Unit-2

Measurement: Concept of measurements, errors in measurement, Temperature, Pressure, Velocity, Flow strain, Force and torque measurement, Vernier caliper, Micrometer, Dial gauge, slip gauge, Sine-bar and Combination set.

Production Engineering: Elementary theoretical aspects of production processes like casting, carpentry, welding etc. Introduction to Lathe and Drilling machines and their various operations.

Measurement: Measurement is an act of assigning an accurate and precise value to a physical variable. The physical variable then gets transformed into a measured variable. Measurement is an act of obtaining quantitative comparison between an unknown quantity (measurand) and known fixed quantity of the same kind (predefined standard or referance).

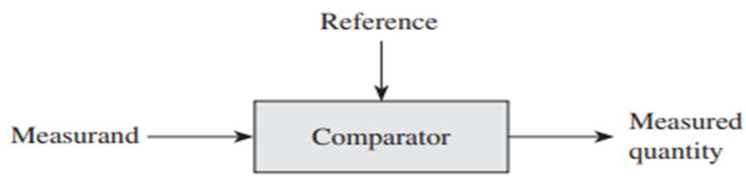


Fig.1

Elements of measurement

1. Measurand: a physical quantity such as length, weight, and angle to be measured
2. Comparator: to compare the measurand (physical quantity) with a known standard (reference) for evaluation
3. Reference: the physical quantity or property to which quantitative comparisons are to be made.

Significance of measurement:

- A product/system is made of several elements, so each element has to be properly designed to perform the required (desired) function. In order to test whether functioning of each element constituting the product meets the design expectation, and to finally assess the functioning of the whole system, measurements are inevitable (unavoidable).
- For proper operation and maintenance of such a product/system, measurement plays an important role for acquiring very important and necessary data about operations and maintenance, without which the function or analysis cannot be performed properly.
- Establish the cost of products on the basis of amount of material, power, time & labor, etc.
- Measurement also provides the fundamental basis for research and development.

Methods of measurement

a) Direct method and indirect method

Direct method: In this method, the quantity to be measured is directly compared with the primary or secondary standard. It involves no mathematical calculations to arrive at the result. This method is not very accurate because it depends on human insensitiveness in making judgement. Scales, vernier calipers, micrometers, bevel protractors, etc., are used in

the direct method. This method is widely employed in the production field. In the direct method, a very slight difference exists between the actual and the measured values of the quantity. This difference occurs because of the limitation of the human being performing the measurement.
Indirect method: In this method, several parameters (to which quantity to be measured is linked with) are measured directly and the value id determined by mathematical relationship. Some examples of indirect measurement are angle measurement using sine bar, measurement of density by measuring mass and geometrical dimensions.

b) Contact method and contactless method
Contact method: In this method, the surface to be measured is touched by the sensor or measuring tip of the instrument. Care needs to be taken to provide constant contact pressure in order to avoid errors due to excess constant pressure. Examples of this method include measurements using micrometer, vernier caliper, and dial indicator.
Contactless method: As the name indicates, there is no direct contact with the surface to be measured. Examples of this method include the use of microscope etc.

Levels of measurement:
1. Primary measurement
- A primary measurement is one that can be made by direct observation without involving any conversion (translation) of the measured quantity into length.
- Examples of primary measurement

1. The matching of two lengths such as when determining the length of an object with a meter rod.
2. Matching two colors such as when judging the color of red hot metal.

Fig.2

2. Secondary measurement
- Secondary measurement involves only one translation to be done on the quantity under measurement to convert into a change of length.
- The measured quantity may be pressure of a gas and therefore, may not be observable.

- Therefore, a secondary measurement requires,
  a. An instrument which translates pressure change into length change.
  b. A length scale or a standard to show the reading equivalent to know the change in pressure

Fig.3

3.Tertiary measurement

- The tertiary measurement involves two translations.
- For example: The measurement of temperature of an object by thermocouple.
  1. The first translation is temperature of a body to voltage which is a function of temperature.
  2 The second translation is then voltage into length.

Concept of error:
While performing physical measurements, it is important to note that the value of the unknown quantity obtained by the measuring instrument is not completely accurate, there is always some error. Thus, in order to analyses the measurement data, we need to understand the nature of errors associated with the measurements. The error in measurement may be expressed or evaluated either as an absolute error or as a relative error.
Absolute error: It is defined as the difference between the measured value and the true value of the unknown quantity.
Relative error: Ratio of absolute error to the true value of the quantity to be measured.

Types of error:

a. Gross Errors: These errors are due to the blunder (a stupid mistake) made by observers in using instruments, recording data and calculating measurement results. For example: A person may read a pressure gage indicating 1.01 N/m2 as 1.10 N/m^2. Someone may have a bad habit of memorizing data at a time of reading and writing a number of data together at later time. This may cause error in the data. Errors may be made in calculating the final results. To avoid these errors great care should be taken during reading and recording data.

b. Systematic Errors: The errors result from improper conditions, improper procedures or method and poor construction of instrument. These are inherent errors of apparatus or method. Such errors change the reading of instrument by a fixed magnitude. These errors are caused due to the following:

1. Instrument Error: These errors are caused to poor design or construction of instrument such as the division of the scale not being uniform and clear, the pointer is not fine and straight etc. Such errors can be avoided by selecting a suitable instrument for a given application and applying suitable correction after determining the amount of instrumental error.
2. Environmental Error: These types of error are caused due to variation of conditions such as variation in temperature, variation in pressure, variation in external electrostatic and magnetic fields etc. These errors can be eliminated by using instrument in controlled conditions of pressure, temperature etc.

c. Random error: Random errors are non-consistent. They occur randomly and are accidental in nature. It is difficult to eliminate such errors. These errors are due to so many reasons such as noise and fatigue in the working persons. The possible sources of such errors are:

a. Friction and stickiness in instrument.
b. Vibration in instrument frame or supports.
c. Elastic deformation.
d. Supply power fluctuations.

The effect of random errors can be reduced by measuring the given quantity many times under the same conditions and calculating arithmetical mean value obtained.

Properties of measuring instrument:

1. Hysteresis: Hysteresis is a phenomenon under which the measuring instrument shows different output effects during loading and unloading. Hysteresis results from the inelastic quality of an element or device This effect arises due to the fact that all energy is put into the stressed part when loading is not recoverable upon unloading.

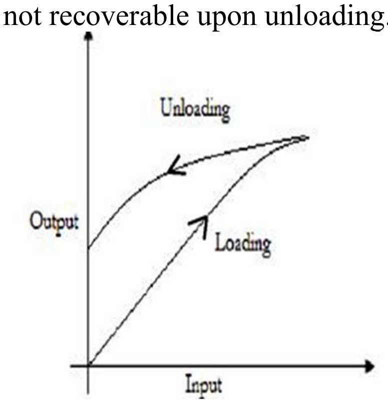


Fig.4

2.Sensitivity: It is the ratio of change in output (or response) of the instrument to change in input or measured variable.

3.**Accuracy**

Accuracy: The ability of an instrument to measure the accurate value is known as accuracy. In other words, it is the degree of closeness of the measured value to a standard or true value.

4.**Precision:** The closeness of two or more measurements to each other is known as the precision of a substance. If you weigh a given substance five times whose true weight is 3.5

kg and get 3.2 kg each time, then your measurement is very precise but not necessarily accurate.

5. Repeatability: The variation arising when the conditions are kept identical and repeated measurements are taken during a short time period.

6. Reproducibility: The variation arises using the same measurement process among different instruments and operators, and over longer time periods.

7. Span: It is defined as the difference between the largest (upper range) and the smallest (lower range) reading of the instrument.

8. Range: It is defined as a largest reading a instrument can read or it is minimum value to maximum value. It can be defined as the measure of the instrument between the lowest and highest readings it can measure.

Example: Suppose a thermometer having a calibration of -40˚C to 400˚C. Therefore, the range is 400˚C or -40˚C to 400˚C and Span = 400 – (-40) =440˚C.

9. Response Time: It is defined as the time required for an instrument to respond to a unit change in input signal. The response time can be defined as how quickly a sensor is able to react to changes in the measured variable. Response time is the time it takes for a system to react to a given input

10. System response: Response of a system may be defined as the ability of the system to transmit & present all the relevant information contained in the input signal.

11. Drift: The tendency pf instrument to lose its accuracy relative to standard.

12. Threshold value: If the instrument input is increased very gradually from zero there will be some minimum vale below which no output can be can be detected. This minimum value defined the threshold of the instrument.

13. Resolution: Resolution of an instrument is the smallest value of change in physical quantity that an instrument can read. It is the ability of a measuring instrument to detect the difference between two slightly different reading and display it.

Temperature measurement: Temperature can be defined as a condition of a body by virtue of which heat is transferred from one system to another. Temperature is a measure of the internal energy of a system. Heat transfer takes place from a body at a higher temperature to one at a lower temperature. The two bodies are said to be in thermal equilibrium when both of them are at the same temperature and no heat transfer takes place between them.

Principle of temperature measurement: The principle of temperature measurement is the zeroth law of thermodynamic. According to zeroth law of thermodynamic "When a body 'A' is in thermal equilibrium with another body 'b', and also separately in thermal equilibrium with a body 'C', then body 'B' and 'C' will also be in thermal equilibrium with each other". This is the Zeroth Law of Thermodynamics and provides the basis for temperature measurements.

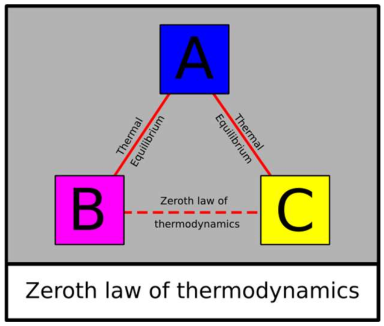


Fig.5

The scales used to measure temperature can be divided into relative scales [Fahrenheit (°F) and Celsius (°C)] and absolute scales [Rankine (°R) and Kelvin (K)]. The various temperature scales are related as follows:

F = 1.8C + 32
C = (F − 32)/1.8
R = F + 460
K = C + 273

Methods of measuring temperature:

Measurement of temperature cannot be accomplished by direct comparison with basic standards such as length and mass. A standardized calibrated device or system is necessary to determine temperature. In order to measure temperature, various primary effects that are caused by the changes in temperature can be used. The temperature change may cause changes in physical or chemical states, electrical property, radiation ability, or physical dimensions etc. Temperature measurement methods can broadly be classified into two categories: contact and non-contact-type
Contact-type method: In contact-type method, the object whose temperature is to be measured remains in contact with the temperature sensor. Contact-type method sensors are classified as follows:
1. Thermocouples
2. Resistance temperature detectors (RTDs)
3. Bimetallic strip thermometers

Contact-type measuring method can be further classified into two categories: electrical and non-electrical. Electrical type method utilizes a signal which can be easily detected, amplified and used for control process. Non- electrical type method can be based on one of the following principles: change in physical state, change in the physical properties or change in the chemical properties.

