ABES ENGINEERING COLLEGE, GHAZIABAD

Subject: Fundamentals of Mechanical Engineering (BME101)

Unit 5

Topic: Mechanical Measurements, Mechatronics fundamentals, Actuation systems and Valves

Lecture Notes

INDEX

Syllabus: Introduction to Measurement and Mechatronics : UNIT 5

Introduction to Measurement: Concept of Measurement, Error in measurements, Calibration, measurements of pressure (Bourdon Tube Pressure and U-Tube Manometer), temperature (Thermocouple and Optical Pyrometer), mass flow rate (Venturi Meter and Orifice Meter), strain (Bonded and Unbonded Strain Gauge), force (Proving Ring) and torques (Prony Brake Dynamometer); Concepts of accuracy, precision and resolution.

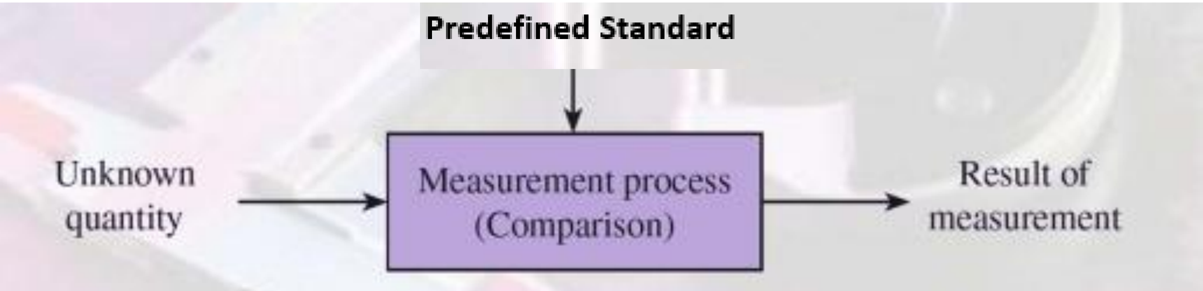
Introduction to Mechatronic Systems: Evolution, Scope, Advantages and disadvantages of Mechatronics, Industrial applications of Mechatronics, Introduction to autotronics, bionics, and avionics and their applications. Sensors and Transducers: Types of sensors, types of transducers and their characteristics.

Overview of Mechanical Actuation System – Kinematic Chains, Cam, Ratchet Mechanism, Gears and its type, Belt, Bearing.

Hydraulic and Pneumatic Actuation Systems: Overview: Pressure Control Valves, Direction Control Valves, Rotary Actuators, Accumulators and Pneumatic Sequencing Problems.

1. Introduction to measurement

Concept of measurement : The science of measurement is known as **metrology**. Measurement is done to know whether the component which has been manufactured is as per the requirements or not. Measurements will be of mainly length, mass, time, angle, temperature, squareness, roundness, roughness, parallelism etc. For measuring any quantity there must be some unit to measure and express. **Measurement is defined as the process or the act of measuring some physical quantity. It consists of obtaining a quantitative comparison between a predefined standard and a measurand or unknown magnitude.**



Direct and indirect measurements (Primary, secondary and tertiary measurements) :

Direct measurement : When the value of the physical quantity is determined by comparing it directly with reference standards (e.g. measurement of mass, length, time) it is also called **primary** measurement. (comparing colours to identify darker one, matching lengths, comparing bearable temperatures by touching, etc.

Indirect Measurement : When the value of the physical quantity is determined by indirect comparison with secondary standards through **calibration**. The measurand value is converted into a proportional secondary signal, or if needed into a tertiary signal, and then this last signal is measured to get the desired value of the measurand. Accordingly, I may be called as **secondary** or **tertiary** measurements.

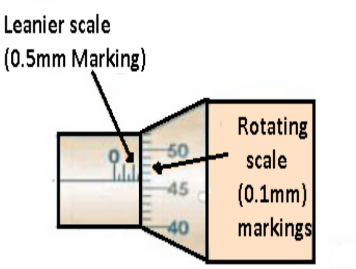
In primary measurements, the value of a physical quantity is found by comparing it directly with the reference standards. E.g. matching of two lengths, time measurements, matching of colours, measurement of mass.

In secondary measurements, the physical value is converted into some other signal or effect, and then this second signal or effect is measured directly. E.g. Bellows – it convert the pressure in a pipe into displacement, and this displacement is measured for the measurement of pressure. Other examples are – liquid in glass thermometer, venturimeter, etc.

In Tertiary measurements, the main first signal is transformed into second and the second signal is transformed into third signal. At last this third signal is measured directly for the measurement of the first signal. E.g. Bourdon tube – converts pressure into expansion of the c-shaped tube, and this expansion is converted into rotation of the central pinion rotation, which is used for the measurements.

Some Basic Properties of Measurements

- **Readibility** : This term indicates the closeness with which the scale of the instrument may be read. For example, an instrument with 30 cm scale will have a higher readability than an instrument with a 15 cm scale. Closeness of graduated scale also changes the readability of scale.



Least Count = Pitch of the Micrometer / Total number of circular scale division

Least Count = 1/100=0.01mm
= 0.001cm

- **Least Count:** It is the smallest difference between two indications that can be detected on the instrument scale. or in other words, it is the least value that can be measured with that particular device.

- **Resolution:** Resolution is also called as **discrimination** and defined as the smallest increment of the input signal that a measuring system is capable of displaying. (smallest change in non-zero input value, shown by an instrument).

- **Threshold:** If the instrument input is increased very gradually from zero, there will be some minimum value below which no output change can be detected. This minimum value defined the threshold of the instrument. The main difference between threshold and resolution are :

Resolution defines the smallest measurable input-change. While threshold defines the smallest measurable input (from zero value).

The threshold is measured when the input is varied from zero while the resolution is measured when the input is varied from any arbitrary non-zero value.

- **Calibration:** Any measuring system must be provable, i.e., it must prove its ability to measure reliably. The procedure adopted for this is called ‘calibration’. Calibration is the periodic assessment of the outputs of an instrument by comparing its output (readings) with standard or true values, and tuning them if required. Calibration is the procedure used to establish a relationship between the values of the quantities indicated by the measuring instrument and the corresponding values realized by standards under specified condition.

  In other words it is the act of marking units of measurement on an instrument so that it can be used for measuring something accurately. It is the process of configuring the instrument to provide a correct measurement result, within an acceptable range. It is a fundamental aspect of instrumentation design, to eliminate or minimize the factors that cause inaccurate measurement.

- **Accuracy and Precision :** Accuracy refers to the degree of conformity and correctness of something when compared to a true or absolute value. Precision refers to a state of strict exactness — how consistently something is strictly exact.

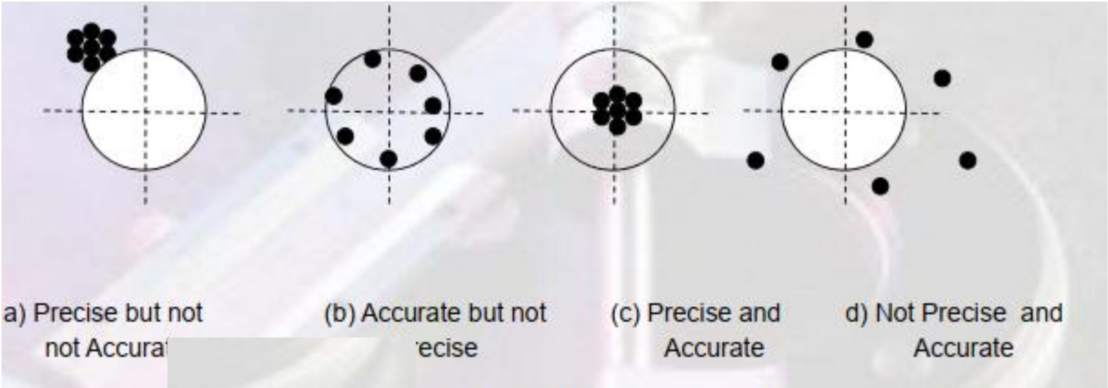


Figure 1.1: Accuracy and Precision.

Accuracy indicates how close is the measured or obtained value, to the true value. When the measured value is closer to the true value, that means error is smaller, subsequently accuracy is more. And vice-versa. Whereas **Precision** indicates the closeness of repeated measurement outputs. When a measuring device is used repeatedly for measurements under same circumstances and for same inputs, and it gives you very close outputs (very less variations in readings), that means it has very high precision. So, precision indicates the closeness of repeated measurement readings for same input.

2. Errors in measurement :

Errors accompany any measurement, however well it has been conducted. The error may be inherent in the measurement process or it may be induced due to variations in the way the experiment is conducted. Mathematically it Can be described as the difference between the standard/true value (Vs) and the observed/measured value (Vm).

$$\text{error} = Vs - Vm$$

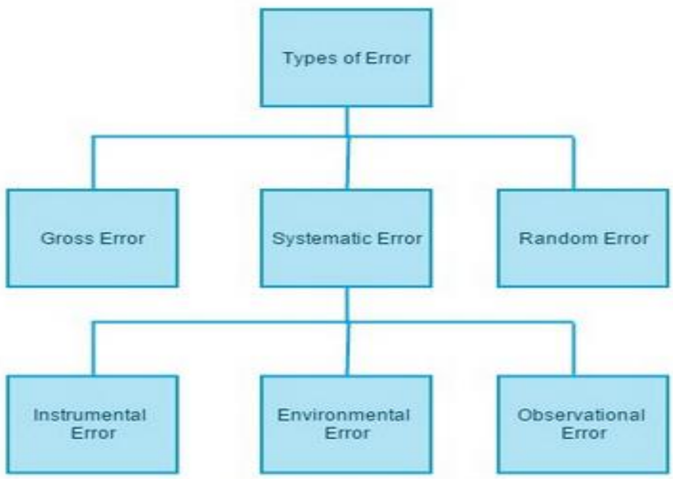
Preferably, error is given as % error :

$$\%\ \text{error} = ((Vs - Vm)/Vs) \times 100$$

Errors are studied under three categories :

- i) Systematic errors, ii) Random errors, iii) Gross errors

i) Systematic errors (or Bias) : A systematic error is a type of error that deviates by a fixed amount from the true value of measurement. These types of errors are controllable in both their magnitude and their direction. Systematic error or bias is due to faulty or improperly calibrated instruments. These may be reduced or eliminated by careful choice and calibration of instruments. Sometimes bias may be linked to a specific cause and estimated by analysis. In such a case a correction may be applied to eliminate or reduce bias. Bias is an indication of the accuracy of the measurement. Smaller the bias more accurate the data.



The following are the reasons for their occurrence-

1) Calibration errors (i.e. instrumental errors),

2) Ambient/environmental errors,

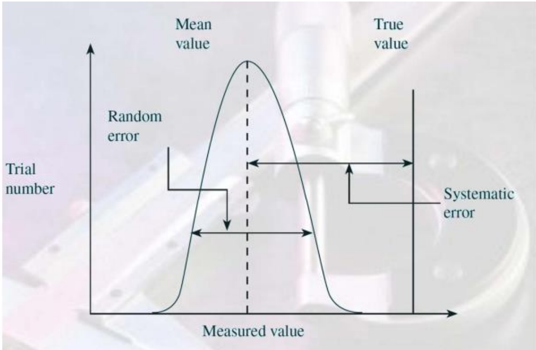
3) Deformation of the work piece itself, while measurements.

4) Other avoidable observational errors which include-

- datum error or zero error,
- error due to parallax effect,
- errors due to different sensing capabilities of different observers,
- misalignment error, etc.

ii) Random errors :

- Random errors provide a measure of random deviations when measurements of a physical quantity are carried out repeatedly.
- Random errors are due to non-specific causes like natural disturbances that may occur during the measurement process.



Relationship between systematic and random errors with measured value

- These cannot be eliminated completely. The magnitude of the spread in the data due to the presence of random errors is a measure of the precision of the data.
- Smaller the random error more precise is the data.
- Random errors are statistical in nature. These may be characterized by statistical analysis. The values lie around a central mean value.
- They are of variable magnitude and may be either positive or negative.
- Probable reasons are : Presence of friction in the movable parts, difference in operators' judgement, looseness/play in linkages, fluctuations in input, small variations in settings.

iii) Gross Errors :

- These are the human errors, due to lack of care taken by the observer, or due to his/her lack of attention. These can be minimized by careful observation.

