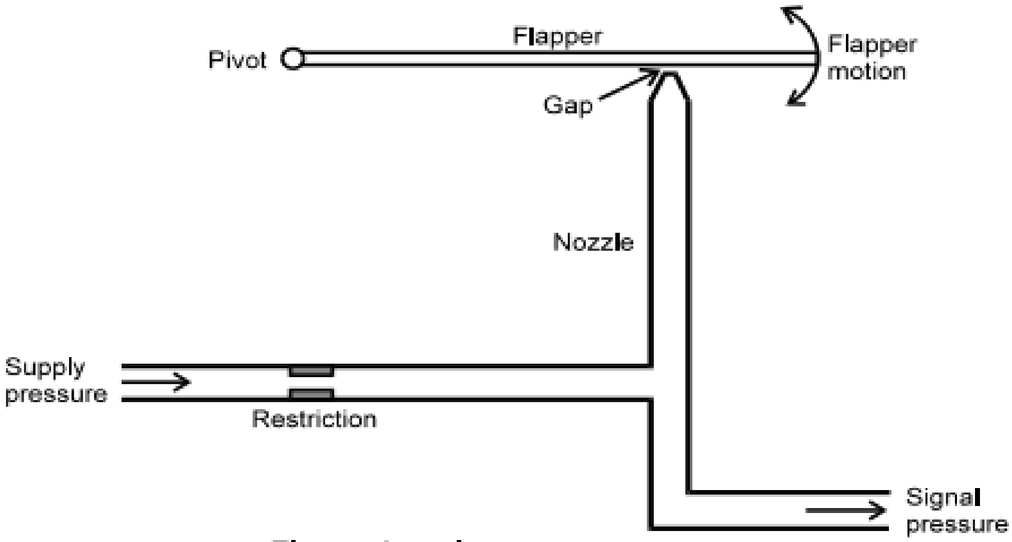
8. Minimum continuous flow should be based on hydraulic stability.

9. The pump should not be operated below minimum continuous flow rate.

10. For safe operation, NPSHA (net positive suction head available) should exceed NPSHR (net positive suction head required) by more than 1m at the rated condition.

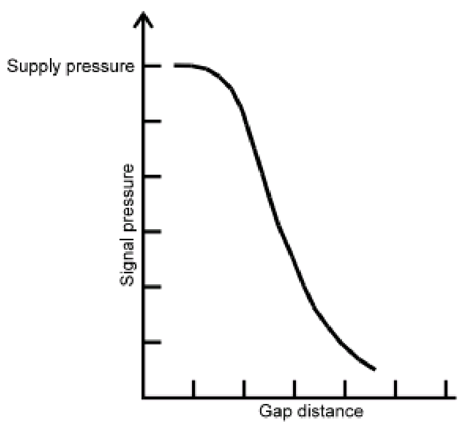
Flapper nozzle system:

A very important signal conversion is from pressure to mechanical motion and vice versa. This conversion can be provided by a flapper/nozzle. A diagram of this device is shown below. A regulated supply of pressure, usually 20 psig, provides a source of air through the restriction. The nozzle is open at the end where the gap exists between the nozzle and flapper, and air escapes in this region. If the flapper moves down and closes off the nozzle opening so that no air leaks, the signal pressure will rise to the supply pressure. As the flapper moves away, the signal pressure will drop because of leaking of the leaking air. Finally, when the flapper is far away, the pressure will stabilise at some value determined by the maximum leak through the nozzle.



Flapper/nozzle system

Following figure shows the relationship between signal pressure and gap distance. Note the great sensitivity in the central region. A nozzle/flapper is designed to operate in the central region where the slope of the line is greatest. In this region, the response will be such that a very small motion of the flapper can change the pressure by an order of magnitude.



Signal pressure versus gap distance

Working principle of I/P converter:

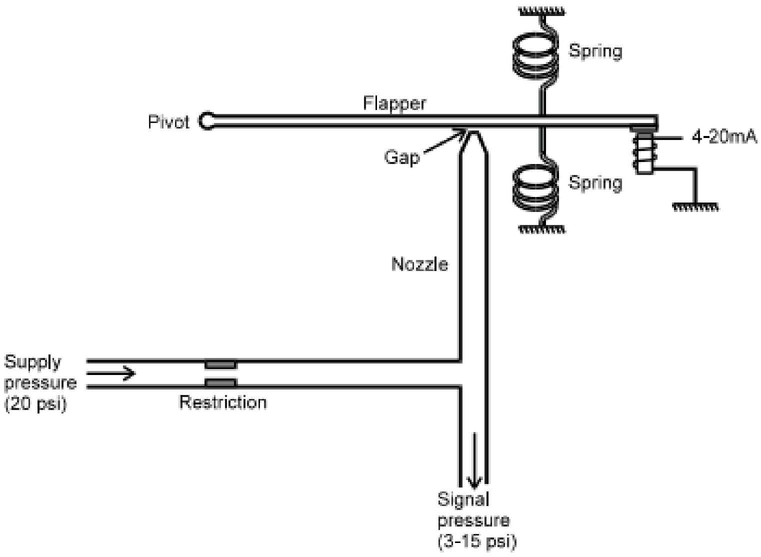
Current flowing through the operating coil energizes all I/P converters. They can be operated from a voltage supply from which the corresponding current will be drawn (Ohms law V = IR. The I/P converter gives us a linear way of translating the 4-20 mA current into 3-15-psi signal. There are many designs for these converters, but the basic principle almost always involves the use of a flapper nozzle system. Refer Figure below. The current through coil produces a force that will tend to pull the flapper down and close off the gap. A high current produces a high pressure so that the device is direct acting. Adjustment of the springs and perhaps the position relative to the pivot to which they are attached allows the unit to calibrated so that 4 mA corresponds to 3 psig and 20 mA corresponds to 15 psig.