Non-Contact-type: In case of non-contact-type method, the radiant power of the infrared or optical radiation received by the object or system is measured. Temperature is determined using instruments such as radiation or optical pyrometers. Non-contact-type sensors are categorized as follows:
1. Radiation pyrometers
2. Optical pyrometers

3. Fiber-optic thermometer

Temperature measuring devices:

1.Thermocouple: Thermocouples are active sensors employed for the measurement of temperature. Thermocouple are made by twisting two wires of dissimilar metals, and making a junction between them by brazing or welding. Thermocouple is based on Seebeck effect "when two dissimilar metals are joined together to form two junctions such that one junction (known as the hot junction or the measured junction) is at a higher temperature than the other junction (known as the cold junction or the reference junction), a net emf is generated". This emf, which also establishes the flow of current, can be measured using an instrument connected. The magnitude of emf generated is a function of the junction temperature. By using a relation between voltage and junction temperature we can find the temperature.

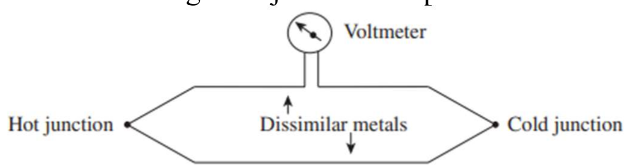


Fig.6

2. Bimetallic strip thermometers: Bimetallic strip thermometers are devices employed for the measurement of temperature

Working principle: A bimetallic strip thermometer works on the well-known principle that different metals expand and contract to different rates, depending on the coefficient of expansion of the individual metals. Hence the difference in thermal expansion rates is used to produce a deflection which is proportional to temperature changes

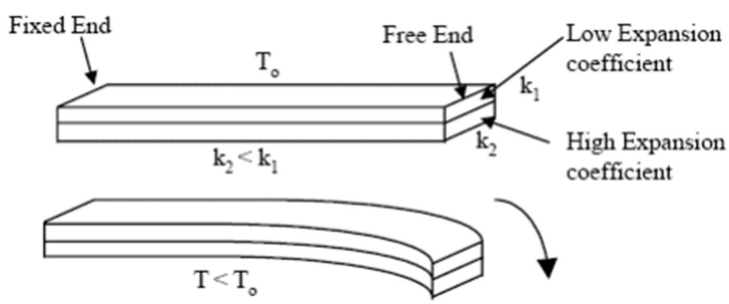


Fig.7

Construction The bimetallic thermometer consists of a bimetallic strip. A bimetallic strip is made of two thin strips of metals which have different coefficients of expansion. If two strips of two different metals (steel and copper) are firmly welded, riveted, or brazed together so that the relative motion between them is arrested. The strips are wrapped around a spindle into a helical coil. One end of the helix is fixed permanently to the casing and the other end is connected to a pointer which sweeps over a circular dial graduated in degree of temperature.

Working:

When bimetallic strip subjected to temperature changes, either cooling or heating. In response to temperature change, the bimetal expands and the helical bimetal rotates at its free end, thus deflecting the pointer to a new position on the dial. This deflection is linear and can be related to temperature changes.

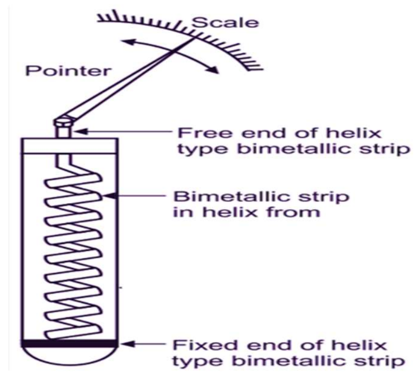


Fig.8

3. Resistance Thermometer or **RTD :** Resistance Temperature Detector (also known as a Resistance Thermometer or RTD) is an electronic device used to determine the temperature by measuring the resistance of an electrical wire.

Working Principle: Resistance thermometers or resistance temperature detector works on the principle that as temperature increases, resistance of a metal in the thermometer also increases. When a metal wire is heated the resistance increases. So, a temperature can be measured using the resistance of a wire.

Construction: The construction of resistance thermometer detector is shown in figure. RTD uses platinum, nickel or copper as a resistance element. Generally, platinum wire is wound on either ceramic support to form a resistance element. This resistance element is placed inside the hollow structure called protection tube. It is made up of stainless steel or carbon steel. Internally lead wire is used to connect resistance element with external lead terminals. Lead wire covered by insulated tube for short circuit prevention.

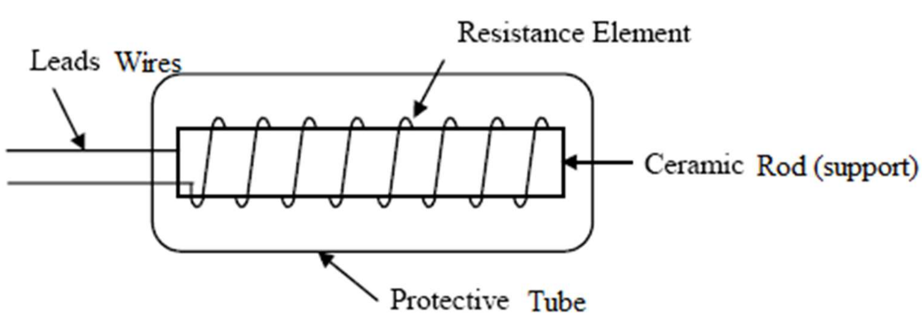


Fig.9

Working: The Wheatstone bridge consist of a four resistance, a source of e.m.f. (a battery) and a galvanometer.

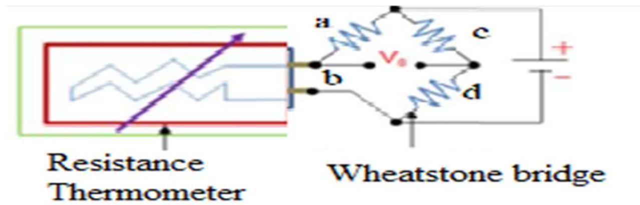


Fig.10

When no current flow through the galvanometer the ratio of resistance according the principle of Wheatstone bridge,

$$\frac{a}{b} = \frac{c}{d}$$

Initial resistance ($b = R_0$) is measured by using Wheatstone bridge using above relation. Now, RTD is placed near the heat source. Outer cover uniformly distributes heat to sensing resistance wire. As the temperature varies, the resistance of the material also varies and Wheatstone bridge unbalanced and current flows. After balancing Wheatstone bridge final resistance (R_T) of resistance wire is again measured from Wheatstone bridge. From the above measurement, variation in temperature can be calculated by using following relation,

$$R_T = R_0[1+\alpha(T-T_0)]$$

R_T: Resistance at temperature (T)
R_0: Resistance at temperature (0˚C)
α: Temp. coefficient
T: temp (˚C)
T_0: Initial temp.

Thus, from the above formula by knowing R_T, R_0 and α, the difference in temperature can be calculated.

Vernier Caliper: A vernier caliper is defined as a measuring device that is used for the measurement of linear dimensions (length, thickness, inside diameter, outside diameter, depth etc.) with the help of the measuring jaws.

Principle: The principle of vernier is that when two scales or divisions slightly different in size are used, the difference between them can be utilized to enhance the accuracy of measurement.

Construction: A vernier caliper consists of two main parts: the main scale made on a solid L-shaped frame and the vernier scale that can slide along the main scale. The main scale is graduated in millimeters, up to a least count of 1mm. The vernier caliper is made of either stainless steel or tool steel, depending on the nature and severity of application. Figure illustrates the main parts of a vernier caliper. The L-shaped main frame also serves as the fixed jaw at its end. The movable jaw present on a vernier scale plate, can slide over the entire length of the main scale, which is engraved on the main frame or the beam. A locking screw enables locking of the movable jaw in a particular position after the jaws have been set accurately over the job being measured. This arrests further motion of the movable jaw, so that the operator can note down the reading in a convenient position.

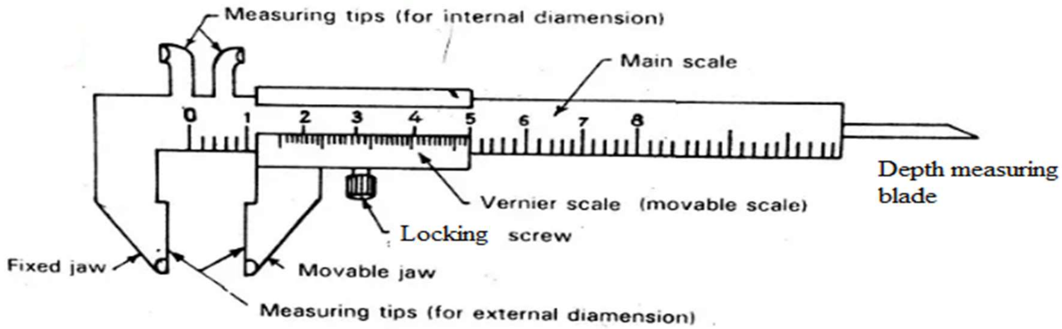


Fig.11

Calculation of least count: The minimum length or thickness that can be measured with a vernier scale is called the least count.

N VSD = (N−1) MSD
1 VSD = $\frac{N-1}{N}$ MSD
Least count = 1 MSD − 1 VSD

Therefore, least count = 1 MSD − $\frac{N-1}{N}$ MSD

Least count = [1− $\frac{N-1}{N}$] MSD

Least count = 1 MSD/N

Total reading = MSR + (VC × LC), where MSR is the main scale reading, LC is the least count, and VC is the vernier coinciding division.

Operating procedure of vernier caliper: To obtain the reading, the number of divisions of the main scale are first read off. The vernier scale is examined to determine which of the division coincide or most coincident with a division on the main scale. The number of these divisions multiply by least count are added to the main scale reading to give the total reading.

Total reading = MSR + (VC × LC) mm

Example:

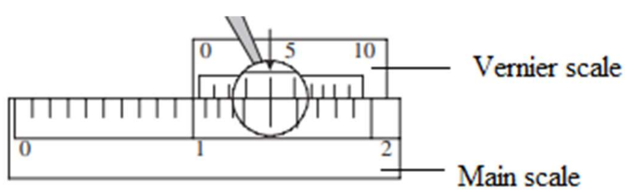


Fig.12

Fourth division of vernier coinciding with a division on the main scale:

Let the number of divisions on vernier = 50
Value of 1 division on main scale = 1mm
So, least count = 1 MSD/N = 1mm/50 = 0.02mm
Therefore, total reading = 1 + (4 × 0.02) = 1.08 mm

Micrometer (Screw Gauge): A micrometer is an instrument used for making precise linear measurements of dimensions such as diameter, thickness, and lengths of solid bodies. s. A micrometer can provide better least counts and accuracy than a vernier caliper.

Working Principle: The amount of rotation of an accurately made screw can be directly and precisely correlated to a certain amount of axial movement (and vice versa), through the constant known as the pitch. A pitch is the distance screw moves forward axially with one complete turn (360°).
Construction: It consists of a C-shaped frame with a stationary anvil and a movable spindle. A graduated scale is made on the stationary sleeve and the rotating thimble. The zeroth mark on the thimble will coincide with the zeroth division on the sleeve when the anvil and spindle faces are brought together. The locknut enables the locking of the spindle while taking a reading. The ratchet prevents application of excessive force on the job. The graduations on the sleeve are in millimeters and can be referred to as the main scale. The scale on the thimble can be referred as circular scale.A micrometer is made of steel or cast steel. The faces are also tipped with tungsten carbide or a similar material to prevent rapid wear. The material used for thimble and ratchet should be wear-resistant steel.