3. Measurtement of various physical quantities

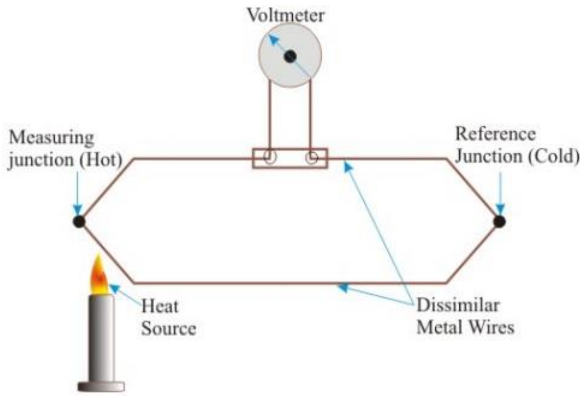
Temperature Measurement:

The temperature is a thermal state of a body which distinguishes a hot body from a cold body. It can be defined as a condition of a body by virtue of which heat is transferred from one system to another system. Temperature can be sensed using many devices, which can broadly be
classified into two categories: **contact types and non-contact types**.

Instruments for measuring ordinary temperatures are known as **thermometers** and those for measuring high temperatures without contact are known as **pyrometers**.

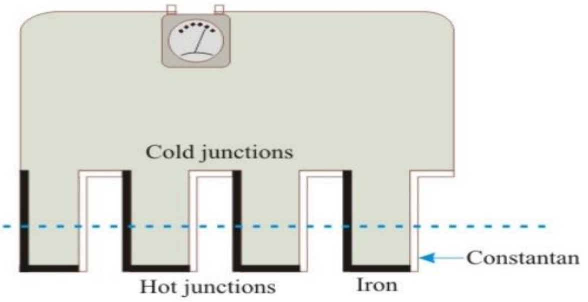
Various temperature measuring instruments are expansion thermometers (liquid in glass thermometers, bimetallic strip), thermocouples, RTDs (resistance temperature detectors), thermistors, pyrometers - infrared type, total radiation type and optical type.

Thermocouples :



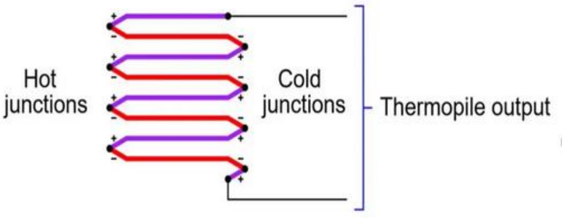
Principle of Thermocouples : When two dissimilar metals such a iron and copper are gained to form a closed circuit, current flow when one junction is at higher temperature and the other one is at lower temperature as shown in the figure. The emf driving the current is called a thermoelectric emf and the phenomenon is known as **thermoelectric effect** or **SEEBACK'S effect**.

Usually a thermoelectric emf is very small. When several thermocouples are arranged in series, the emf is added together to give an appreciable output, this arrangement is called **thermopile** as shown in the figure.



Advantages

- Better response
- High range of temperature measurements
- Cheaper than resistance thermometers



Disadvantages

- Low accuracy
- Complex electrical circuits.

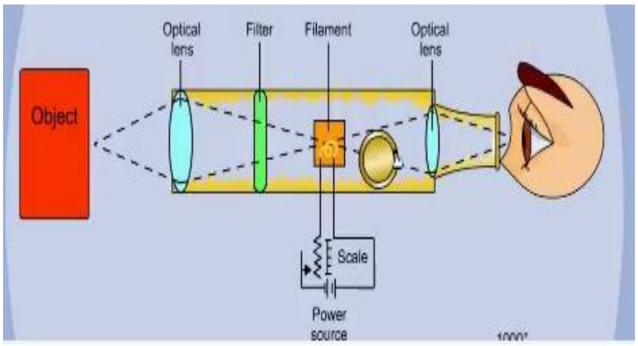
Suitable material for thermocouple : Platinum (Pt) with Constantan (40% Ni + 60% Cu) (There are many other suitable combinations also).

Optical Pyrometer:

Optical pyrometer employs an optical means for estimating the change in average wavelength of visual radiation with temperature. The instrument works on the principle of Wien's displacement law.

Wien's displacement law provides a relationship between the temperature of a blackbody and the wavelength at which it emits the most light. It states that the blackbody radiation curve for different temperatures will peak at different wavelengths that are inversely proportional to the temperature. i.e., $\lambda_{max} = b/T$ (here, $b = 2.898 \times 10^{-3}$ m.K).

In the operation of the optical pyrometer, method of matching is used. Reference temperature is obtained by an electrically heated filament lamp which is controllable through a variable resistance (rheostat). A measure of temperature is obtained by optically comparing the visual radiation from filament with that from the unknown source. Current in the circuit is adjusted until the filament brightness exactly matches with that of the external object. At this moment the filament disappears (figure B) and temperature can be found on variable resistance reading using calibration techniques.



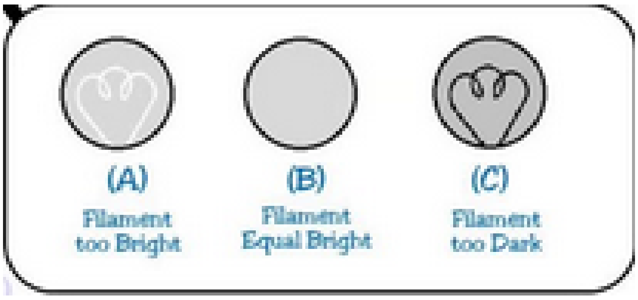


Fig (1) : Temperature of filament < temperature of Object

Fig (2) : Temperature of filament = temperature of Object ***(filament disappeared.*** *Condition used for measurement)*

Fig (3) : Temperature of filament > temperature of Object.

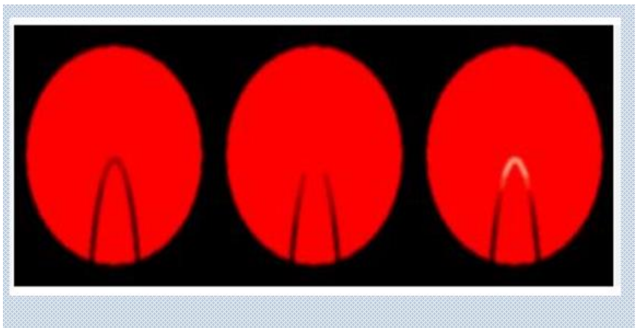


Fig (1) Fig (2) Fig (3)

Optical Pyrometer Advantages

- It can be used for high temperature measurements.
- It can be used to check the temperature of distant objects as well as moving objects.
- It can be used without direct physical contact with the target.
- Lesser weight
- It is flexible and portable.

Optical Pyrometer Disadvantages

- Due to the radiation of thermal background, dust, and smoke, the accuracy of this device can be affected.
- The device is more expensive.
- Manual type pyrometers are not suitable for evaluating the object's temperature under 800°C because, at less temperature, the generated energy will be too low.

Applications

- It is used to measure the temperature of highly heated materials
- It is useful to measure furnace temperatures.
- It is used in critical process measurements of semiconductor, medical, induction heat treating, crystal growth, furnace control, glass manufacture, medical, etc.

Strain Measurement

When a force is applied to a structure, the components of the structure change slightly in their dimensions and are said to be strained. Devices to measure these small changes in dimensions are called strain gauges. It is one of the significant sensors used in the geotechnical field to measure the amount of strain on any structure (Dams, Buildings, Nuclear Plants, Tunnels, etc.). The resistance of a strain gauge varies with applied force and, it converts parameters such as force, pressure, tension, weight, etc. into a change in resistance that can be measured later on.

For a wire to function as a strain gauge, we must determine the relationship between the strain and the change in resistance. The resistance of a wire is:

$$R = \frac{\rho L}{A}$$

R = Resistance L = Length A = Cross-Sectional Area ρ = Resistivity of the material

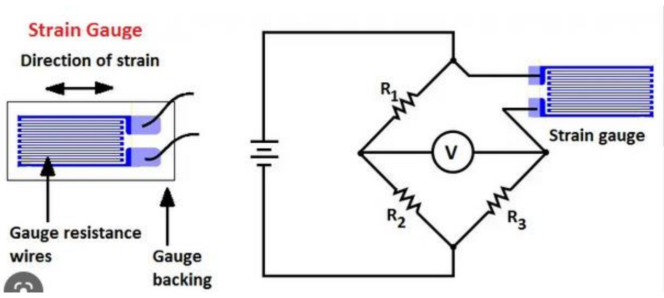
There is term known as '**Strain Gauge factor (S)'** which is defined as "the ratio of (ΔR/R) to the longitudinal strain (ΔL/L in wire. i.e., the ratio of resistive strain to the longitudinal strain is called as strain gauge factor. It indicates the relative change in electrical resistance per unit change in longitudinal strain. For manufacturing strain gauges, the metals/alloys are chosen which have higher values of strain gauge factor. It increases the accuracy in measurements.

The relationship between the strain gauge factor, Poisson's ratio of the material, longitudinal strain and change in resistivity of the material is given as:

$$S = 1 + 2\mu + \frac{d\rho/\rho}{\epsilon_a}$$

If resistivity is constant for a material, means strain gauge factor is also constant for that material –

$$S = 1 + 2\mu$$



A strain gauge is basically a thin wire or metal foil, whose electrical resistance changes with change in its length. When dimensional changes in an object are to be found, a strain gauge is firmly GLUED on that object. Due to external forces when the dimensions change, the length of the wire of strain gauge also change with it. It causes change in its electrical resistance. The strain gauge is connected with a balanced WHEATSTONE BRIDGE circuit in which the central wire shows zero current. Due to change in resistance, the current in the central wire starts to flow, which can be read on a voltmeter. This deflection in voltmeter is calibrated directly to read the value of change in dimension of the object.

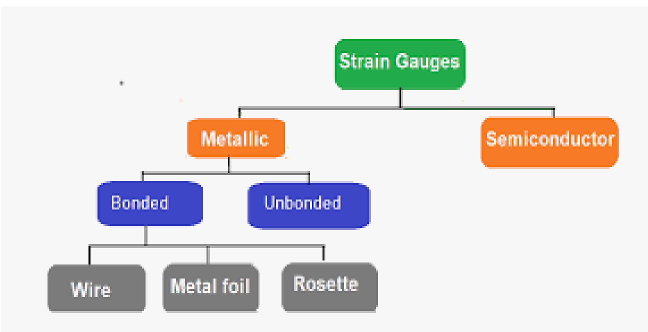
Characteristic / Advantages of Strain gauges:

- They are highly precise and don't get influenced due to temperature changes. However, if they do get affected by temperature changes, a thermistor is available for temperature corrections.
- 2. They are ideal for long distance communication as the output is an electrical signal.
- 3. Strain Gauges require easy maintenance and have a long operating life.
- 4. The production of strain gauges is easy because of the simple operating principle and a small number of components.
- 5. The strain gauges are suitable for long-term installation. However, they require certain precautions while installing.
- 6. They are fully encapsulated for protection against handling and installation damage.
- 7. The remote digital readout for strain gauges is also possible.

Types of Strain Gauge

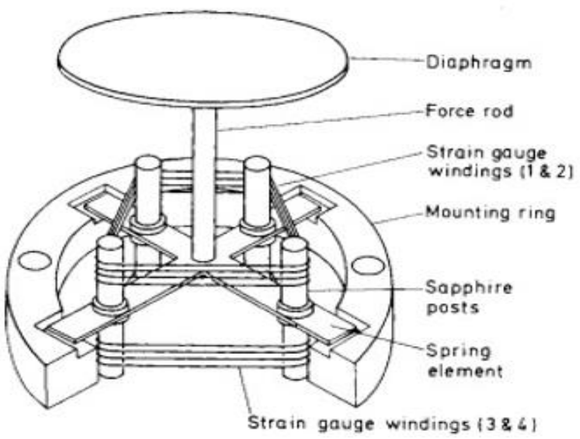
The type of strain gauge are as

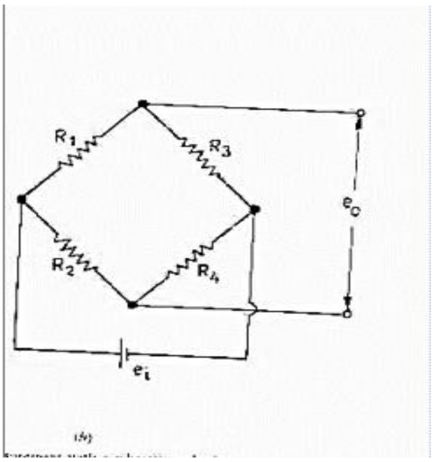
1. Wire gauge: a) Unbonded, b) Bonded (wire, metal foil and rosette types)
2. Semiconductor gauge
3. Capacitive type

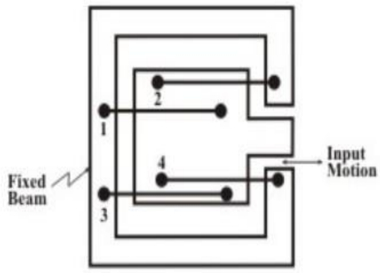


(a) Unbonded Strain gauge

An unbonded meter strain gauge is shown in fig







This gauge consists of a wire stretched between two point in an insulating medium such as air. The wires may be made of various metals or alloys like copper, nickel, crome-nickel or nickel iron alloys. The wire is not joined or bonded on any base material and it is like a free wire. That is why, it is called as unbonded type strain gauge.