Current to pneumatic converters are two-wire precision instruments designed to convert standard industrial electrical input signals into proportional pneumatic output signal. They are force balance instruments using a coil suspended in a magnetic field to operate a flapper valve against an air nozzle to create back pressure on the control diaphragm of a booster relay.

Input signal: 4-20 mA DC.

Output signal: 3-15 psi

Supply pressure: 20 psig



Principles of a current-to-pressure converter

Pressure to current (P/I) converters

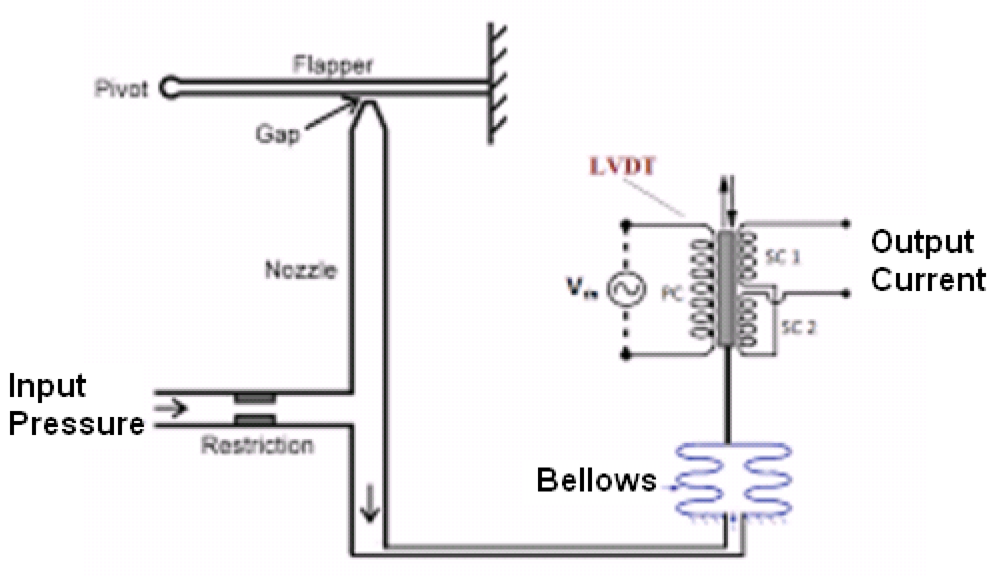
Pressure to current (P/I) converters is two-wire precision instrument designed to convert standard pneumatic input signals into proportional output electrical signal. They are compact robust instruments suitable for panel or field mounting applications.

Input signal: 3-15 psi.

Output signal: 4-20 mA DC

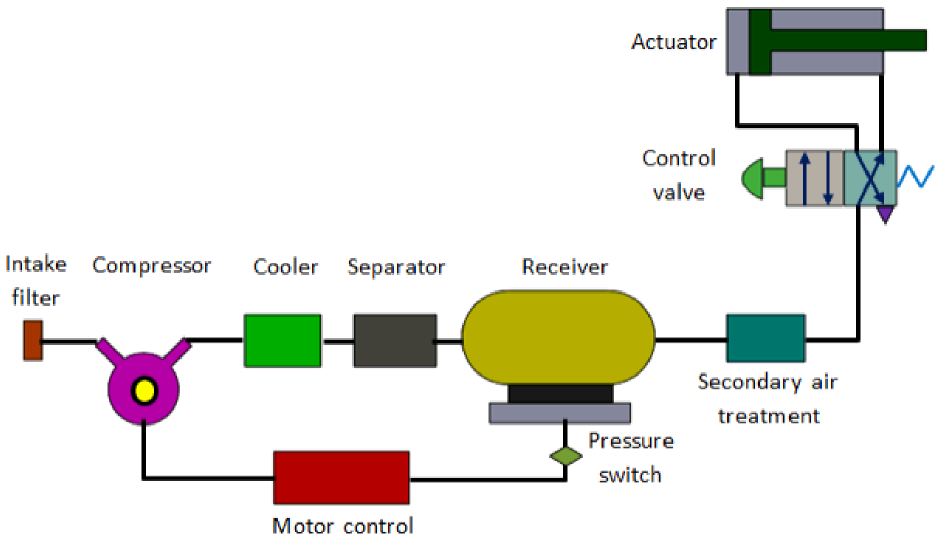
Supply voltage: 24 VDC

When pressure is applied to bellows, they will expand thus core displaces and the voltage is induced on the secondary coils of LVDT. As voltage is induced, current will flow through the coil. That current is proportional to the input pressure applied.



COMPLETE AIR SUPPLY SYSTEM FOR PNEUMATIC CONTROL EQUIPMENTS:

Pneumatic technology deals with the study of behaviour and applications of compressed air in manufacturing automation. Pneumatic systems use air as the medium which is abundantly available and can be exhausted into the atmosphere after completion of the assigned task.



Air filters:

These are used to filter out the contaminants from the air.

Compressor:

Compressed air is generated by using air compressors. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressors may be used.

Air cooler:

During compression operation, air temperature increases. Therefore coolers are used to reduce the temperature of the compressed air.

Dryer:

The water vapor or moisture in the air is separated from the air by using a dryer.

Control Valves:

Control valves are used to regulate, control and monitor for control of direction flow, pressure etc.

Air Actuator:

Air cylinders and motors are used to obtain the required movements of mechanical elements of pneumatic system.

Electric Motor:

Transforms electrical energy into mechanical energy. It is used to drive the compressor.

Receiver tank:

The compressed air coming from the compressor is stored in the air receiver.