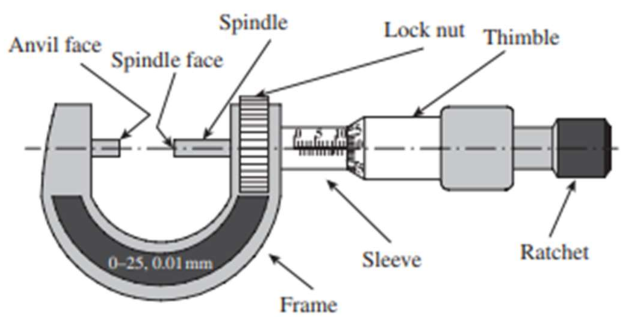


Fig.13

Least Count:

$$\text{Least Count} = \frac{\text{Pitch}}{\textit{Number of divisions on circular scale}}$$

If the smallest division on this scale reads 0.5mm, each revolution of the thimble advances the spindle face by 0.5mm. Suppose the number of divisions on the thimble is 50, then the least count of the micrometer is 0.5/50, that is, 0.01mm.

Working:

1. Check the zero reading.
2. Place the component to be measured in between the measuring faces.
3. Advance the spindle by rotating the ratchet and until it begins to slip and chicks are heard. This shows that there is no further moment on the spindle. Note the reading both on the barrel scale and on the circular scale of thimble.

Figure illustrates how the micrometer scale is read when a job is held between the anvil face and the spindle face

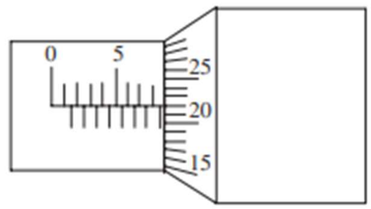


Fig.14

In this example, the main scale reading is 8.5mm, which is the division immediately preceding the position of the thimble on the main scale. As already pointed out, let us assume the least count of the instrument to be 0.01mm. The 22nd division on the thimble is coinciding with the reference line of the main scale.
Therefore, the reading is as follows: 8.5 + 22 (0.01) mm = 8.72mm

Types of micrometers: -

1) Outside or External micrometer: It is mainly used to measure outside diameter of shaft and other circular sections parts or length and thickness of small parts.
2) Inside micrometer: It is used for measuring large internal diameters of hole of diameter over 50 mm.
3) Depth micrometer: It is used to measure the depth of the hole and slots.

Pressure measurement:

Pressure is also defined as the force exerted over a unit area. Force may be exerted by liquids, gases, and solids.

$$Pressure = \frac{Force}{Area}$$

$SI\ unit\ of\ pressure = \frac{N\ (Newton)}{m^2\ (meter^2)} = Pascal\ (Pa)$

$Other\ units\ of\ pressure = bar, mm\ of\ mercury, atm\ (atmospheric\ pressure)\ etc$

1 bar = 10^5 Pa (Pascal)= 100 KPa (Kilo-pascal)

1 atm = 1.013 bar = 1.013 x 10^5 Pa (Pascal) =1.013 x 100 KPa (Kilo-pascal) = 760 mm of mercury (Hg) = 1013 mbar(milli-bar)

1 $\frac{kgf\ (kilogram-forc\ )}{cm^2}$= 9.807 $\frac{N\ (Newton)}{cm^2}$ = 9.807 × $10^4 \frac{N\ (Newton)}{c^2}$ = 9.807 × 10^4 Pa = 0.9807 bar = 0.9679 atm

Atmospheric pressure(P_{atm})**:** The atmospheric air exerts a normal pressure upon all the surfaces with which it is in contact, and is known as atmospheric pressure.

Absolute Pressure (P_{abs}) **:** The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure). Any pressure measured above the absolute zero pressure (considering absolute zero as a datum or reference) is termed as absolute pressure. An absolute zero pressure can exist only in complete vacuum.

Gauge Pressure: Any pressure measured above the atmospheric pressure (considering atmospheric pressure as a datum or reference) is termed as absolute pressure. The difference between the absolute pressure and the local atmospheric pressure is called the gauge pressure (P_{gauge})can be positive or negative.

Vacuum Pressure (P_{vac})**:** Pressures below atmospheric pressure are sometimes called vacuum pressures and are measured by vacuum gages that indicate the difference between the atmospheric pressure and the absolute pressure.

Absolute, gauge, and vacuum pressures are related to each other by following relations:

$$Pgauge = Pabs - Patm$$

$$Pvac = Patm - Pabs$$

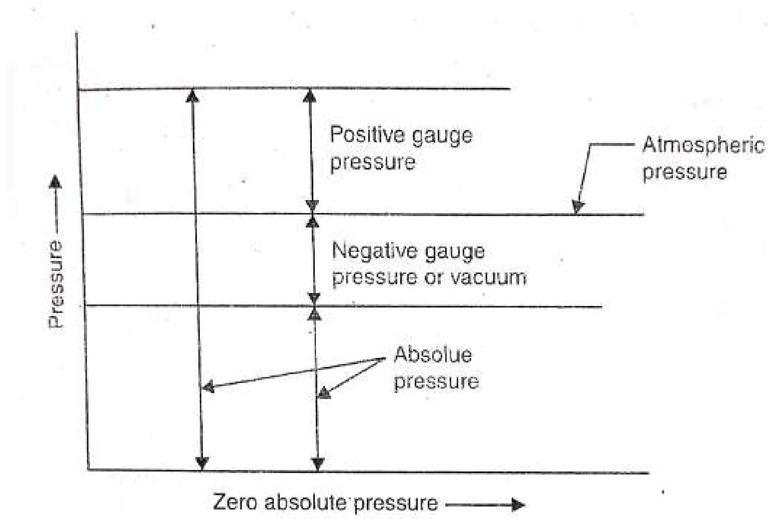


Figure shows Relationship between pressures.

Fig.15

Pressure measuring devices:

1. Piezometer: A piezometer is either a device used to measure liquid pressure in a system by measuring the height to which a column of the liquid rises against gravity, or a device which measures the pressure of groundwater at a specific point. It is a vertical transparent glass tube, the upper end of which is open to atmosphere and the lower end is in communication with the gauge point; a point in the fluid container at which pressure is to be measured.

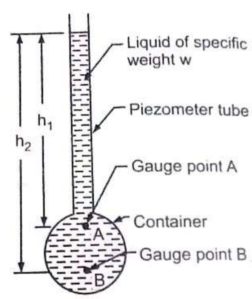


Fig.16

Fluid pressure at point A = atmospheric pressure (P_a) at the free surface of water + pressure due to liquid column of height h_1

Fluid pressure at point A = $P_a + \rho g h_1$

ρ = density of fluid

P_a = atmospheric pressure at the free surface of water

h_1 =liquid column height at point A

2. U-tube manometer: A U-tube manometer is an instrument that measures the pressure. he U-tube manometer has a U-shaped glass tube that is filled with a reference liquid (mercury) to display the pressure level and a measuring scale.

The U-tube manometer has openings at both ends of it. The pressure to be measured is applied to one opening end of the U-shaped glass tube and other end is exposed to atmosphere. The applied pressure presses the liquid and thus the liquid moves down the tube. We can see in the above picture that the level goes down in the left limb of the tube, while in the right limb the liquid level rise. A scale fitted between the tube measures this displacement. Suppose the applied pressure to the left leg of the tube becomes constant. When the pressure exerted by column h balance the pressure applied to the left side of the manometer, then the liquid will stop moving in the tube.

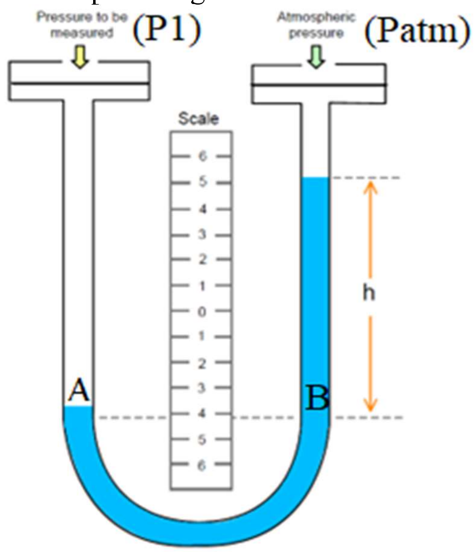


Fig.17

We can calculate the applied pressure by knowing the column of liquid, and the density of the filling liquid.

We know that in a liquid at same horizontal level pressure is same i.e.

Pressure at point A = Pressure at point B

$$P_1 = P_{atm} + \rho gh$$

P_1= Pressure to be measured which is applied on left limb

P_{atm} = Atmospheric pressure which is acting on right limb

ρ = Density of fluid

g = Acceleration due to gravity

h =liquid column height at point B

3.Elastic transducer: A transducer is a device that converts energy from one form to another. In the elastic transducer elastic element when subjected to pressure elastic element get deformed. The deformation of elastic element gives the indication of pressure. The elastic element may be of the following forms:

a. Bourdon tube

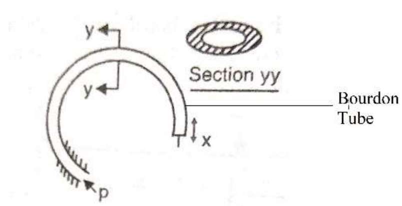


Fig.18

b. Diaphragm etc.

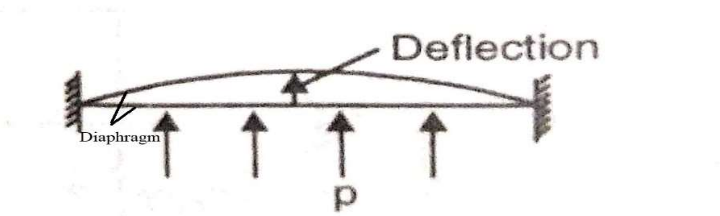


Fig.19

a. Bourdon tube pressure gauge: The most widely used gauge for pressure measurement is the Bourdon tube.
Construction: Bourdon tube is composed of a C-shaped hollow metal tube having an elliptical cross section. One end of the Bourdon tube is fixed and can be used as the pressure inlet, as shown in Figure. The other end is free and closed.

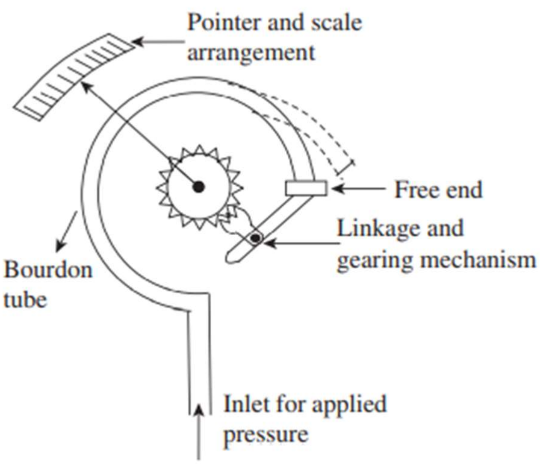


Fig.20

Working: Due to the applied pressure, the tube straightens out and tends to acquire a circular cross section. Thus, pressure causes the free end to move. This movement is proportional to the difference between inside and outside pressures. To measure pressure, movement of the free end is often magnified and transmitted to a pointer that moves over the scale through a linkage and gearing mechanism. The pointer indicates gauge pressure, since the reference pressure is atmospheric.

b. Diaphragm pressure gauge:
This type of gauge employs a metallic disc or diaphragm instead of a bent tube. The diaphragm is used as an elastic element in this gauge. When pressure is applied on lower side of diaphragm, it gets deflected upward. The movement of diaphragm is transmitted to a rack and pinion. The rack and pinion are attached to the needle moving on the graduated scale to give the reading.