In fig the element is connected via a rod to diaphragm which is used for sensing the pressure. The wire are pre-tensed to avoid buckling when they experience the compressive force.

Working : When the diaphragm is pressed down via some external force / pressure, it creates elastic buckling of the cross-link. This further, creates inclination of the vertical four rods on its extremities. The upper ends of these four rods comes a bit closer, causing some relief in the upper tensed wire. On the contrary, the gap between lower ends of the four rods widen, causing further increase in the tension in the lower wound wire. Hence, the resistance of the upper wire decreases and the resistance of lower wire increases. This can be sensed proportionally using a Wheatstone bridge.

- The unbounded wire gauges are used almost exclusively in transducer application which employ preloaded resistance wires connected in Wheatstone bridge as shown in fig.
- At initial preload the strain and resistance of the four arms are nominally equal with the result the output voltage of the bridge is equal to zero.

Application of Unbonded strain gauge:

- Unbonded strain gauge is used in places where the gauge is to be detached and used again and again.
- unbonded strain gauges are used in force, pressure and acceleration measurement.

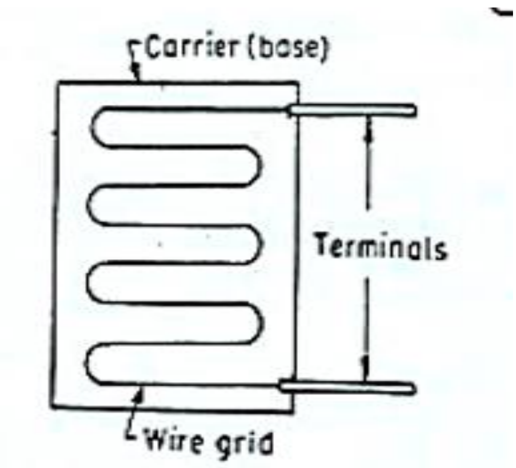
Advantages of Unbonded strain gauge:

- The range of this gauge is +/- 0.15% strain.
- This gauge has a very high accuracy.

Limitation of unbonded strain gauges:

- It occupies more space.
- Higher initial cost.

(b-1) Bonded wire Strain gauge



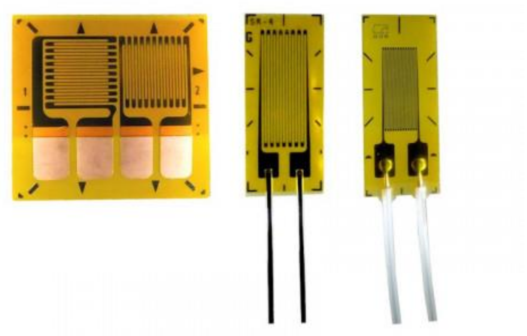
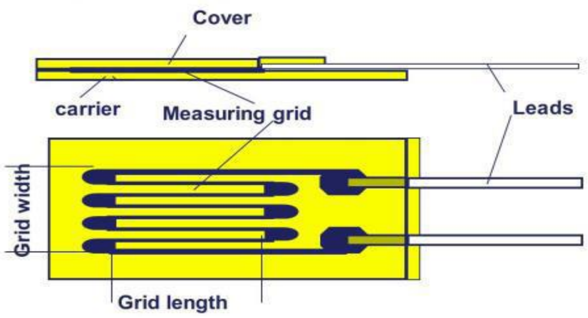
The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer. A resistance wire strain gauge consist of a grid of fine resistance wire. The grid is cemented firmly to a carrier or base which may be a thin sheet of paper Bakelite or Teflon. The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical damage or oxidation. The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires. Bonded wire strain gauges are of various types, such as Strain rosettes, torque type, grid type (shown in the figure above), helical type, etc.

Parts:

It consists of following parts:

1. **Base (carrier) Materials:** several types of base material are used to support the wires. Paper is used for room temp applications.
2. **Adhesive:** The adhesive acts as bonding materials. Like other bonding operation, successful strain gauge bonding depends upon careful surface preparation and use of the correct bonding agent. In order that the strain be faithfully transferred on to the strain gauge, the bond has to be formed between the surface to be strained and the plastic backing material on which the gauge is mounted. It is important that the adhesive should be suited to this backing and adhesive material should be quick drying type and also insensitive to moisture.
3. **Leads:** The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficient This class of strain gauge is only an extension of the bonded metal wire strain gauges.

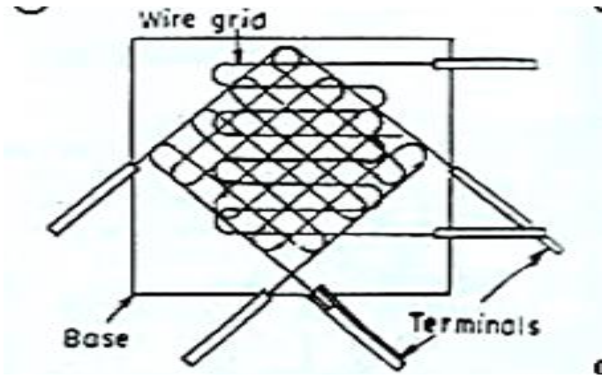
(b-2) Bonded Metal foil strain gauge

The bonded metal wire strain gauge have been completely superseded by bonded metal foil strain gauges. Metal foil strain gauge use identical material to wire strain gauge and are used for most general purpose stress analysis application and for many transducers. The difference is that in the bonded metal foil type strain gauges, a metallic foil is used in place of metallic wire.

(b-3) Strain Rosette Type :

A strain rosette, in simple form is a combination of various bonded wire strain gauges in different axial positions (such as 0°, 90°, 45°, etc). A single bonded wire strain gauge can measure strain in single direction only. With the help of a strain rosette, we can measure dimensional changes in different directions without changing the orientation of the strain gauge.



Measurement of Force

We all know that force is defined as the product of mass and acceleration, as per Newton's second law of motion. Force is a vector quantity whose unit of measurement is Newton (N)

The methods for measuring force can be classified into two basic categories:

(i) Direct Methods (ii) Indirect Methods

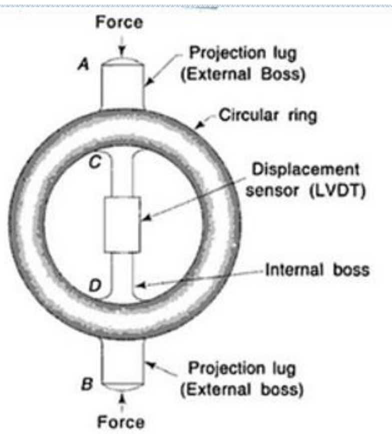
In case of **direct methods**, a direct comparison is made between an unknown force and the known gravitational force on a standard mass. For this purpose, a beam balance may be employed wherein masses are compared. Direct methods involve the comparison of an unknown force with a known gravitational force on the standard mass. A force is exerted on a body of mass *m* due to the earth's gravitational field, which can be represented by the following equation:

$$W = mg$$

Here *m* is the standard mass, *g* is the acceleration due to gravity, and *W* is the weight of the body. Direct methods are mainly of two types – (a) Equal arm balance, (b) Unequal arm balance

In case of **Indirect methods,** comparison is made by a calibrated transducer that senses gravitational attraction or weight. Force is measured indirectly in terms of displacement, or electrical outputs, etc. Sometimes, the deformation due to a force applied on an elastic member is measured.

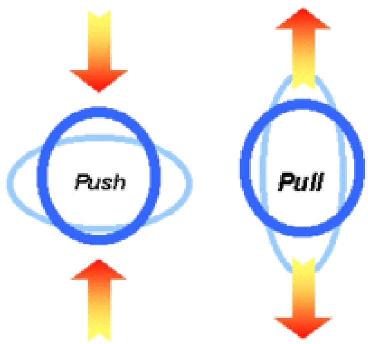
Proving Ring



One of the most popular devices used for force measurement is the proving ring. In order to measure the displacement caused by the applied force, a displacement transducer is connected between the top and bottom of the ring. Measurement of the relative displacement gives a measure of the applied force.

A proving ring can be employed for measuring the applied load/force, with deflection being measured using a precise micrometer, or a a linear variable differential transformer (LVDT), or a strain gauge. When compared to other devices, a proving ring develops more strain owing to its construction. A proving ring, which is made up of steel, can be used for measuring static loads, and is hence employed in the calibration of tensile testing machines. It can be employed over a wide range of loads (1.5 kN to 2 MN).

Construction and Working: A proving ring comprises a circular ring having a rectangular cross-section, as shown in figure. It has a radius *R*, thickness *t*, and an axial width *b*. The proving ring may be subjected to either tensile or compressive forces across its diameters. The two ends between which force is measured are attached with structures.



When we apply Force to the ring through the external bosses. The resulting change in diameter, referred to as the deflection of the ring, is measured with a micrometer screw which is installed between internal bosses. Micrometer gives the deflection (y), by measuring the deflection of ring we can calculate the applied force by using deflection formula given here-

$$F = \frac{16}{\left(\frac{\pi}{2} - \frac{4}{\pi}\right)} \cdot \frac{EI}{D^3} \cdot y$$

Torque Measurement

Torque is measured with the help of Dynamometers. A **dynamometer** is a brake, but in addition it has a device to measure the frictional resistance. Knowing the frictional resistance, we may obtain the **Torque** transmitted (T = F x r) and hence the **Power** of the engine (P = T x angular velocity). Hence, *"A dynamometer is a device used to measure frictional torque, for finding the power of the engine."*

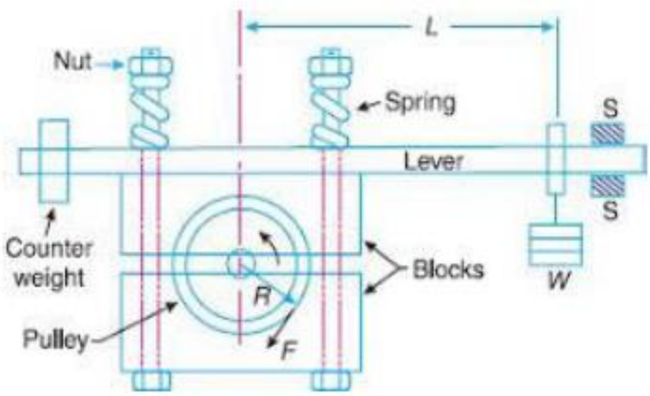
Types of Dynamometers

Following are the two types of dynamometers, used for measuring the brake power of an engine-

1. Absorption dynamometers (Prony brake type, rope brake type): In the absorption dynamometers**,** *the* entire energy or power produced by the engine is absorbed by the friction resistances of the brake and is transformed into heat, during the process of measurement. e.g. Prony brake dynamometer, Rope brake dynamometer.

2. Transmission dynamometers (Bewis-Gibson Torsion dynamometers, belt-transmission type dynamometers): In the transmission dynamometers, the energy is not wasted in friction but is used for doing work. The energy or power produced by the engine is transmitted through the dynamometer to some other machines where the power developed is suitably measured.

Prony Brake Dynamometer



A simplest form of an absorption type dynamometer is a Prony brake dynamometer, as shown in Fig. It consists of two wooden blocks placed around a pulley fixed to the shaft of an engine whose power is required to be measured. The blocks are clamped by means of two bolts and nuts, as shown in Fig. A helical spring is provided between the nut and the upper block to adjust the pressure on the pulley to control its speed. The upper block has a long lever attached to it and carries a weight W at its outer end. A counter weight is placed at the other end of the lever which balances the brake when unloaded. Two stops S, S are provided to limit the motion of the lever.

When the brake is to be put in operation, the long end of the lever is loaded with suitable weights W and the nuts are tightened until the engine shaft runs at a constant speed and the lever is in horizontal position. Under these conditions, the moment due to the weight W must balance the moment of the frictional resistance between the blocks and the pulley.

Frictional resistance between the blocks and the pulley (Anticlockwise) = T

Balancing moment provided by the externally hanging weight W about pulley centre (Clockwise) = W.L = Mg.L

In equilibrium, frictional resistance (anticlockwise) = Balancing moment (clockwise), or

$$T = Mg.L$$

Power of the machine under test = $T.\omega = Mg.L(2\pi N/60) = MNk$ where, k = a constant for a particular brake.