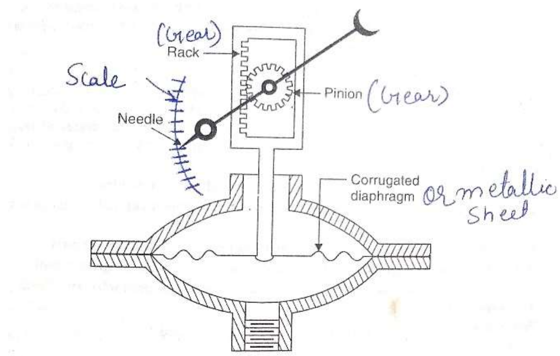

(Gear)
Rack
Scale
Needle
Pinion (Gear)
Corrugated diaphragm Or metallic Sheet

Fig.22

Velocity Measurement:

Velocity: The rate of change in displacement is referred to as velocity. Velocity can be linear or angular.

Linear Velocity: Linear velocity is defined as the rate of change of displacement with respect to time when the object moves along a straight path. S.I unit is $\frac{m}{s}$.

$$v = \frac{dx}{dt}$$

Where,

- v = Linear velocity
- $\frac{dx}{dt} = Rate\ of\ change\ of\ displacement$
- x = Displacement
- t = Time taken to cover the displacement(x).

Angular Velocity: Angular velocity is defined as the rate of change of the angular position of a rotating body. S.I unit is $\frac{radians}{s}$.

$$\omega = \frac{d\theta}{dt}$$

Where,

- v = Linear velocity
- $\frac{d\theta}{dt} = Rate\ of\ change\ of\ angular\ velocity\ displacement$
- θ= Angular displacement
- t = Time taken to cover the displacement(x).

Linear velocity of solid objects can be determine using following methods: Electromagnetic transducer, digital transducer, transducer using Doppler effect, by using displacement and acceleration sensor, linear velocity transducer etc.

Angular velocity of solid objects can be determine using a device called tachometer.

Tachometer, device for indicating the angular (rotary) speed of a rotating shaft. Tachometers may be broadly classified into two categories: Mechanical tachometers and Electrical tachometers

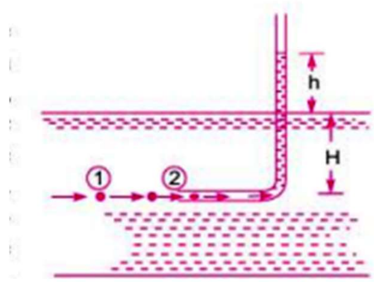
Velocity at a different point in the flow field can be determined by using pitot tube, current meter and hot wire anemometer.

Velocity measuring device

1. Pitot tube: Pitot tube is a mechanical device which is used to measure velocity of flow at any point in a pipe or a channel. Pitot Tube works on a basic principle that, if velocity of flow at any point is reduced to zero (point is known as stagnation point), the pressure there increases because all its kinetic energy gets converted into pressure energy. Thus by measuring the increase in pressure energy velocity of flow at that point can be determined. It helps us in measuring that pressure energy of stopped fluid.

in its simplest form a pitot tube consists of a glass tube and at a right angle as and large enough for capillary effect to be negligible.

In its simplest form a pitot tube consists of a glass tube bent at a right angle. The lower end which is bend through 90^0 is directed in the upstream direction. The liquid rises up in the tube due to the conversion of kinetic energy into the pressure energy. The velocity is determined by measuring the rise of liquid in the tube.



Let
p_1 = intensity of pressure at point (1)
v_1 = velocity of flow at (1)
p_2 = pressure at point (2)
v_2 = velocity at point (2), which is zero
H = depth of tube in the liquid
h = rise of liquid in the tube above the free surface.

Applying Bernoulli's equation at points (1) and (2), we get

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

But $z_1 = z_2$ as points (1) and (2) are on the same line and $v_2 = 0$.

$$\frac{p_1}{\rho g} = \text{pressure head at (1)} = H$$

$$\frac{p_2}{\rho g} = \text{pressure head at (2)} = (h + H)$$

Substituting these values, we get

$$\therefore \quad H + \frac{v_1^2}{2g} = (h + H) \quad \therefore \quad h = \frac{v_1^2}{2g} \quad \text{or} \quad v_1 = \sqrt{2gh}$$

This is theoretical velocity.

2. Mechanical Tachometer (Centrifugal): Centrifugal tachometer works on the principle that when a revolves about an axis, it experiences a radially outward force. This force is called centrifugal force. This centrifugal force is a function of rotational speed of shaft. Two flyballs are arranged about central spindle. Shaft whose speed is to be measured is connected to this spindle. As soon as shaft whose speed is to be measured is connected to this spindle, central spindle starts rotating, a centrifugal force is developed, which causes the flyball to move outward in radial direction, i.e., away from the spindle. Sleeve move upward and spring attached to spindle is compressed. This motion of sleeve is transferred to pointer by motion transferring link and gear and pointer shows the reading on scale. Value of compression or decrease in length of spring becomes a function of rotational speed and accordingly pointer move on the scale.

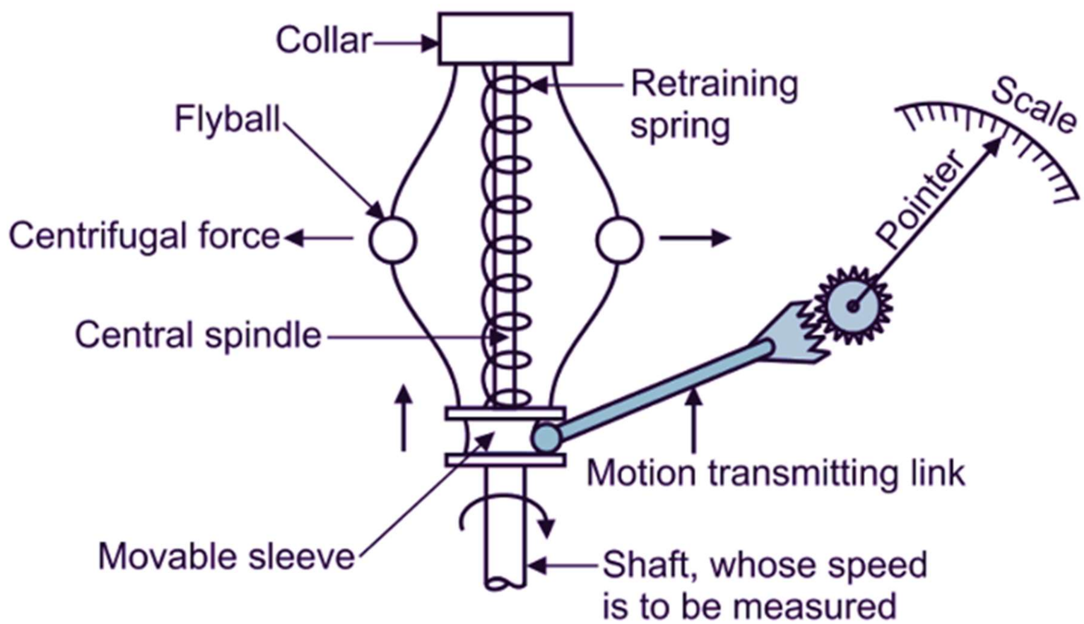


Fig.23

3.Electrical Tachometer: The main parts of a tachometer include a permanent magnet, armature coil, commutator and brushes, a variable resistor, and a moving coil voltmeter. The shaft of the DC tachometer generator is coupled to the shaft of the machine whose speed is to be measured.

The working principle of a tachometer is simply the electromagnetic induction principle, i.e., when a closed conductor coil is moved in a magnetic field, an emf is induced in the coil. This developed electromotive force is directly proportional to the shaft speed. The motor of the tachometer then produces a corresponding voltage relative to the shaft velocity. The tachometer counts the number of rotations that the shaft makes per minute.

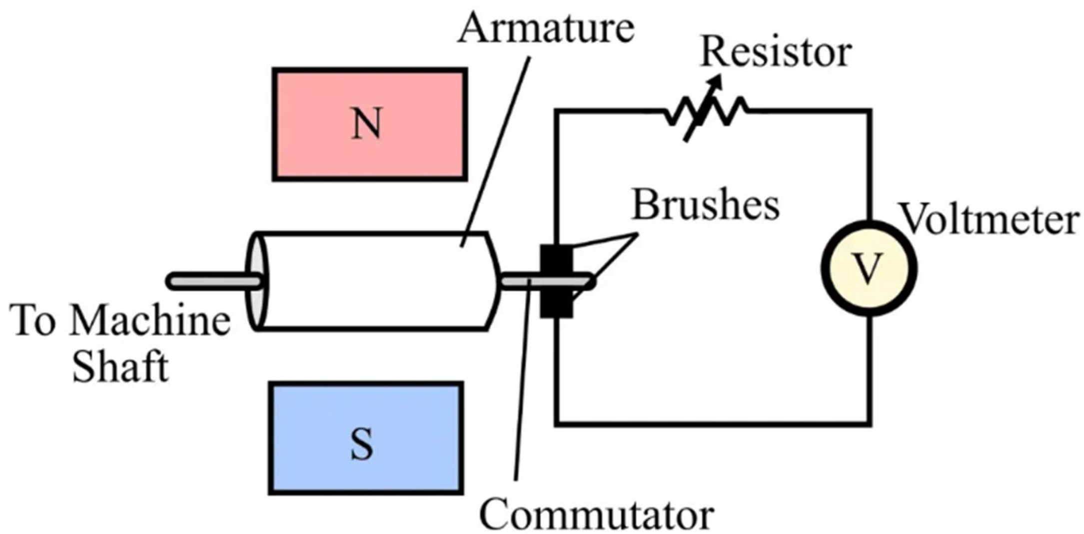


Fig.24

Strain Measurement:

When a body is subjected to some external force, there is some change in dimensions of the body. The ratio of change in dimension of the body to original dimension is known as strain. Strain is a dimensionless quantity.

$$\varepsilon = \frac{\text{Change in dimension}}{\text{Origional dimension}} \text{ (Unitless)}$$

The most widely used sensor for the measurement of strain is Electrical Resistance Strain Gauge.

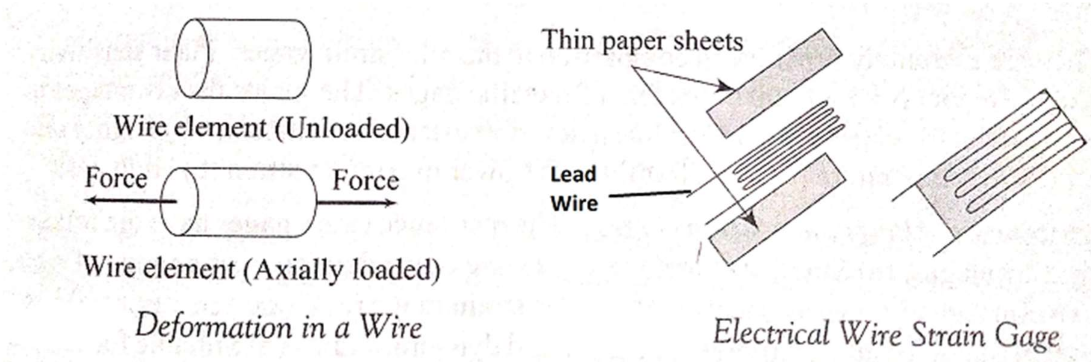
Electrical Resistance strain gauge: A Strain gauge (resistance strain gauge) is an important type of resistance transducer whose resistance varies with applied force. It can be used to convert force, pressure, tension into a change in electrical resistance. The applied strain can be measured by this change in resistance.

Basic Principle: We know that the resistance of a conductor is given by

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

Where ρ is the specific resistivity, L is the length and A is the area of cross-section of the resistance material.
When this material is under a strain, the resistance R will change because of the change in L, A or ρ. This is the principle on which electrical strain gauge work

The strain gauge employed for the measurement of strain is called Bonded Resistance Gauge.



Deformation in a Wire *Electrical Wire Strain Gage*

Fig.25

Figure shows the construction of bonded wire flat resistance gauge. A fine resistance wire is made into a form of a grid and is cemented (sandwiched) between the two thin sheets known as carrier. Resistance wire with a high gauge factor is chosen. The wire is spread so that the stress is uniformly distributed over the grid.

The strain gauge is bonded on the surface, where strain to be measure, by mean of an adhesive material and due to this, a good transfer of strain from carrier to a grid of wires is achieved.

Gauge factor: The sensitivity of a strain gauge is expressed in the gauge factor. The resistance change is due to the change in length, the change in the area of cross-section and the change in resistivity The strain that is applied to the gauge can be determined by the gauge factor and by the measure of the resistance change. The gauge factor and resistance is mentioned by manufacturer. By measuring change in resistance strain can be find.

$$G = \frac{\frac{dR}{R}}{\frac{dL}{L}} = \frac{\frac{dR}{R}}{\varepsilon}$$

Here G is gauge factor, dR is change in resistance, dL is change in length and ε is strain.

Flow Measurement: Flow measurement is concerned with the measurement of the rate of flow.

Rate of flow or Discharge (Q): It is defined as the quantity of fluid flowing per second through a cross section of a pipe or channel.

For a liquid:

$$Q = AV$$

Units of Q are $\frac{m^3}{s}$ or $\frac{liters}{s}$
A= Cross sectional area of pipe
V= Average velocity of fluid across the section
Some commonly used instrument for measuring flow include: -

1. Rotameter
2. Venturimeter
3. Orifcemeter

Venturimeter: Venturimeter is a device used for measuring the rate of flow of fluid flowing through the pipe. It is based on the principle of Bernoulli's Equation. The cross-sectional area of throat is smaller than that of the inlet pipe, thus the velocity of flow gets increased as per the continuity equation ($Q = a_1 v_1 = a_2 v_2$). This increase in the velocity of flow reduces the pressure at the throat of the Venturimeter by measuring the pressure difference with the help of a differential manometer that of flow of fluid discharge can be measured

Construction: Venturimeter consists of four parts: -

1. Cylindrical inlet section: The inlet of the Venturimeter is of same diameter as that of a pipe which is followed by a convergent cone.
2. A short convergent part: Convergent part is a short pipe which tapers from the inlet pipe diameter to a throat diameter.
3. Throat: The throat is a cylindrical pipe of a cross sectional area smaller than that of pipe.
4. A short divergent part: The divergent part is a long pipe which tapers gradually from throat diameter to the outlet pipe diameter.
5. Cylindrical outlet section: The outlet of the Venturimeter is of same diameter as that of a pipe which is followed by the pipe.

Expression for rate of flow through venturimeter

Consider a venturimeter fitted in a horizontal pipe through which a fluid is flowing (say water), as shown in Fig.

Let d_1 = diameter at inlet or at section (1),
p_1 = pressure at section (1)
v_1 = velocity of fluid at section (1),
a = area at section (1) = $\frac{\pi}{4} d_1^2$

and d_2, p_2, v_2, a_2 are corresponding values at section (2).

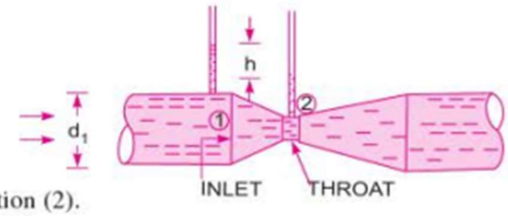


Fig. Venturimeter.

Applying Bernoulli's equation at sections (1) and (2), we get

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

As pipe is horizontal, hence $z_1 = z_2$

$$\therefore \quad \frac{p_1}{\rho g} + \frac{v_1^2}{2g} = \frac{p_2}{\rho g} + \frac{v_2^2}{2g} \quad \text{or} \quad \frac{p_1 - p_2}{\rho g} = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

We know that,

$$\frac{P_1 - P_2}{\rho\, g} = h$$

Substituting this value of $\frac{p_1 - p_2}{\rho g}$ in the above equation, we get

$$h = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \qquad \text{...(6.6)}$$

Now applying continuity equation at sections 1 and 2

$$a_1 v_1 = a_2 v_2 \quad \text{or} \quad v_1 = \frac{a_2 v_2}{a_1}$$

Substituting this value of v_1 in equation (6.6)

$$h = \frac{v_2^2}{2g} - \frac{\left(\frac{a_2 v_2}{a_1}\right)^2}{2g} = \frac{v_2^2}{2g}\left[1 - \frac{a_2^2}{a_1^2}\right] = \frac{v_2^2}{2g}\left[\frac{a_1^2 - a_2^2}{a_1^2}\right]$$

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

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

$\therefore$ Discharge,
$$Q = a_2 v_2$$
$$= a_2 \frac{a_1}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} = \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \times \sqrt{2gh} \qquad \text{...(6.7)}$$

Equation (6.7) gives the discharge under ideal conditions and is called, theoretical discharge. Actual discharge will be less than theoretical discharge.

Orificemeter: An Orificemeter is used to measure the rate of flow fluids. The orifice meter works on the same principle that of Venturimeter. It consists of a flat circular plate which has a circular sharped edged hole called orifice, which is concentric with pipe. A differential manometer is connected to measure the pressure difference between section 1-1 and section 2-2.

Orifice Meter Construction or Parts:

1. **Inlet Section:** The fluid will enter into the orifice meter through the inlet section.
2. **Orifice Plate:** The orifice plate is situated between the inlet and outlet and the plate is used to generate pressure drop that will enable to measure the flow rate.
3. **Outlet section:** The fluid will leave the orifice meter through the outlet section.

Let p_1 = pressure at section (1),
v_1 = velocity at section (1),
a_1 = area of pipe at section (1), and

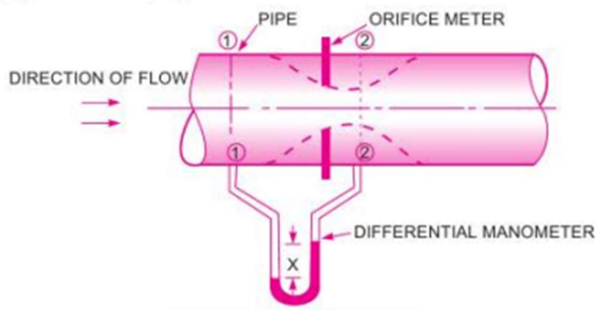


Fig. 6.12. *Orifice meter.*

p_2, v_2, a_2 are corresponding values at section (2). Applying Bernoulli's equation at sections (1) and (2), we get

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

or $$\left(\frac{p_1}{\rho g} + z_1\right) - \left(\frac{p_2}{\rho g} + z_2\right) = \frac{v_2^2}{2g} - \frac{v_1^2}{2g}$$

But $$\left(\frac{p_1}{\rho g} + z_1\right) - \left(\frac{p_2}{\rho g} + z_2\right) = h = \text{Differential head}$$

$\therefore$ $$h = \frac{v_2^2}{2g} - \frac{v_1^2}{2g} \quad \text{or} \quad 2gh = {v_2}^2 - {v_1}^2$$

or $$v_2 = \sqrt{2gh + v_1^2} \quad \text{...(i)}$$

Now section (2) is at the vena-contracta and a_2 represents the area at the vena-contracta. If a_0 is the area of orifice then, we have

$$C_c = \frac{a_2}{a_0}$$

where C_c = Co-efficient of contraction

$$\therefore \quad a_2 = a_0 \times C_c \quad \text{...(ii)}$$

By continuity equation, we have

$$a_1 v_1 = a_2 v_2 \quad \text{or} \quad v_1 = \frac{a_2}{a_1} v_2 = \frac{a_0\, C_c}{a_1} v_2 \quad \text{...(iii)}$$

Substituting the value of v_1 in equation (*i*), we get

$$v_2 = \sqrt{2gh + \frac{a_0^2 C_c^2 v_2^2}{a_1^2}}$$

or $$v_2{}^2 = 2gh + \left(\frac{a_0}{a_1}\right)^2 C_c{}^2 v_2{}^2 \text{ or } v_2{}^2 \left[1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2\right] = 2gh$$

$$\therefore \quad v_2 = \frac{\sqrt{2gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}}$$

$\therefore$ The discharge $Q = v_2 \times a_2 = v_2 \times a_0\, C_c$ $\qquad \{\because a_2 = a_0 C_c \text{ from } (ii)\}$

$$= \frac{a_0 C_c \sqrt{2gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 C_c^2}} \quad \text{...(iv)}$$

Working of Orifice meter:

- The fluid flows inside the inlet section having a pressure P_1.
- As the fluid proceeds through converging section further, its pressure reduces gradually (because area decreases and velocity increases) and it finally reaches a value of P_2 at vena-contracta (area minimum and velocity maximum) at section 2-2.
- The differential pressure sensor connected between the Inlet and the vena-contracta of the Orificemeter displays the difference in pressure (P_1-P_2). This difference in pressure is in direct proportion to the flow rate of the liquid flowing through the Orifice meter.
- Further, the fluid passed through the diverging section and the velocity reduces thereby it regains its pressures.

Rotameter: A rotameter is a device that measures the flow rate of fluid in a closed tube. It uses the natural principles of buoyancy, drag, and acceleration due to gravity to measure the fluid flow.

Rotameter Construction

1. Transparent tube and scale: The shape of the transparent tube is conical which includes a scale and float within it. This transparent tube is very helpful in observing the measurements directly.

2. Float: A float is a small device within the tube of a rotameter with precise dimensions. The float is used to indicate the rate of flow of liquid within the tube, which can be designed with plastic, glass, or metal.

3. Scale: The scale on this meter displays the flow measurements by showing with float displacement.

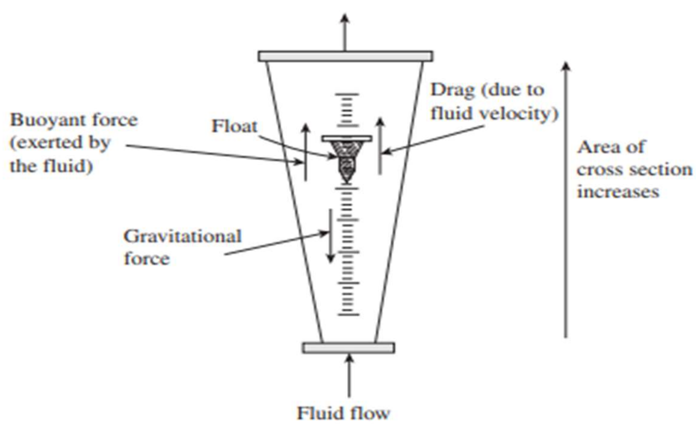


Fig.26

Rotameter Working:

In a rotameter, liquid flows from the base of the tapered tube, after that some of the liquid directly hits the bottom of the float & the remaining liquid will flow away from the float. So, the float in the rotameter experiences three forces, the gravitational force is a downside, buoyancy force upward and the drag force is on the upside. The flow of liquid pushes the float up from gravity. After some time, the float will come in equilibrium when all the three forces are balanced. The reading on the scale where the float stops give the reading of flow rate. The scale on the glass measuring the displacement of the float is directly proportional to the fluid flow rate.