Advantages:

1. Simple construction

2. Less cost

3. Suitable for measuring small torque

Disadvantages:

1. Not suitable for large torque/power.

2. Cooling system required because large heat is generated.

3. Friction is not uniform; dynamometer is subjected to severe oscillations.

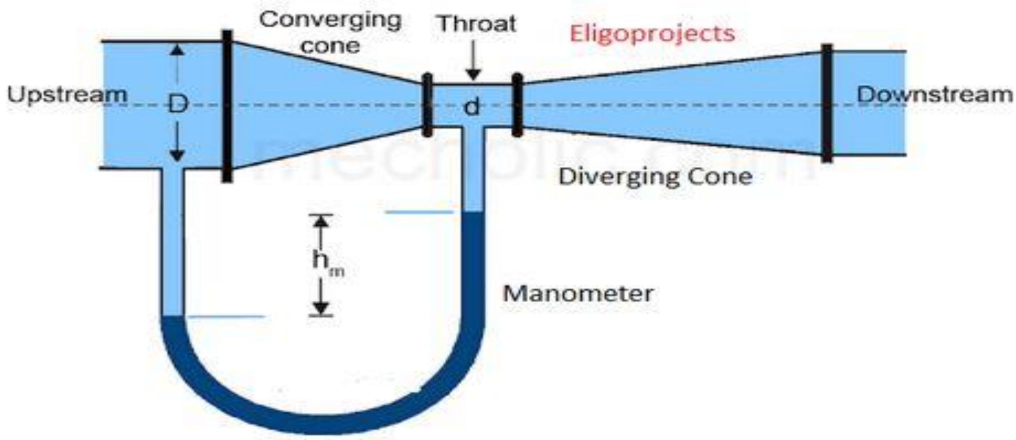
Flow Measurement

There are various types of liquid flow measurement devices, as listed below:

- Venturi meter,
- Orifice meter,
- Rotameter,
- Pitot Tube, etc.

Venturimeter

A venturi meter is a device that is used to measure the speed flow of incompressible fluid through a pipe. The device converts pressure energy into kinetic energy and measures the rate of flow of liquid through pipes. It has a tube of broad diameter and a small constriction towards the middle. Venturi meter works on the principle of the Bernoulli equation such that the velocity of the fluid increases as the pressure decreases. The theory states that when the cross-sectional area of the flow decreases, a pressure difference is created between the different regions of the flow. his helps measure the difference under pressure which further helps to measure the discharge inflow.



Components of a Venturi Meter

A Venturi meter is made up of the following components:

- **Converging Part**: The area of the cone decreases when water flows through it. Therefore, there is an increase in the speed of flowing water and a decrease in the pressure.
- **Throat Diameter**: The area remains constant in a throat diameter when water flows through it therefore the speed and pressure also remain constant.
- **Diverging Part**: The area increases when water flows through the cone and therefore the speed decreases and the pressure decreases.

Working of a Venturi Meter

The venturi meter works on the principle of Bernoulli's equation which states that the pressure decreases as the velocity increases.

- The cross section of the throat is less than that of the inlet pipe.
- As the cross section from the inlet pipe to the throat of venturimeter decreases, the fluid velocity increases, and therefore the pressure decreases.
- Due to a decrease in the pressure, a pressure difference is created between the throat of the venturi meter and the inlet pipe.
- This is further measured by applying a differential manometer between the throat section and the inlet section. It can also be measured by using two gauges on the inlet section and throat.
- The pressure difference through the pipe is then calculated after obtaining the rate of flow.

Expression for the rate of flow through a Venturimeter

Let d1, p1, v1 & a1, are the diameter at the inlet, pressure at the inlet, velocity at the inlet and area at the cross section 1.

And d2, p2, v2 and a2 are the corresponding values at section 2.

Applying bernoulli's equation at sections 1 and 2

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

As the pipe is horizontal, so z1 = z2

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g}$$

$$\frac{p_1 - p_2}{\rho g} = \frac{v_2^2 - v_1^2}{2g} \qquad \ldots\ldots\ldots..(1)$$

Therefore

(P1 – P2)/ρg is the difference of pressure heads at section 1 and 2 and it is equal to h. so

$$h = \frac{p_1 - p_2}{\rho g}$$

Substituting this value of h in equation (1), we get

$$h = \frac{v_2^2 - v_1^2}{2g} \qquad \ldots\ldots\ldots\ldots\ldots..(2)$$

Now applying continuity equation at section 1 and 2

$$a_1 v_1 = a_2 v_2$$

$$v_1 = \frac{a_2 v_2}{a_1}$$

Substituting this value of v1 in equation (2) and solving, we get

$$v_2 = \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

Discharge

$$Q = a_2 v_2$$

Substituting value of v2 in above equation

$$Q = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

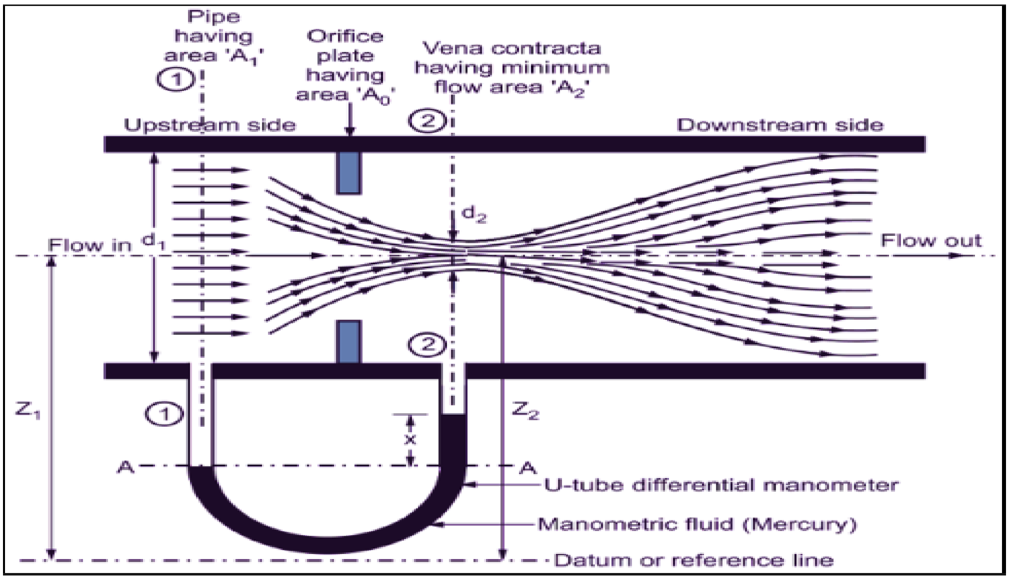
Q is the theoretical discharge under ideal conditions. Actual discharge will be less than the theoretical discharge. The actual discharge is given by the formula

$$Q_{act} = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

Where Cd is the coefficient of venturimeter and its value is less than 1.

Orificemeter

Orifice : It is an abrupt or sudden hole or opening in a flowing fluid passage (pipeline).

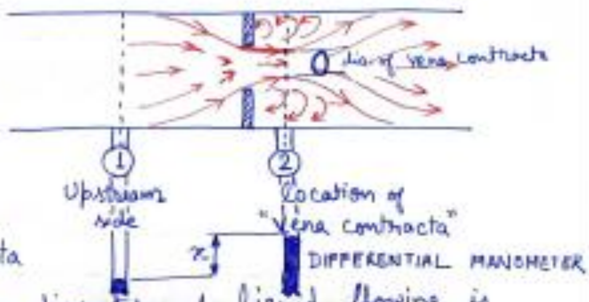


Vena Contracta: When a fluid passes through an orifice in a pipeline, the diameter of this passing stream keeps on decreasing up to a little distance. *Vena contracta* is the point in the fluid stream where the diameter of the stream is the least, and the fluid velocity is at its maximum.

Working: By the application of Bernoulli's equation between the location of the orifice and vena contracta, we can find the rate of discharge theoretically. An additional factor for *vena contracta* is also considered. Also, there are just converging and diverging streams, in place of converging and diverging nozzles. Rest all principle of working is same as Venturimeter.

Orifice Meter

It is a device to measure the rate of flow of liquid through a pipeline. An orifice is basically a hole through which liquid is passed. The dia. of orifice is between 0.4 to 0.8 times the dia. of pipeline.



Vena contracta appears a few distance away from the orifice. (Vena Contracta is a location where the downstream diameter of liquid flowing is minimum. This diameter is less than that of the orifice diameter. A differential manometer is connected between the upstream side and vena contracta the get the differential pressure head.

Let, d_1 = diameter at section ① ; d_2 at section ②
p_1 = pressure at section ① ; p_2 at section ②
v_1 = velocity at section ① ; v_2 at section ②
A_1 = Area at section ① ; A_2 at section ②

Applying Bernoulli's eq^n between ① and ② —

$$\frac{p_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

elevation of both ~~the~~ the sides is same, i.e. $z_1 = z_2$

$$\Rightarrow \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g}$$

$$\Rightarrow \frac{p_1 - p_2}{\rho g} = \frac{v_2^2 - v_1^2}{2g}$$

Let $\frac{p_1 - p_2}{\rho g}$ = difference in pressure head. = h (in meters)

$$\Rightarrow h = \frac{v_2^2 - v_1^2}{2g}$$

$$\Rightarrow v_2^2 = v_1^2 + 2gh \quad \text{—— (I)}$$

from continuity equation,

$$A_1 v_1 = A_2 v_2 \Rightarrow v_1 = \frac{A_2 v_2}{A_1} \quad \text{—— (II)}$$

Let A_0 = Area of the orifice,

$$\boxed{\text{Coefficient of contraction } C_c = \frac{A_2}{A_0} = \frac{(\text{Area at vena Contracta})}{(\text{Area at orifice})}}$$

$$\Rightarrow \boxed{A_2 = A_0 \cdot C_c} \quad \text{—— (X)}$$

$$\Rightarrow v_1 = \frac{A_0 \cdot C_c}{A_1} \cdot v_2 \quad (\text{from (II)})$$

putting this value in eq^n (I) →

$$v_2^2 = \left(\frac{A_0 C_c}{A_1}\right)^2 \cdot v_2^2 + 2gh$$

$$\Rightarrow v_2 = \frac{\sqrt{2gh}}{\sqrt{\left(1 - \frac{A_0^2}{A_1^2} \cdot C_c^2\right)}}$$

$$\Rightarrow \text{Discharge } Q = A_2 \cdot v_2 = A_0 \cdot C_c \cdot v_2 \quad (\text{from (X)})$$

$$\boxed{Q = \frac{A_0 \cdot C_c \cdot \sqrt{2gh}}{\sqrt{\left(1 - \frac{A_0^2}{A^2} \cdot C_c^2\right)}}} \quad \text{—— (III)}$$

Now, C_d = coefficient of discharge of orificemeter is defined as —

$$\boxed{C_d = \frac{C_c \cdot \sqrt{1 - (A_0/A_1)^2}}{\sqrt{1 - (A_2/A_1)^2}}} = \frac{C_c \cdot \sqrt{1 - (A_0/A_1)^2}}{\sqrt{1 - \left(\frac{A_0 C_c}{A_1}\right)^2}}$$

$$\Rightarrow C_c = C_d \cdot \frac{\sqrt{1 - (A_0 C_c / A_1)^2}}{\sqrt{(1 - A_0/A_1)^2}}$$

putting the value of C_c in eq^n (III), we get —

$$\boxed{Q = C_d \cdot \frac{A_0 A_1 \sqrt{2gh}}{\sqrt{A_1^2 - A_0^2}}} \quad \text{(The desired Relation)}$$

Note: The coeff. of discharge of orificemeter (C_d) is much smaller than that of a Venturimeter.

Pressure Measurement

Pressure is an essential component of everyday life of human beings. We talk about atmospheric pressure, blood pressure, gauge pressure, vacuum, etc. Pressure may be measured in atmospheres, bars, or in terms of the height of a liquid column. Standard atmospheric pressure is usually referred to as 760 mmHg. The standard atmospheric level is always measured at the sea level.