The advantages of a rotameter are that it can directly measure flow rate values and its construction is also relatively simple and inexpensive. However, it cannot be used when the fluid is opaque because the float cannot be seen from outside. In addition, when there is an increased velocity of fluid flow, there is a possibility of breakage of the glass tube.

Force Measurement: Force is an external agent capable of changing a body's state of rest or motion. 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); 1 N = 1kg × 1 m/s^2.

The methods for measuring force can be classified into two basic categories: direct and indirect.

Direct Methods: Direct methods involve the comparison of an unknown force with a known gravitational force on the standard mass

1.Balance: A simple lever system is called balance, has been used as a force measuring device. To measure the unknown force F_e at a distance L from the pivot, a mass m at a distance l from the pivot is used. The system is in equilibrium when,

$$F\,L = mgl$$

Here m is the standard mass, g is the acceleration due to gravity and F_e is forced to be measure.

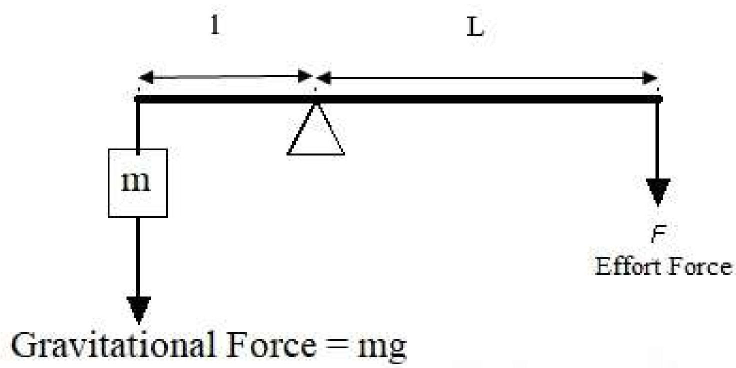


Fig.27

Indirect Method: This involves the measurement of the effect of force on a body. For example. Measurement of resultant effect (deformation) when the force is applied to an elastic.

1.Hydraulic load cell: Hydraulic load cell can be used to measure force of very high magnitude. Hydraulic load cell consists of a closed container filled with oil and covered with diaphragm. A pressure measuring device, such as, Bourdon tube pressure gauge is connected to the container.

Principle of hydraulic load cell: When a force is applied on a liquid medium contained in a confined space, the pressure of the liquid increases. This increase in pressure of the liquid is proportional to the applied force. Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force.

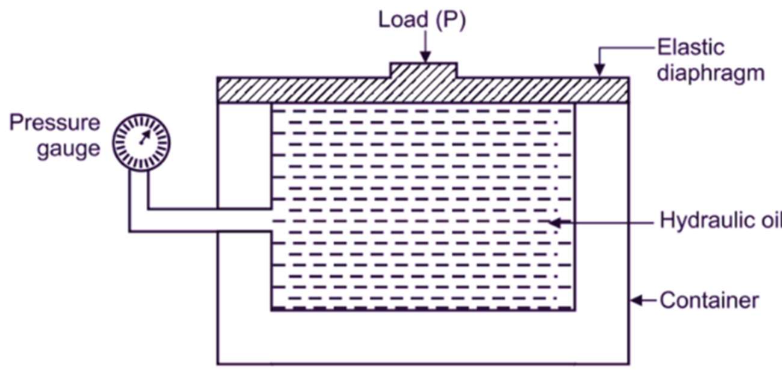


Fig.28

Working: The force to be measured is applied to the diaphragm. The deflects the diaphragm and this deflection of the diaphragm increases the pressure in the liquid medium (oil). This increase in pressure of the liquid medium is proportional to the applied force. The increase in pressure is measured by the pressure gauge which is connected to the liquid medium. The indication of the pressure in the pressure gauge becomes a measure of the force applied on the piston.

2.Pnumatic load cell: Pneumatic load cell consists of a chamber covered with elastic diaphragm, nozzle, air supply regulator and pressure gauge chamber to the container.

Principle of pneumatic load cell: If a force is applied to one side of a diaphragm and an air pressure is applied to the other side, some particular value of pressure will be necessary to exactly balance the force. This pressure is proportional to the applied force.

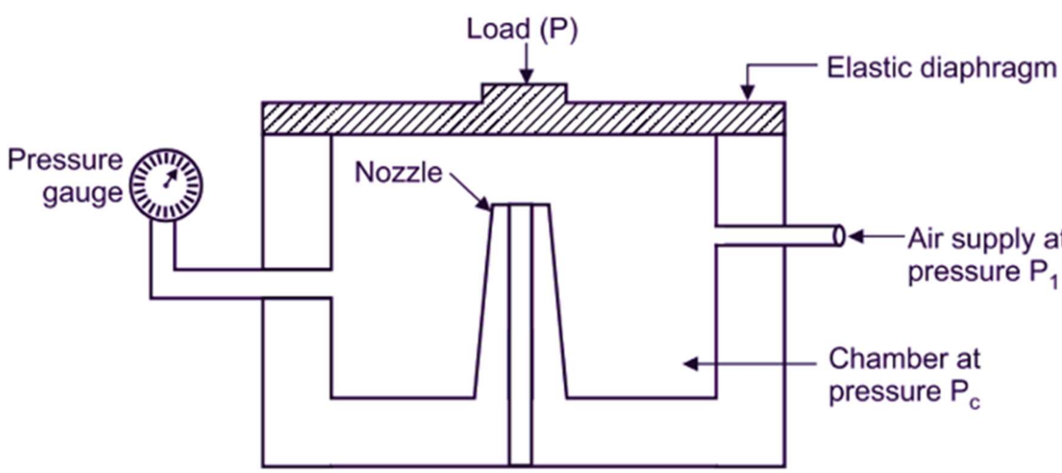


Fig.29

Working: The force to be measured is applied to the top side of the diaphragm. Due to this force, the diaphragm deflects and gap between nozzle and diaphragm reduces. Now an air supply is provided at the bottom of the diaphragm. The pressure inside the chamber increases. Rise in pressure of a chamber exert a force on the diaphragm opposite to applied force. For any value of applied force, diaphragm attains equilibrium under the impact of two equal and opposite forces. At this state, chamber pressure is noted using pressure gauge. The indication of the pressure in the pressure gauge becomes a measure of the force applied on the piston.

3.Strain gauge load cell: Strain gauge load cell is used in an indirect method of force measurement where force or weight is converted into an electrical signal.

A load cell comprises four strain gauges; two of these are used for measuring the longitudinal strain while the other two for measuring the lateral strain. The four strain gauges are mounted at 90° to each other. Two gauges experience tensile stresses while the other two are subjected to compressive stresses.

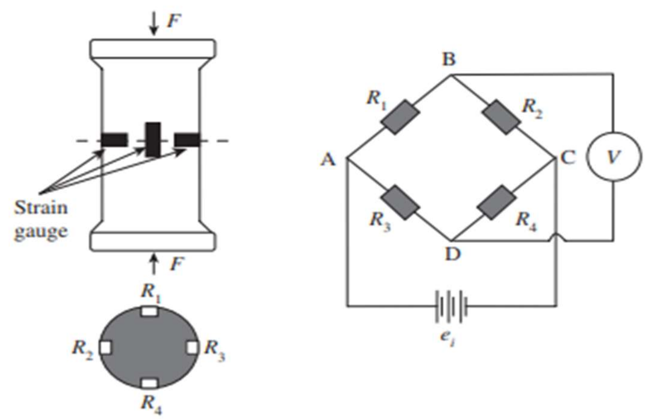


Fig.30

At the no-load condition, resistance in all the four gauges will be same. The Wheatstone bridge is now balanced and hence output voltage is zero. When the specimen is stressed due to the applied force, the strain induced is measured by the gauges due to change in resistance. Gauges R_1 and R_4 measure the strain, while gauges R_2 and R_3 measure the lateral strain. In this case, Wheatstone bridge is unbalanced and hence output voltage is not zero, which becomes a measure of the applied force upon calibration.

Torque: Torque is a twisting or turning force that tends to cause rotation around an axis, which might be a center of mass or a fixed point. Torque is the measure of the force that can cause an object to rotate about an axis. Just as force is what causes an object to accelerate in linear kinematics, torque is what causes an object to acquire angular acceleration. It is also called moment of force.

So, mathematically torque about point O by force F is represented as:

$$Torque\ about\ point\ O\ by\ force\ (F) = Force\ (F) X\ \ Perpendicular\ distance\ of\ force\ from\ point\ O$$

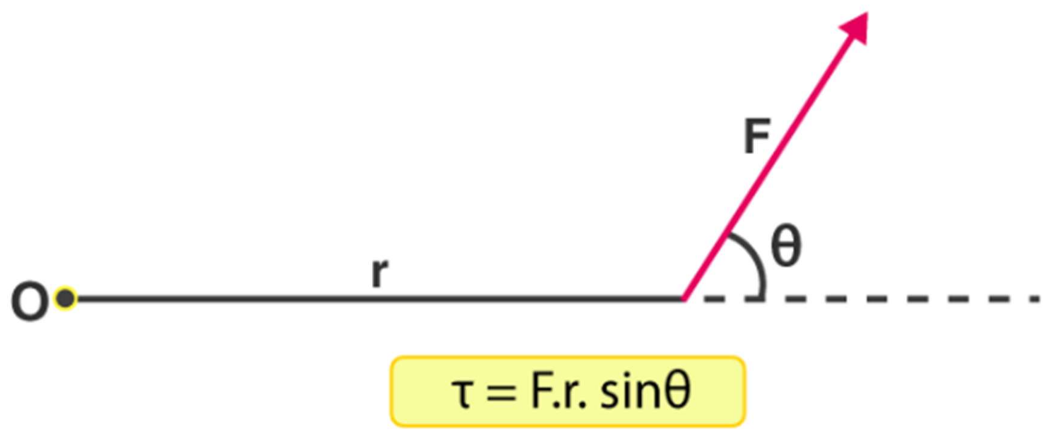


Fig.31

where **r** is the length of the lever arm and **θ** is the angle between the force vector and the lever arm.

S.I unit of torque: N-m

Measurement of torque is essential in the determination of mechanical power. Mechanical power is nothing but the power required to operate a machine or the power developed by the machine, and is computed using the following relation:

$$\boldsymbol{Power = 2\pi NTorque}$$

Here, N is the angular speed in revolution per second.

Instruments used for torque measurement are:
1. Measurement of torque using strain gauges
2. Dynamometer

Measurement of torque using strain gauges**:** It is used for torque measurement from a rotating shaft.

Construction: Four bounded wire strain gauges are mounted on the shaft on 45 ° with the axis of rotation and are placed in pairs diametrically opposite to form a Wheatstone bridge In order to allow the bridge to rotate along the shaft, slip rings may use.

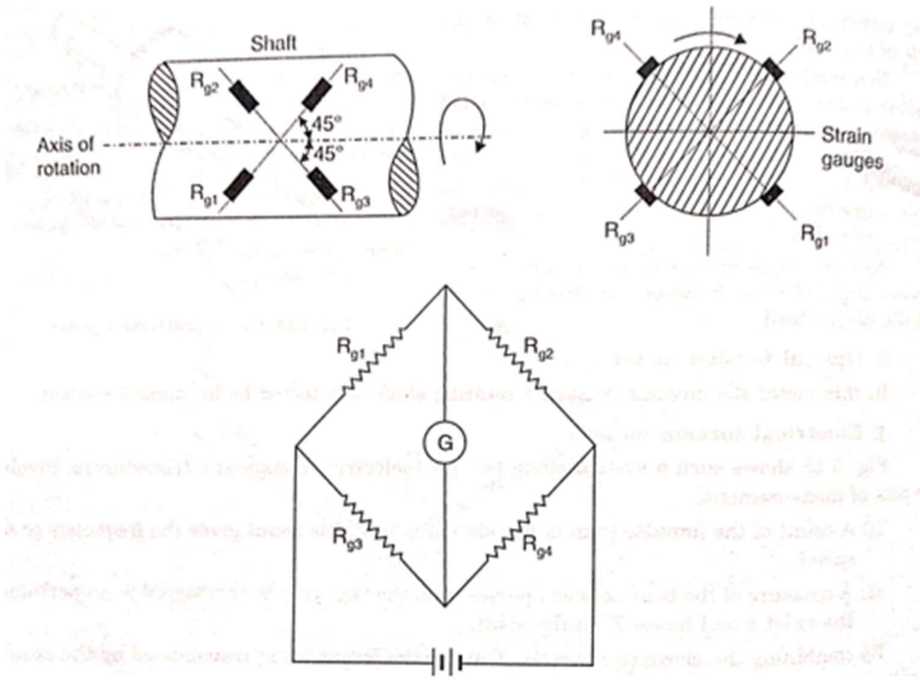


Fig.32

Working: When the shaft is subjected to torque, stresses are generated. These stresses cause strain. Gauge 1 and 4 will elongate due to tensile stress and gauge 2 and 3 will contract due to compressive stress. These stresses can be measured using this strain gauges and torque can be calculated.

2. Dynamometer: A dynamometer, or "dyno" for short, is a device for measuring force, moment of force (torque), or power required to operate the drive on a machine or motor. Dynamometers are used to measure torque in internal combustion machines, small steam turbines, pumps, compressors, etc.

Dynamometer can be classified into three main types:

1. Absorption Dynamometer: If the machine generates power, the dynamometer employed must have the capability of absorbing that power. These dynamometers are called absorption dynamometers, which are particularly useful for measuring the power or torque developed by power sources such as engines or electric motors. Examples: Prony brake dynamometer and rope brake dynamometer.
2. Transmission Dynamometer: In a transmission dynamometer, work done by the prime mover (machine) under test, is not wasted in friction, instead it is transmitted to some other machine to do some useful work, after it has been measured.

3. Driving Dynamometer: In case the machine is a power absorber, the dynamometer must have the capacity to drive it; such a dynamometer is known as a driving dynamometer.

Driving dynamometers are therefore useful in determining performance characteristics of devices such as pumps and compressors.

Absorption Dynamometer:

a. Prony brake dynamometer: A Prony brake dynamometer is one of the simplest, inexpensive, and the most popular absorption dynamometers, this is because the measurement is done by absorbing the power

Construction: As illustrated in Fig. a Prony brake dynamometer comprises two wooden blocks that are mounted on either side of the fly wheel in diagrammatically opposite directions. The fly wheel is attached to the shaft whose power and torque needs to be determined. A lever arm is fixed to one block and the other arm is connected to an arrangement provided to tighten the rope. Tightening of the rope is performed in order to enhance the frictional resistance between the blocks and the flywheel.

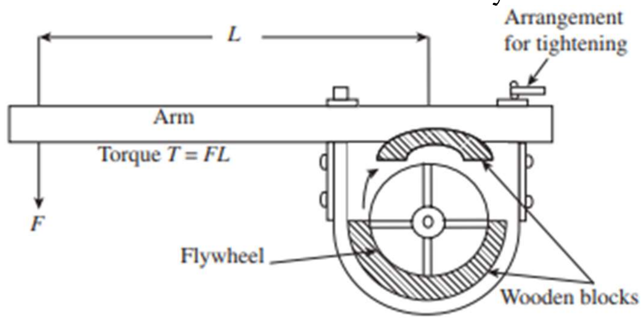


Fig.33

Working: When the brake is to be put in operation the friction between the blocks and the flywheel tends to rotate the block in the direction of rotation of the shaft. To prevent this tendency, the long end of the lever is loaded with the suitable force until the engine shaft runs at a constant speed and the lever in horizontal position.

The torque exerted by the Prony brake is given by the following equation:

T = FL

Here, force F is measured by conventional force-measuring instruments such as load cells or balances.

The power dissipated in the brake is then calculated by the following equation:

$$P = \frac{2\Pi NT}{60} = \frac{2\Pi NFL}{60}$$

Here, P is the dissipated power in watts, L is the length of the lever arm in meters, N is the angular speed in revolution per minute, and F is the force in Newton.

b. Rope dynamometer: The rope brake dynamometer is the device that measures the power or torque of the engine shaft by applying frictional resistance to the motion of the shaft by use of rope.

Construction: It simply consists rope wound around the flywheel mounted on shaft. The shaft is connected to prime mover (engine). One end of rope is connected to spring balance to measure the tension in ropes and other ends carries weight. \

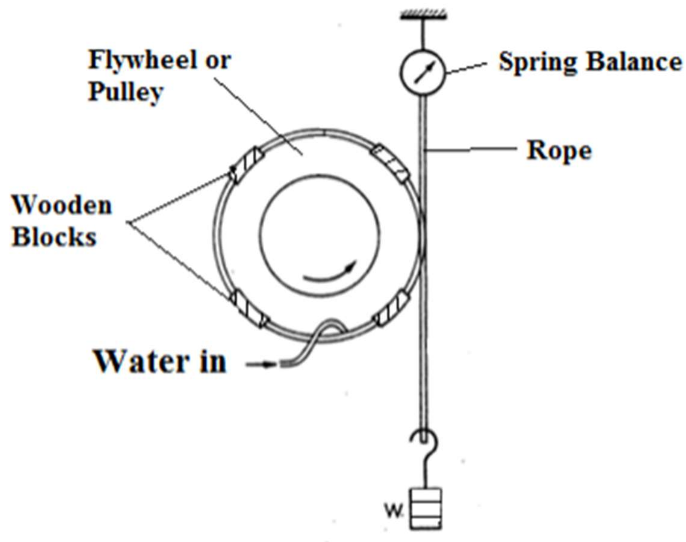


Fig.34

Working: As the shaft rotates, the two end of the rope applies moment on the flywheel due to tension means the tension produce in the rope apply torque on the flywheel. The tension produced in upper part of the rope is measured by the soring balance and tension in lower part of the rope is equal to the force applied by the weight.

Torque applied by the rope on the flywheel = Difference between the tension in upper part and lower part of spring X distance of rope from the center of shaft

Machine Tool: A machine tool is a device which securely holds the work piece and cutting tool for performing various machining processes
Lathe Machine: The lathe is one of the oldest and most important machine tools. The lathe has become a general-purpose machine tool which is used widely in production works.
Principle of lathe machine: The lathe removes the excess material from the work piece by rotating it against a cutting tool. The tools can be fed deep through the excess material on the work piece. The job is held between rigid supports. Figure shows the working principle of a lathe.

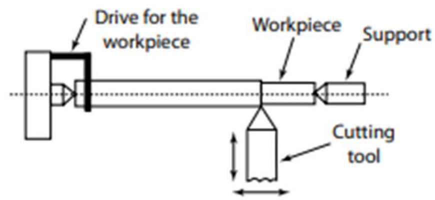


Fig.35

Types of lathes:

1. Speed Lathe: It is the simplest form of a lathe and it consists of all the main components of a lathe. Its spindle can rotate at a very high speed. The work piece is held between centres or attached to some other work holding devices and the tools are hand operated. It is mainly used by woodworkers.
2. Centre Lathe or Engine Lathe: It is the most commonly used lathe and is normally used in all types of machine shops. In its earlier version, steam engines were used to supply the power required for the machine. It has additional features for varying the speed of the lathe spindle compared to the speed lathes. This type of lathe machine is used for woodworking and metalworking.
3. Bench Lathe: It is a small lathe which can be mounted on a bench. It may have the same features as a speed lathe or an engine lathe but, differs from them in size and mountings. Hence, it finds wider applications in small and light works.
4.Tool Room Lathe: As the name indicates, it is used mainly for accurate tool room works. It is the most modern engine lathe employed for making small tools, test gauges, dies and other precision parts.
5. Special Purpose Lathe: In addition to the above types, some lathes have been specially designed and manufactured for doing some specific set of operations for making a particular product. Such lathes are called special purpose lathes.
6. Turret and Capstan Lathes: These are production lathes having provisions for holding several tools for performing a wider range of operations on a job within a minimum time. The cost of these lathes is quite high.

Main Parts of a lathe:

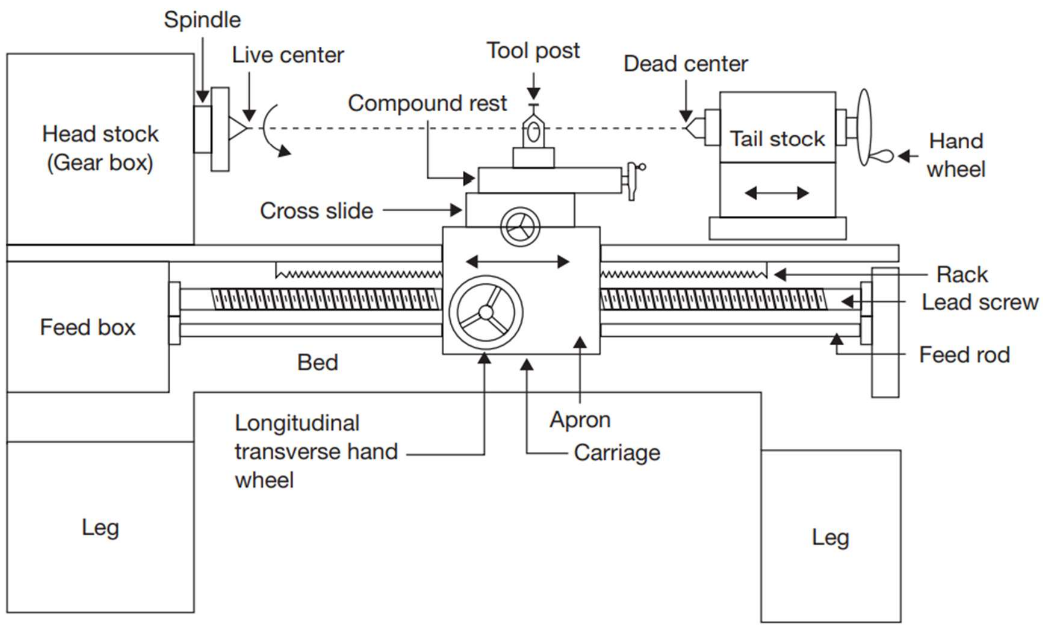


Fig.36

1. Bed: The bed is the basic structure of the lathe and constitutes 70-90 percent of the total weight of the lathe. All other parts are fitted on to this bed.
2. Head Stock Assembly: The head stock is mounted at the left end of the bed. It provides the power required for rotating the work at various speeds and for the tool movement as well. The head stock receives the drive from an electrical motor and it makes use of the cone pulleys and gears for getting various spindle speeds. There are speed change levers on the head stock for this purpose. The head stock mounts the live centre. The head stock also contains work holding devices such as chucks.
Chucks: The function of the chuck is to hold the job.
3. Tail Stock Assembly: The tail stock is mounted at the right end of the bed. It mounts the dead centre. It can be moved along the lathe bed for accommodating work pieces of different sizes. It is mainly used for the following purposes: (a) to support one end of a long work piece. (b) to hold a tool for the operations like drilling, reaming, tapping etc.
4. Carriage Assembly: The carriage provides the means for mounting and moving the cutting tools. The carriage has the following parts:
(a) The saddle: It is H-shaped casting fitted onto the bed and moves along the outer set of guideways on the bed surface.
(b) The cross slide: It is mounted on a transverse bar on the saddle and can be moved by means of the feed screw that is controlled by a small hand wheel. The cross slide is used to move the cutting tool along a perpendicular direction to the axis of rotation of the work piece.
(c) The compound rest: It consists of a base, which is mounted on the cross slide and an upper casting. The base is graduated in angle for swivel of the compound rest through any