Pressure Measurement Scales

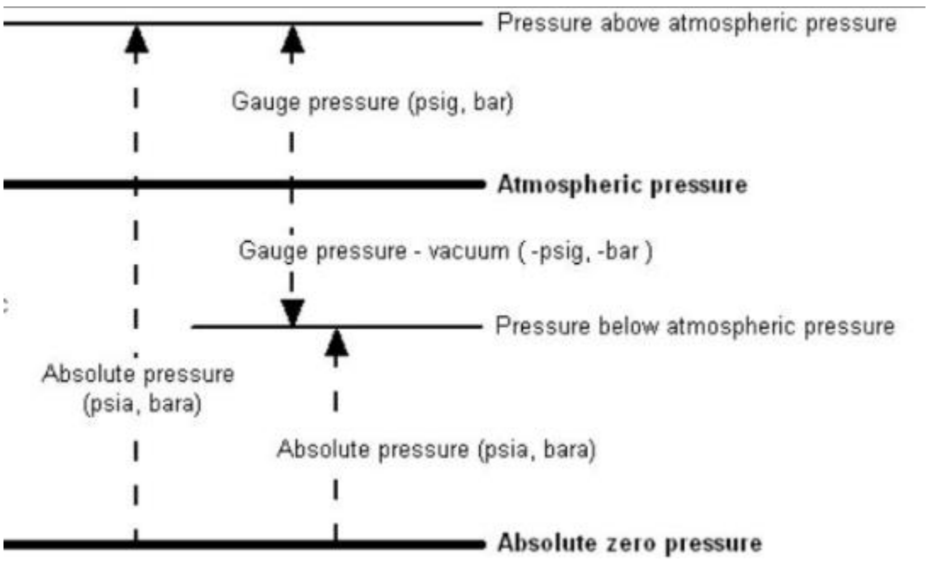
The following four basic scales are employed in pressure measurement:

1. Gauge pressure is measured above the local atmospheric pressure.

2. Total or absolute pressure is the total pressure measured from zero pressure as the datum point.

$$\boxed{\text{Total absolute pressure} = \text{Atmospheric pressure} + \text{Gauge pressure}}$$

3. Differential pressure is the difference in pressure measured between two points.



4. When the pressure to be measured is less than the local atmospheric pressure, it is called vacuum pressure.

$$\boxed{\text{Vacuum pressure} = \text{Atmospheric pressure} - \text{Absolute pressure}}$$

5. Total or absolute pressure is measured above total vacuum or zero absolute. Zero absolute represents total lack of pressure. The relationship between absolute, gauge, and barometric pressures are represented in the above figure.

Units of pressure

There are various popular units of pressure like Pa(= N/m^2), psi(= pounds/in^2), bar (=10^5 Pa = 100 kPa), mbar (=100 Pa), AtmP (=101.32 kPa), mmHg (or Torr), in Hg, etc. 1 bar = 14.5038 psi, 1psi = 6894.76 Pa.

Pressure Measuring Instruments

i) for low pressure

- Manometers (various types): Piezometer, U-tube manometer, Inverted U-tube manometer, inclined tube manometer, well type manometers, inverted well manometer

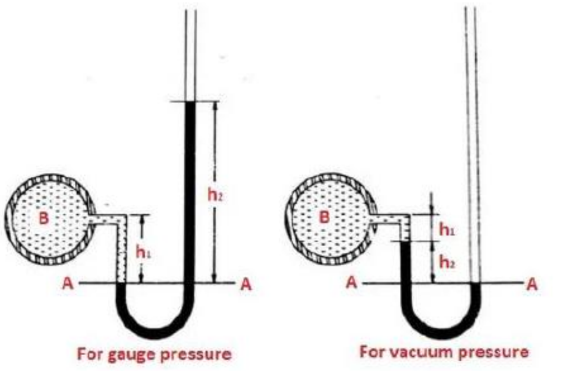
ii) For medium and high pressure

- Bourdon tube, Diaphragm gauge, Bellows

iii) For measuring vacuum Pressure

- McLeod gauge, Pirani gauge

U tube Manometer : Working principle

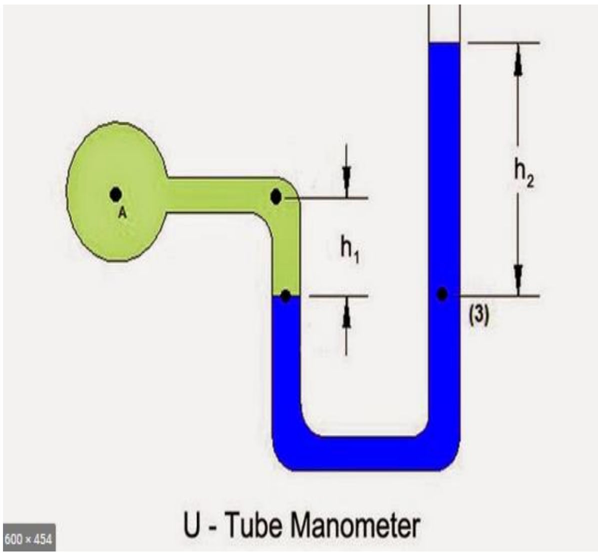


U-tube Manometer

It consists of a U shaped tube, in which a suitable liquid (mostly mercury) is filled. Initially the level of the liquid is same in both the legs of manometer. But when one of the leg is connected with a pressure line (like hydrostatic pressure), it pushes the liquid down in one leg, and consequently raises the level into the other leg. The level-difference can be read directly on a scale attached there, which reflects the amount of gauge pressure in the leg. (P = h.ρ.g)

If we observe the diagram to the right, The pressure in pipe A can be calculated using this equation-

$$P(A) + \rho_1.g.h_1 = \rho_2.g.h_2$$



U - Tube Manometer

A U tube manometer can be used for measuring gauge pressures. An inverted U tube manometer can be used to measure vacuum pressures.

Some of the important and desirable properties of the manometric liquids are:

- High chemical stability
- Low viscosity
- Low capillary constant
- Low coefficient of thermal expansion
- Low volatility
- Low vapour pressure

U-tube Differential Manometer

It is a device that is used to measure the pressure difference between two points in a pipe or between two different pipes. This manometer is consisting of a U-shaped tube containing a heavy liquid. The two ends are connected to the two desired points in the pipe whose difference of pressure is required. Let pressure at point A be more than at point B. Then the greater pressure at A will force the heavy liquid in U-tube to move downwards. This downwards movement of the heavy liquid in the left limb will cause a corresponding rise of the heavy liquid in the right limb.

Advantages of Manometers

Following are the main advantages of manometer:
1. It is simple to construct.
2. It has great accuracy.

Disadvantages of Manometers

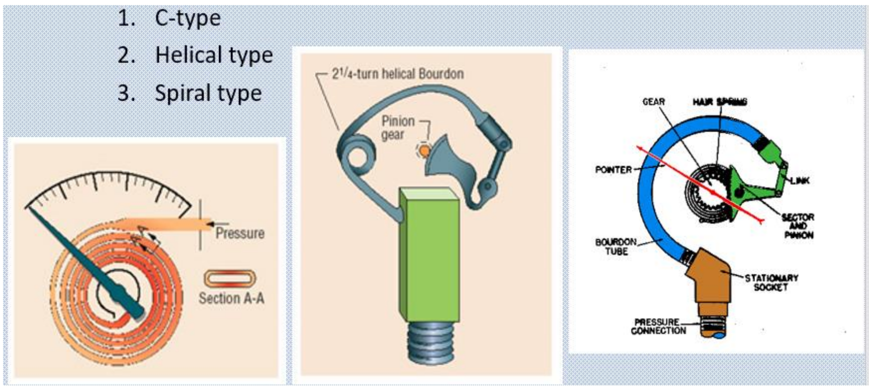
Following are the main disadvantages of manometer:

1. The manometer has a smaller dynamic response.
2. They have small operational limits which are on the order of 1000 kN/m2.
3. The density of manometric fluid depends on temperature. Therefore, errors may occur due to change in temperature.

Application of Manometers

Following are the main application of the manometer:
1. It is used to construct bridges, swimming pools and other engineering purposes.
2. Used in climate forecasting.
3. In clinical applications such as blood pressure measuring and physiotherapy.

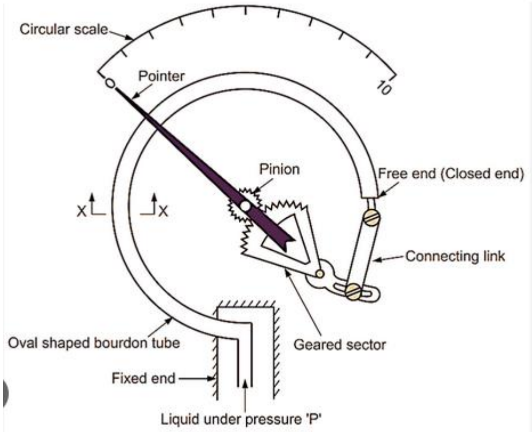
Bourdon Tube Pressure Gauge



It consists of a elastic hollow tube. When pressure is to be measured, this tube is connected with the pressure line. Due to fluid pressure, the tube elastically deforms, i.e., its shape changes. This temporary elastic deformation is transformed into the movement of certain dial pointer which can show the amount of pressure by direct calibration.

The shape of elastic tube can be C-type, helical (spring shaped) type or spiral type. Accordingly, the names are: 1) C-type, 2) helical type and 3) spiral type bourdon tubes.

C-Type Bourdon tube:



In this, the pressure line is connected with the C-shaped hollow elastic tube. Due to pressure of the fluid, the C-shaped tube expands elastically, which causes the movement of its extreme free end. This free end is connected with a connection linkage, which causes angular displacement in a 'geared sector link', causing rotation of the centrally placed pinion (small gear) and ultimately the pointer. The movement of the pointer can be calibrated to read the amount of pressure inside the tube directly on the scale. Bourdon gauges are employed to measure pressures of up to 500 MPa.

Principle of Bourdon tube pressure gauge:

When an elastic transducer (bourdon tube in this case) is subjected to a pressure, it defects. This deflection is proportional to the applied pressure when calibrated. The Bourdon pressure gauge uses the principle that a flattened tube tends to change to a more circular cross-section when pressurized. Although this change in cross-section may be hardly noticeable, the displacement of the material of the tube is magnified by forming the tube into a C shape or even a helix, such that the entire tube tends to straighten out or uncoil, elastically, as it is pressurized.

Applications of Bourdon pressure gauge:

1. They are used to measure medium to very high pressures.
2. For measuring high pressures e.g., in steam boilers, compressors.
3. For measuring pressures in vehicles tube tire.

Advantages of bourdon pressure gauge:

1. These Bourdon tube pressure gauges give accurate results.
2. Bourdon tube cost low.
3. Bourdon tubes are simple in construction.
4. They can be modified to give electrical outputs.
5. They are safe even for high-pressure measurement.

Disadvantages of bourdon pressure gauge: -

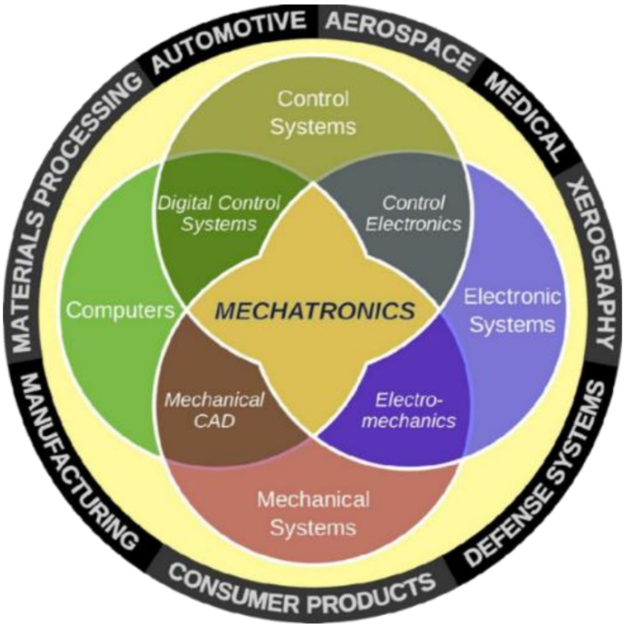
1. They respond slowly to changes in pressure
2. They are subjected to hysteresis.
3. They are sensitive to shocks and vibrations.
4. Amplification is a must as the displacement of the free end of the bourdon tube is low.

4. Introduction to MECHATRONICS system

The word mechatronics is composed of "mecha" from mechanical and the "tronics" from electronics.

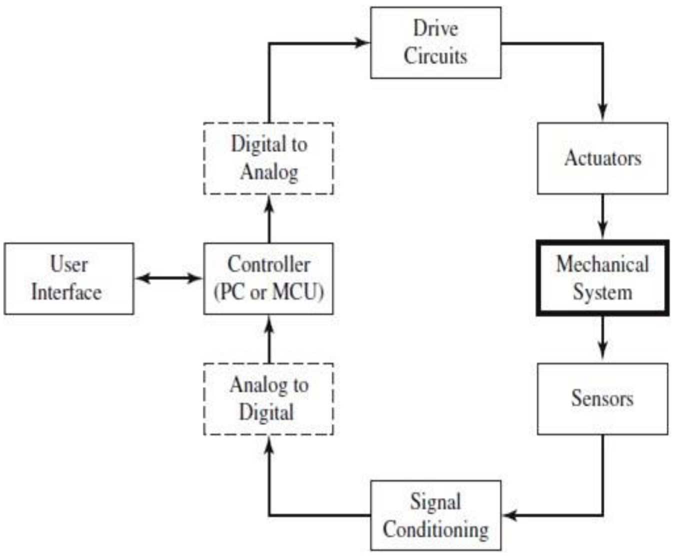
"Mecha" + "tronics" = Mechatronics

The term "Mechatronics" was coined by Tetsuro Mori, a senior Japanese engineer at Yasakawa Company in 1969. *Mechatronics is synergistic integration of mechanical engineering, electronics engineering, control engineering and computer science.*



Mechatronics engineering is the design of computer- controlled electromechanical systems. A mechatronic system is a computer controlled mechanical system.

- A mechatronic system has at its core a mechanical system which needs to be commanded or controlled by a controller.
- The controller needs information about the state of the system. This information is obtained from sensors.
- In many cases, the signals produced by the sensors are not in a form ready to be read by the controller and need some signal conditioning operations performed on them.
- The conditioned, sensed signals are then converted to a digital form by Analog-to-Digital Convertor (ADC) and are then sent to the controller.



- The controller is the 'mind' of the mechatronic system, which processes user commands and sensed signals to generate command signals to be sent to the actuators in the system. Actuators are devices that can convert electrical energy to mechanical energy
- The user commands are obtained from a variety of devices, including command buttons, graphical user interfaces (GUIs), touch screens, or pads.

Main Components of a Mechatronic System:

- Mechanical: All static or dynamic physical parts
- Electronics: ADC and DAC convertors, chipsets, etc
- Sensors: As input source or for feedback
- Actuators: To provide mechanical movements
- Control: for feedback of output and necessary correction
- Computing: for deciding required input for desired output

Examples of Mechatronic Systems:

- Antilock Brake System (ABS)
- Electronic Fuel Injection (EFI)
- Traction Control System (TCS) just like ABS.
- Adaptive Cruise Control (ACC)
- Automatic Camera
- Scanner
- Hard Disk Drive
- Industrial Robots
- Mobile Robots (Wheeled Robots, Legged Robots)

Evolution of Mechatronics

- The word 'mechatronics' was first introduced by Tetsuro Mori, an engineer of Yaskawa Electric Corporation in 1969.
- Completely mechanical systems (before and early 1900s)
- Automatic devices with electronic components such as relays, transistors, op-amps (early 1900s to 1970s)
- Computer controlled automatic systems (1970s–present)

Advantages of Mechatronic Systems:

- Increase labour productivity and reduce labour cost.
- Mitigate the effects of labour shortage.
- Reduce or eliminate routine manual or clerical tasks.
- Improved safety –Worker and system (working conditions).
- Improve product quality.
- Reduction of manufacturing lead time.
- Accomplishing processes that cannot be done manually.
- Lesser working hours for the same production.
- Elimination of set up time.
- Increased standard of living.
- Greater extend of machine utilization.
- Possibility of controlling remotely.

Disadvantages of Mechatronic Systems:

- Lower skill levels of workers
- High initial investment
- Retrenchment or unemployment
- Not suitable for short product life cycle
- Not economically justifiable for small scale production
- Multi-disciplinary engineering background required to design and develop systems
- Complexity in identification and correction of problems

Industrial Applications/examples of mechatronics systems:

- Automotive Systems: Drive by Wire, Cam less Engines
- Robotics: Humanoids, Telemedicine/Remote Surgery
- House Hold appliances: Washing Machine, Iron Box
- A computer disk drive is an example of a rotary mechatronic system.
- Automated movement vehicles.
- Automated crane systems.
- In sub-sea vehicles – In controlling the vehicle by an on-board computer, and use of various sensors.
- Human-less flight control systems.
- Unmanned vehicles
- Manufacturing automation
- Telecommunication Industries

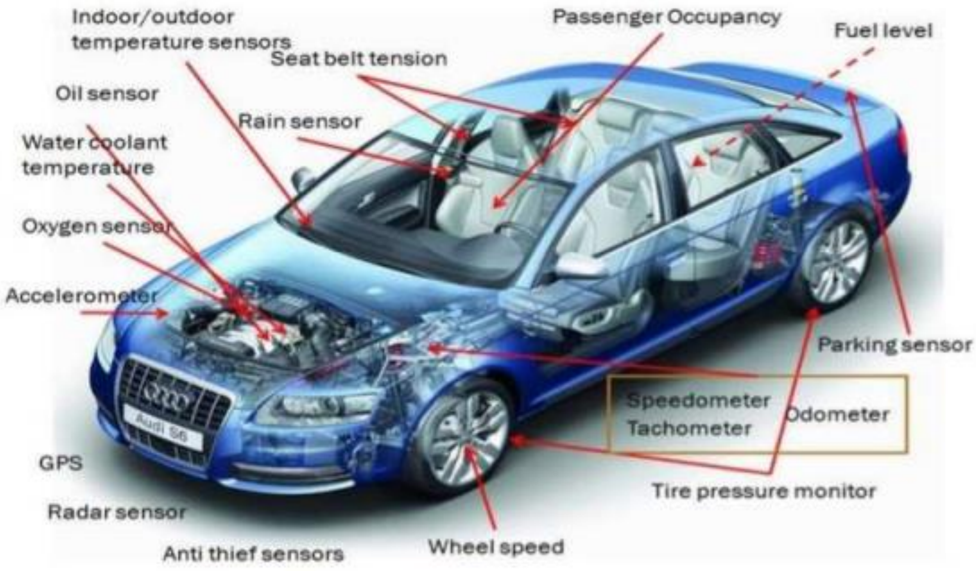
Autotronics:

• Autotronics is the blend of **Automobile + Electronics**.

• The advanced development of vehicles in the last few years was based mainly on electrical and electronic components and modules. There is no end in sight to this development. Analysts estimate that more than 80 % of all automotive innovation now stems from electronics. By definition, automotive electronic systems are embedded mixed-signal systems because they feature multiple analog sensors and analog motor controls under digital control.

• The use of electronics in the automobile field makes the system safe, improved and efficient.

• The main areas of automobiles using autotronics are engine controlling system, airbags, antilock braking system, lightening, interiors, GPS, music systems etc. The application area of autotronics is very vast, brakes, steering system, engine controlling unit, transmission and suspension in the vehicles are the main phases where autotronics are used. This field of Mechatronics is based on various types of sensors used in the automobiles these days. Some of them are shown in the figure below-



various electronic systems used in automobiles are given below

- Autotronic braking system/Electronic braking system
- Control of steering system
- Suspension system
- Transmission control
- Electronic control of fuel intake in engine etc.

Year	Examples of automotive electronics available
1965	Solid-state radio, alternator rectifier
1970	Speed control
1975	Electronic ignition, digital clock
1980	Electronic voltage regulator, electronic engine controller, electronic instrument cluster, electronic fuel injection
1985	Clock integrated with radio, audio graphic equalizer, electronic air suspension
1990	Antilock brakes. integrated engine and speed control, cellular phones, power doors and windows
1995	Navigation systems. advanced entertainment / information systems, active suspensions
2000	Collision avoidance, autonomous cruise control, vehicle stability enhancement, CVT
2005	Hybrid electric vehicles. driver monitoring. drive-by-wire, integrated vehicle controls
2010	Driver-assist systems (e.g.. automated parallel parking). integrated telematics (i.e..location-aware vehicles via mobile devices), plug-in hybrid electric vehicles

Introduction to Bionics:

• Bionics or biologically inspired engineering is the application of biological methods and systems found in nature to the study and design of engineering systems and modern technology.

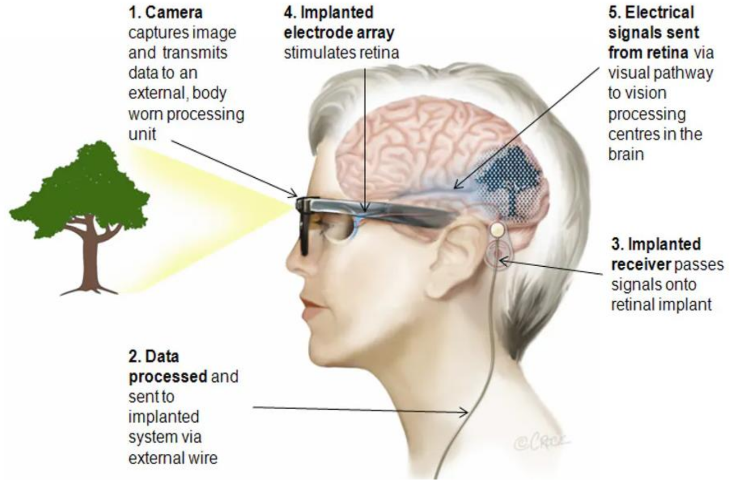
• In medicine, Bionics means the replacement or enhancement of organs or other body parts by using mechanical versions.

• The structural and functional principles of organ systems in living things are analyzed by bionomists and then the principles are applied while building useful artificial systems and machines.

• Bionic implants refer to electronic or mechatronic parts that augment or restore physical functionality to a differently-abled person.

The bionics industry has grown along four major application areas: vision, hearing, orthopaedics and a small, motley group of implants that augment cardiac and neurological functions.

Vision Bionics



• The bionic eye or visual neuro prosthesis, as vision bionics are sometimes called bioelectronic implants that restore functional vision to people suffering from partial or total blindness.

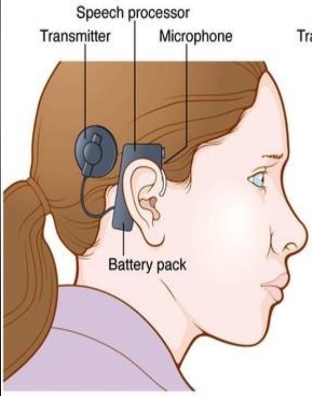
• Researchers and device manufacturers who are designing bionic eyes confront two important challenges: the complexity of mimicking retinal function and the consumer preference (and constraint) for miniature devices that can be implanted into the eye.

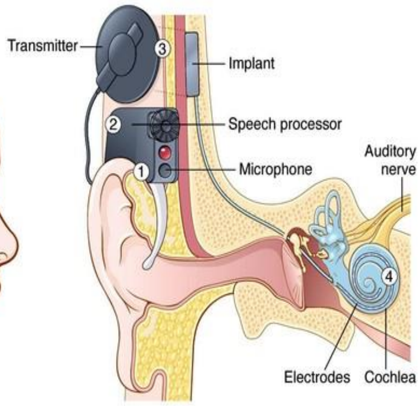
• The camera, integrated into eyeglasses, captures images and transmits them to the portable processing unit, which wirelessly sends electrical signals to the implanted array. The array, in turn, converts these signals into electrical impulses that stimulate the retinal cells that connect to the optic nerve.

Auditory Bionics:

• Cochlear implants, auditory brainstem implants and auditory midbrain implants are the three main classes of periprosthetic devices for people suffering from profound hearing loss.

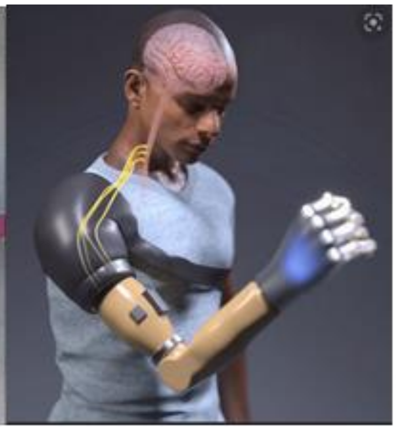
• Auditory bionics creates an artificial link between the source of sound and the brain in this case, with a microelectronic array implanted either in the cochlea or the brain stem.





Orthopaedic Bionics:

• Orthopaedic bionics are designed to restore motor functionality (not necessarily sensory functionality) to the physically challenged.



• A bionic limb is interfaced with a patient’s neuromuscular system for limb control flexing, bending and grasping—using the brain. A similar functional pathway exists here: The damaged peripheral nerves are bypassed and a new electronic pathway connects the mechatronic limb with the brain.

Introduction to Avionics:

• Avionics are the electronic systems used on aircraft, artificial satellites, and spacecraft.

• Avionic systems include communications, navigation, the display and management of multiple systems, and the hundreds of systems that are fitted to aircraft to perform individual functions.

• These can be as simple as a searchlight for a police helicopter or as complicated as the tactical system for an airborne early warning platform.

5. Overview of Some Components of Mechanical Actuation Systems

Actuation systems are the elements of control systems which are responsible for transforming the output of a microcontrollers or microprocessor or control system into a controlling action on machine or device. e.g., Pneumatic, hydraulic, mechanical, and electrical actuation systems.

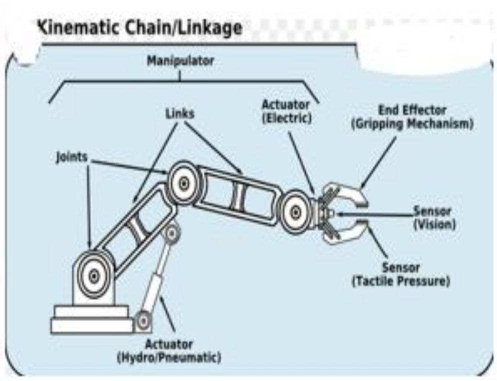
Mechanical Actuation System

- Actuation systems are the elements of control systems which are responsible for transforming the output of a microprocessor or control system into a controlling action on a machine or device. There various components of mechanical actuation systems, which include kinematic chains, cam and followers, belt drives, train ratchet mechanism, ball bearings, various types of gears, etc.
- Generally, two types of actuation systems, namely pneumatic and hydraulic actuation systems, are used.
- Pneumatics is the term used when compressed air is used and hydraulics when a liquid, typically an incompressible dense oil.

Some mechanical components used for actuation purpose

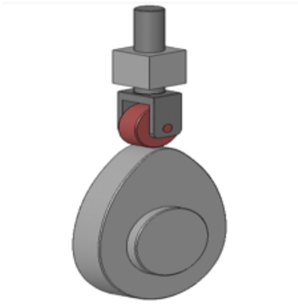
Kinematic chain

- In mechanical engineering, a kinematic chain is an assembly of rigid bodies connected by joints to provide constrained (or desired) motion that is the mathematical model for a mechanical system. The motion of one link causes motion to the other connected links.



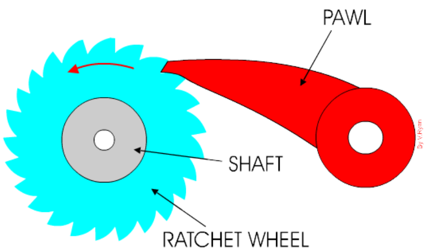
- As in the familiar use of the word chain, the rigid bodies, or links, are constrained by their connections to other links.
- The Kinematic Chain is also the combination of the Kinematic pairs.

Cam and Followers



- A cam is a rotating or sliding piece in a mechanical linkage used especially in transforming rotary motion into linear motion. It is often a part of a rotating wheel (e.g. an eccentric wheel) or shaft (e.g. a cylinder with an irregular shape) that strikes a lever at one or more points on its circular path.
- The cam can be a simple tooth, as is used to deliver pulses of power to a steam hammer, for example, or an eccentric disc or other shape that produces a smooth reciprocating (back and forth) motion in the follower, which is a lever making contact with the cam.
- The cam can be seen as a device that converts rotational motion to reciprocating (or sometimes oscillating) motion.

Train Ratchet Mechanism

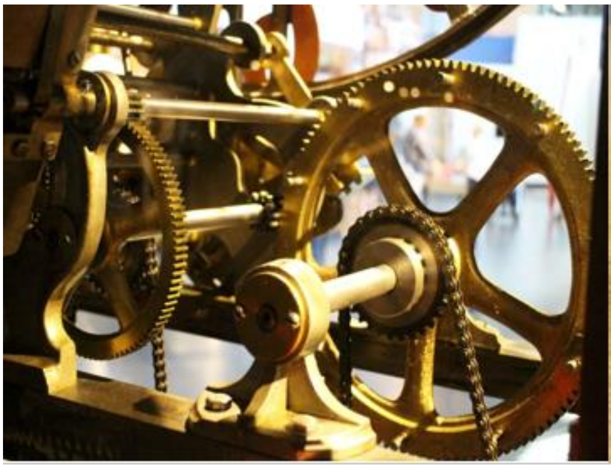


- A ratchet is a fairly simple mechanism that only allows a gear to turn in one direction.
- A ratchet system consists of a gear (sometimes the teeth are different than the standard profile) with a small lever or latch that rotates about a pivot point and catches in the teeth of the gear.

- The latch is designed and oriented such that if the gear were to turn in one direction, the gear could spin freely and the latch would be pushed up by the teeth, but if the gear were to spin in the other direction, the latch would catch in the teeth of the gear and prevent it from moving.
- Ratchets are useful in a variety of applications, because they allow force to be applied in one direction but not the other.
- Bicycles, some wrenches, screw gauge, etc.

Gears and its types

A gear is a wheel with teeth around its circumference. Gears are usually found in sets of two or more, used to transmit rotation from the axis of one gear to the axis of another.



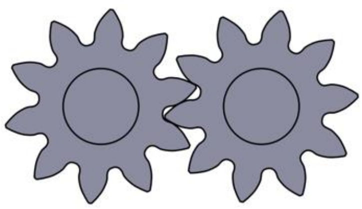
- The teeth of a gear one axis mesh with the teeth of a gear on another, thus creating a relationship between the rotation of the two axes.
- When one axis is spun, the other will too. Two gears of different sizes will make their two axes spin at different speeds.

Why Use Gears?

- Gears are a very useful type of transmission mechanism used to transmit rotation from one axis to another.
- You can use a system of gears to reduce the speed (and likewise increase the torque) so that the output shaft spins at half the speed of the motor.
- Gears are commonly used in high load situations because The teeth of a gear allow for more fine, discrete control over movement of a shaft, which is one advantage gears have over most pulley systems.

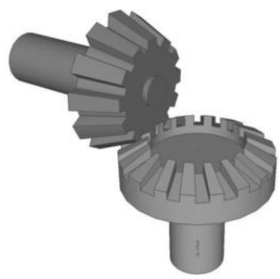
Types of Gears : Spur gears, bevel gears, helical gears, herringbone gears, worm and worm-wheel gears, hypoid gears, etc.

Spur Gears



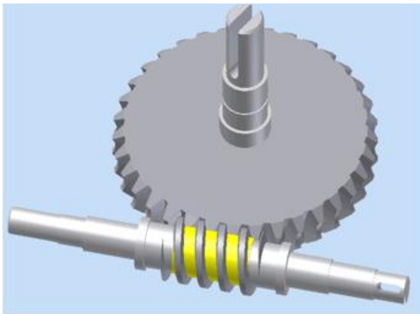
Spur gears are the most common and simplest type of gear. Spur gears are used to transfer motion from one shaft to a parallel shaft. The teeth are cut straight up and down, parallel to the axis of rotation.

Bevel Gears



Bevel gears are a type of gear used to transmit power from one axis to another non-parallel axis. Bevel gears have slanted teeth, which actually makes the shape of their "pitch diameter" a cone. This is why most bevel gears are classified based on the distance from the rear face of the gear to the imaginary tip of the cone that the gear would form if its teeth extended out.

Worm Gears



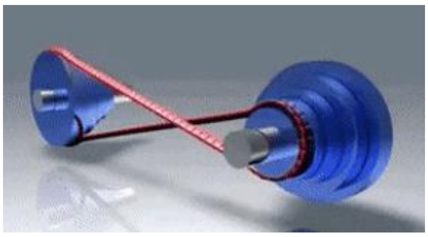
A worm gear is a gear driven by a worm, which is a small, screw-like piece that meshes with the gear. The gear rotates on an axis perpendicular, but on a different plane than, the worm. Worm gears can thus be used to drastically reduce the speed and increase the torque of a system in only one step in a small amount of space. A worm gear mechanism could create a gear ratio of 100:1.

Helical Gears

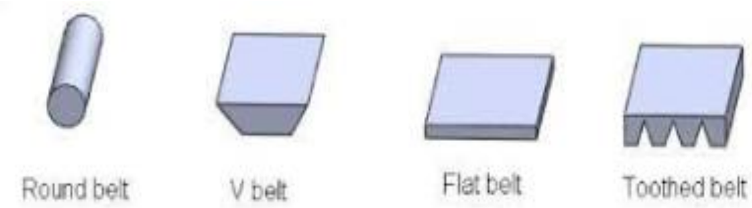
Helical gears are a more efficient type of spur gear. The teeth are set at an angle to the axis of rotation, so they end up curving around the gear instead of straight up and down like spur gears. Helical gears can be mounted between parallel axes, but can also be used to drive non-parallel axes as long as the angled teeth mesh.

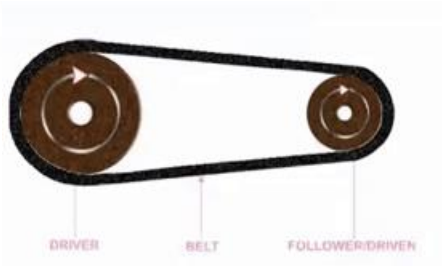
Belt Drives

- A belt is a loop of flexible material used to link two or more rotating shafts mechanically, most often parallel.
- Belts may be used as a source of motion, to transmit power efficiently or to track relative movement.
- Belts are looped over pulleys and may have a twist between the pulleys, and the shafts may or may not be parallel.
- Belt drives may be classified as: **open belt drive** and **crossed belt drive**.
- Another classification is : **Flat belt, V-belt** drives, round belt (rope) drive and toothed belt drive.



As comparative to flat belt, V-belts provide better grip and hence, faster speeds can be attained. Foe even further faster speeds, multiple V-belts can be used in a parallel arrangement.





Bearings

- A bearing is a machine element that constrains relative motion to only the desired motion, and reduces friction between moving parts.
- Bearings support the rotating shafts of the wheels, gears, turbines, rotors, etc. in those machines, allowing them to rotate more smoothly. These are of following types : (1) Ball bearing, (2) Roller bearings, (3) Needle bearings, (4) Tapered Roller bearings, etc.
- They fulfil the following two major functions.

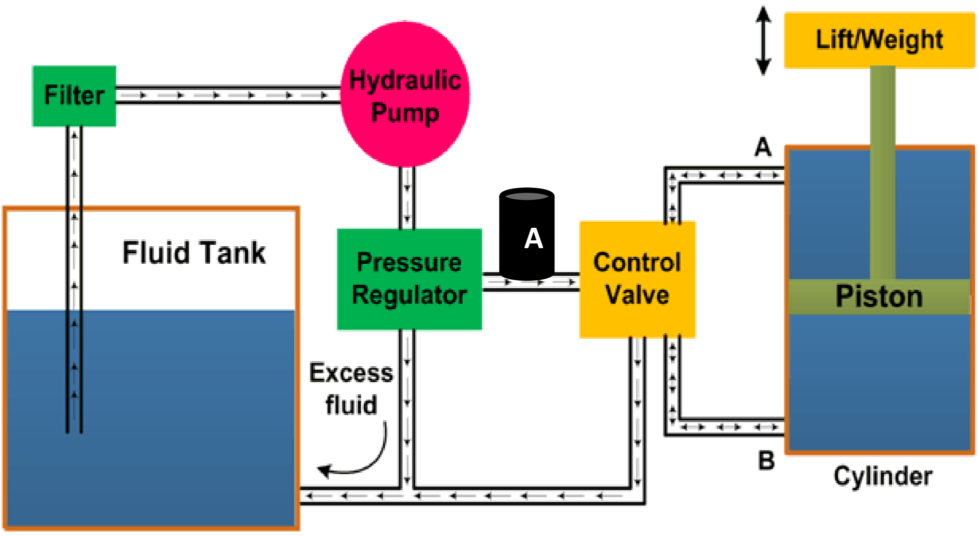
Function 1: Reduce friction and make rotation more smooth
Function 2: Protect the part that supports the rotation, and maintain the correct position for the rotating shaft.

6. Hydraulic and Pneumatic Actuation System

Hydraulic systems

- It is a kind of enclosed fluid-based system using pressurized incompressible liquids as transmission media. And is called as hydraulic system. The hydraulic system works on the principle of Pascal’s law.
- Enclosed fluid systems can provide both linear as well as rotary motions.
- The hydraulic systems consists of storage tank, filter, hydraulic pump, non-return valve, accumulator, pressure regulator, direction control valves, hydraulic cylinder, piston, and leak-proof fluid flow pipelines.

The storage/fluid tank is a reservoir for the liquid used as a transmission media. The liquid used is generally high-density incompressible oil. It is filtered to remove dust or any other unwanted particles and then pumped by the hydraulic pump operated by a motor. The capacity of the pump depends on the hydraulic system design.



hydraulic System

A non-return valve is used to make sure no amount of liquid returns back to the pumping system.
The pumps generally deliver constant volume in each revolution of the pump shaft. Therefore, the fluid pressure can increase indefinitely at the dead-end of the piston until the system fails. The pressure regulator / relief valve is used to avoid such circumstances which redirect the excess fluid back to the storage tank.
In case the pump delivers non-uniform fluid supply, an accumulator needs to be used to regulate and control the amount of fluid flow. It helps in minimizing the pressure fluctuations in supply line.
The movement of the piston is controlled by changing the liquid flow from port A and port B. The cylinder movement is controlled by using a control valve which directs the fluid flow. The fluid pressure line is connected to the port B to raise the piston and it is connected to port A to lower down the piston. The valve can also stop the fluid flow in any of the ports.
The leak-proof piping is also important due to safety, environmental hazards, and economic aspects.
Applications : Machine tools, Material handling equipment, Construction field, Automobiles, Material testing laboratory, Aerospace, Railways, Medical equipment, Agricultural equipment, etc.

Advantages :

- Hydraulic power is easy to produce, transmit, store, regulate and control, maintain and transform.
- It is possible to generate high gain in force and power amplification.
- Hydraulic systems are uniform and smooth, generate step-less motion and variable speed and force to a greater accuracy.
- Frictional resistance is much less in a hydraulic system as compared to a mechanical movement.

- The noise and vibration produced by hydraulic pumps is minimal.
- Weight to power ratio is lesser.
- Hydraulics is a better over-load safe power system.
- Absolutely accurate feedback of load, position, etc. can be achieved.

Disadvantages :

- Increased manufacturing costs
- The leakage of hydraulic oil poses problems to hydraulic users.
- Hydraulic elements have to be specially treated to protect them against rust, corrosion, dirt, etc.
- Hydraulic oil may pose problems if it disintegrates due to aging and chemical deterioration.

Various types of hydraulic pumps

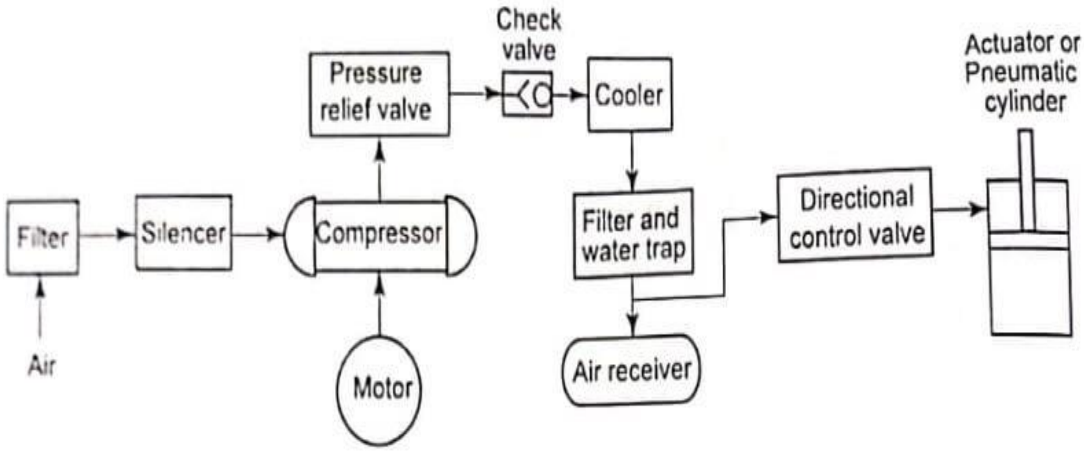
Some Commonly used hydraulic pumps in any hydraulic system are the gear pump, vane pump and piston pump.

a. Gear Pump
b. Vane Pump
c. Piston Pumps
    a. Radial Piston Pump
    b. Axial Piston Pump (Single acting and double acting reciprocating pumps)

Pneumatic systems

- In pneumatic systems, force is produced by gas. It is mainly by air pressure acting on the surface of a piston or valve.
- Compressed air is produced in a compressor and stored in a receiver. From compressor, it is send to valves which control the direction of fluid flow. Also, flow control valves control the amount of power by the cylinder.

- A pneumatic system essentially has the following components-
    - Compressor and Motor
    - Pressure relief valve and Check valve.
    - Cooler, filter and water trap
    - Air receiver
    - Directional control valves
    - Actuator or pneumatic cylinder



- The fresh atmosphere air is not sent directly to the compressor to use in pneumatic systems. First, it is filtered atmosphere air is supplied to the compressor through silencer to reduce noise level. Then it is compressed.
- Pressure relief valve is used to avoid the damage of compressor due to excess pressure raise in the system. Check valve is a one-way valve that allows pressurized air to enter the pneumatic system, but prevents backflow and loss of pressure into the compressor when it is stopped.
- The cooler is used to cool the compressed air which is usually very hot. The filter is used to remove contamination in the compressed air and water trap is used to remove water particles.
- The pressurized air is stored in a device called an air receiver, preventing surges in pressure and relieving the duty cycle of the compressor.
- Directional control valves are used to control flow of pressurized air from the source to the selected port. These valves can be actuated either manually or electrically.
- Actuator or pneumatic cylinder converts energy stored in the compressed air into mechanical motion.

Various types of air compressors used

Commonly used air compressors are

(a) Single acting reciprocating compressor
(b) Rotary Vane Compressor
(c) Screw Compressor
(d) Gear pump

Comparison between Hydraulic and Pneumatic actuation Systems:

Hydraulic System	Pneumatic System
It employs a pressurized liquid as a fluid	It employs a compressed gas, usually air, as a fluid
An oil hydraulic system operates at pressures up to 700 bar	A pneumatic system usually operates at 5–10 bar
Generally designed as closed system	Usually designed as open system
The system slows down when leakage occurs	Leakage does not affect the system much
Valve operations are difficult	Valve operations are easy
Heavier in weight	Lighter in weight
Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gases
The system is unsafe to fire hazards	The system is free from fire hazards
Automatic lubrication is provided	Special arrangements for lubrication are needed

7. Various types of Valves

- Valves are used with hydraulic and pneumatic systems to direct and regulate the fluid flow.
- There are basically just two forms of valve, the finite position and the infinite position valves.
- The **finite position valves** are ones where the action is just to allow or block fluid flow and so can be used to switch actuators **on or off**. They can be used for directional control to switch the flow from one path to another and so from one actuator to another.
- The **infinite position valves** are able **to control flow anywhere between fully on and fully off** and so are used to control varying actuator forces or the rate of fluid flow for a process control situation.

Directional Control Valves

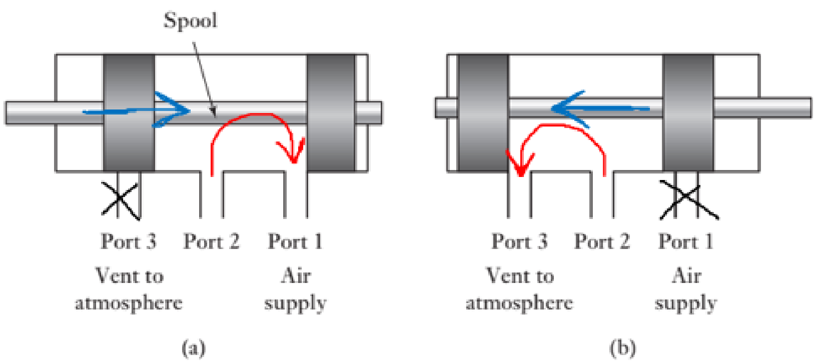
- They are not intended to vary the rate of flow of fluid but are either completely open or completely closed, i.e. on/off devices.

- They might be activated to switch the fluid flow direction by means of mechanical, electrical or fluid pressure signals.

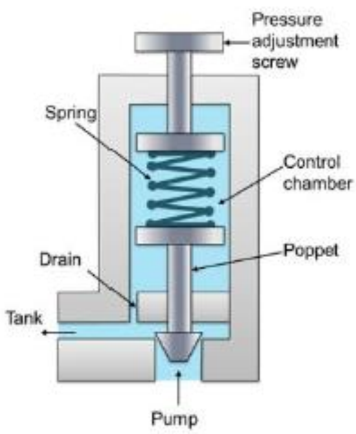
Some common type of directional control valve is the SPOOL VALVE, Poppet valve.

Spool Valve

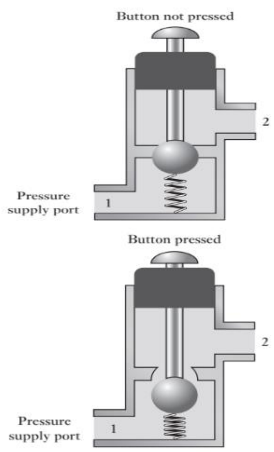
A spool moves horizontally within the valve body to control the flow. In (a) the air supply is connected to port 1 and port 3 is closed. Thus the device connected to port 2 can be pressurised. When the spool is moved to the left the air supply is cut off and port 2 is connected to port 3. Port 3 is a vent to the atmosphere and so the air pressure in the system attached to port 2 is vented. Thus the movement of the spool has allowed the air firstly to flow into the system and then be reversed and flow out of the system.



Poppet Valve



- Common form of pressure relief valve is the poppet valve. If pressure at the inlet of relief valve is not enough to overcome the spring force, in that situation poppet will be remain seated over its seat and will not allow the flow of fluid through it and therefore relief valve will be closed and will not allow flow through it.
- When pressure at the inlet of relief valve increases and overcomes the spring force which was adjusted with the help of pressure adjusting screw displayed at the top of relief valve, in that situation poppet will leave the seat and will permit the flow of fluid through relief valve.
- Hence, if pressure at inlet of relief valve overcomes the setting pressure of relief valve, then fluid will flow to hydraulic reservoir through relief valve and therefore further increment in pressure in pressure line will be avoided.



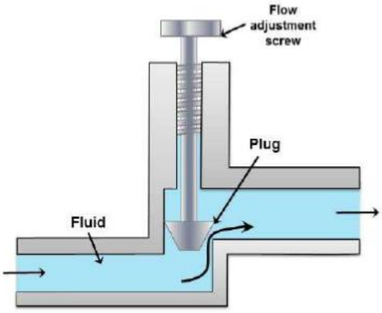
- It may be operated manually also, using a press-button on its top. This valve is normally in the closed condition, there being no connection between port 1 to which the pressure supply is connected and port 2 to which the system is connected.
- In poppet valves, balls, discs or cones are used in conjunction with valve seats to control the flow.
- In the figure a ball is shown. When the push-button is depressed, the ball is pushed out of its seat and flow occurs as a result of port 1 being connected to port 2.
- When the button is released, the spring forces the ball back up against its seat and so closes off the flow.

Flow Control Valves:

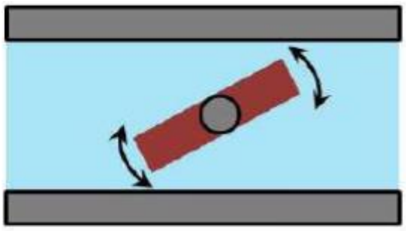
Flow control valves in hydraulics are used for controlling the volume of fluid which is supplied to different parts of the hydraulic system.

The speed of the actuators which is being used in the hydraulic circuits can be controlled by regulating the fluid flow, to carry out this regulation operation we need devices and the device which is providing that regulation operation is flow regulation valves.

Types of flow control valves

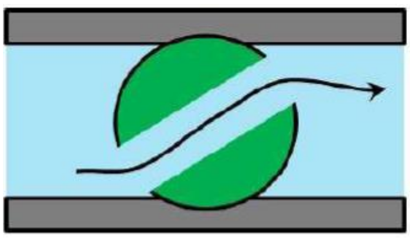


- **Plug or glove valve** : The plug valve is quite commonly used valve. It is also termed as glove valve. This valve has a plug which can be adjusted in vertical direction by setting flow adjustment screw. The adjustment of plug alters the orifice size between plug and valve seat.



- **Butterfly valve :** It consists of a disc which can rotate inside the pipe. The angle of disc determines the restriction. Butterfly valve can be made to any size and is widely used to control the flow of gas. The resilient butterfly valve uses the flexibility of rubber and has the lowest pressure rating.

- **Ball valve** : This type of flow control valve uses a ball rotated inside a machined seat. The ball has a through hole as shown in figure. It has very less leakage in its shut-off condition. These valves are durable and usually work perfectly for many years. They are excellent choice for shutoff applications. They do not offer fine control which may be necessary in throttling applications. These valves are widely used in industries because of their versatility, high supporting



pressures (up to 1000 bar) and temperatures (up to 250°C). They are easy to repair and operate.

- **Pin or needle valve :** Needles valves provide finer control of flow in small diameter pipes. They have sharp pointed conical disc and matching seat. Needle valves are normally made up of steel bar. These are also used as stop valves in hydraulic circuit to shut off the flow of fluid from one part of a circuit to another part. Needle valves are suitable for throttling i.e., the flow area is slowly reduced as the valve is closed, gradually reducing the quantity of fluid passing through the valve.