angle. The upper casting is mounted on guide ways on the base. It can be moved along the guide ways by a hand wheel.
(d) The tool post: It is mounted on the compound rest. The cutting tool is clamped in the tool post.
(e) The Apron: It is attached to the front of the carriage. It contains the mechanism for the manual and automatic motion of the carriage and the cross slide. For the manual movement of the carriage along the bed, there is a hand wheel on the front of the apron. The hand wheel shaft has a pinion at its other end which engages with a rack attached to the bed.
5. Feed Mechanism The power is transmitted to the apron through the feed mechanism. It is located at the left of the bed. Power is transmitted to the apron by a rotating feed rod (lead screw) through the gearing and clutch arrangement in the apron.
6. Legs: The legs provide rigid support to the entire machine tool. Both the legs are firmly secured to the floor by means of foundation bolts in order to prevent vibrations in the machine.

Operations Done on a lathe:

1.Straight Turning: Turning is a lathe operation in which the diameter of cylindrical jobs is reduced to the desired dimensions.
2.Facing: In facing, the ends of the work pieces are made flat.
3. Chamfering: In chamfering, a bevel or small tapered shape is formed at the ends of the work piece.
4.Knurling: Knurling is the process of embossing, producing a roughened surface on a smooth surface of a cylindrical job to provide effective gripping.
5.Drilling: Drilling is the operation by which a hole is produced in the work piece.
6. Reaming: Reaming is the operation by which the dimension of a drilled hole is corrected. This is similar to drilling, but the reaming is more accurate and involves very little metal removal.
7. Boring: Boring is the operation by which a drilled hole is enlarged.
8. Taper Turning: Taper turning is the operation by which the tapered surface is produced on the work piece.

9. Forming: The required profile is obtained by pressing a form tool against the surface of the rotating work piece.

10.Grooving and Parting Off: Grooving is the operation by which some grooves or necking is produced on the work piece. Parting off is the operation by which one section of a work piece is cut or parted off from the remainder by means of a parting off tool.

11. Thread Cutting Thread cutting is the operation by which threads are formed on the surface of the work piece.

Drilling Machine: Drilling machine is one of the important machine tools in a machine shop. It is mostly used to produce a hole in the solid material by making use of a rotating tool called drill bit or the twist drill.

Drilling Machine working principle:

Drilling Machine has based upon the principle that the rotating edge of the tool exerts a large force on the workpiece and holes are being created in the workpiece. The material is removed from the workpiece by the shearing and extrusion process.

Drilling Machine consists of the following Main Parts:

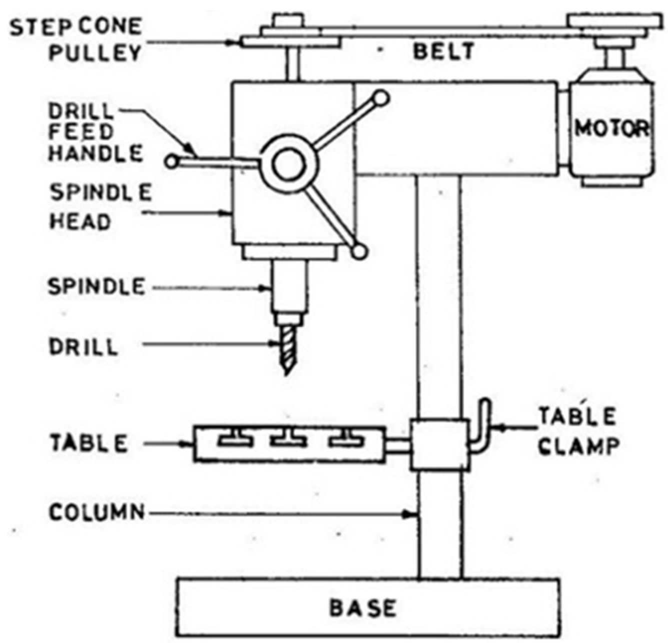


Fig.37

1. Bed:
The bed or base is the main part of the machine on which the whole machine is being mounted.

2. Pillar or column:
The pillar is a type of vertical column that rests on the bed. The pillar supports the motor and the spindle head.

3. Swivel Table:
The table is the place where the workpiece is being mounted. The table is attached to the column and it can be rotated around the column and can have an upward and downward moment. A table can be adjusted at any angle as per the requirement.

4. Motor:

The motor is present at the top of the column. The inside motor shaft is there which is connected to a stepped pulley so that we can increase or decrease the speed of the rotation of the motor.

5. Stepped pulley:
Two steeped pulleys are present on either side of the column at the top. The basic function of the stepped pulley is to control the speed of the rotation of the motor.

6. Spindle head:
Spindle head arrangement is present at top of the column opposite to the arrangement of the motor. Spindle head consists spindle that moves in upward and downward directions and chuck.

7. Chuck:
Chuck is present at the bottom of the spindle. The basic function of the chuck is to hold the cutting tool firmly.

8. Drill bit:
A drill bit is an actual cutting tool that is used to create a hole in the workpiece.

9. Hand Wheel:
The basic function of the handwheel is to adjust the spindle position as per the requirement.

Following are the different operations performed on the drilling machine:

1. Drilling: Drilling is the operation of producing a cylindrical hole by removing metal from the rotating edge of a cutting tool called the drill.

2. Reaming: Reaming is an accurate way of sizing and finishing a hole which has been previously drilled.

3. Boring: To enlarge a hole by means of an adjustable cutting tool with only one cutting edge.

4. Counterboring: Counterboring is the operation of enlarging the end of a hole cylindrically. The enlarged hole forms a square shoulder with the original hole.

5. Countersinking: Countersinking is the operation of making a cone-shaped enlargement of the end of a hole to provide a recess for a flat head screw or countersunk rivet fitted into the hole.

6. Spot facing: It is an operation to make the surface flat around a hole.

7. Tapping: It is an operation of producing internal thread in a hole by means of a tool known as tap.

8. Lapping: It is the operation of sizing and finishing a small diameter hole already drilled by removing a very small amount of material.

Types of Drilling Machines:

1.Portable Drilling Machine Portable drilling machines are small compact machines which can be easily carried around. It has an in-built electric motor which rotates the drill at high speeds. It is used for the jobs which cannot be taken to the drilling machines. It is also used for drilling small holes on large job at any desired angles.

2.Sensitive Drilling Machine It has a base on which a cylindrical post is mounted vertically. The cylindrical post is called the column of the drilling machine. A table is attached to the column by means of a table clamp. The table supports the work piece and work holding devices. It can be moved along the column for proper positioning of the work piece. A spindle head and a drive mechanism are mounted at the top of the column. It has an electric motor which drives the spindle by means of a belt and cone pulley arrangement. Spindle speeds can be changed by shifting the belt from one pulley to another. The drill is held by a proper holding device such as a drilling chuck attached to the spindle. The drill is fed into the work piece placed on the table by manually rotating the drill feed handle. This can be used to drill holes from 1-25 mm

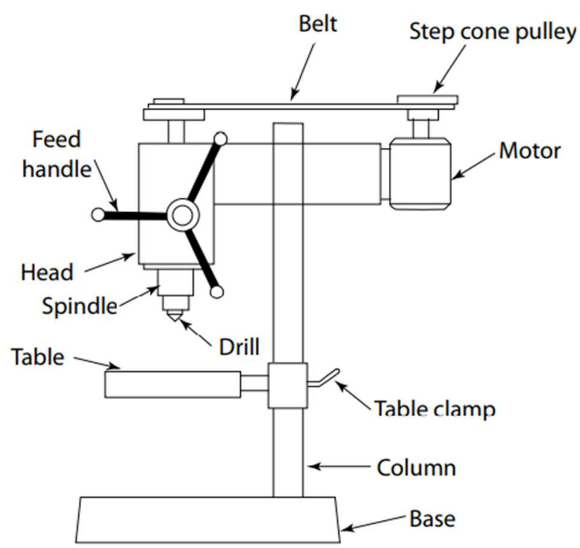


Fig.38

3. Pillar Drilling Machine or Upright Drilling Machine Upright drilling machines are similar to sensitive drilling machines except that these are used for heavier work and have provisions for the power feed mechanism. It has a base, a column, a table and a spindle head. The column may be round or box type. On the column, a table is mounted on vertical guide ways and can be raised using an elevating screw. The spindle head is mounted on the top of the column. It has a power feed mechanism with a wide range of spindle speeds. Upright drilling machine can drill holes up to 25 mm in diameter.

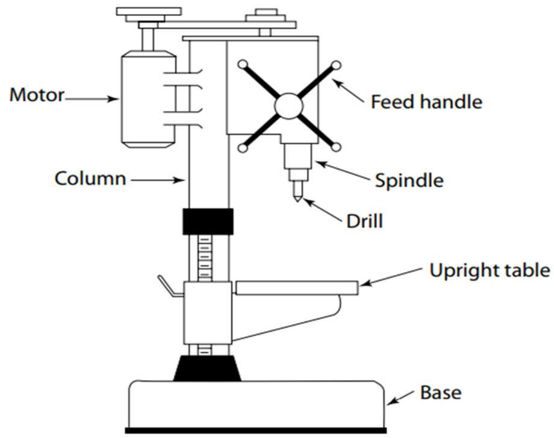


Fig.39

4. Radial Drilling Machine When holes are to be drilled at different locations on large work pieces which cannot be readily moved and clamped on a drilling machine, radial drilling machines are used. Radial drilling machines have a large, heavy, round and vertical column supported on a large base. The column supports a radial arm that can be raised or lowered by an elevating screw and also be swiveledb over the base. The Spindle head and the driving mechanism are mounted on the radial arm. It can be moved horizontally along the guideways in the radial arm so that the spindle can be properly positioned at any desired location on a large work piece.

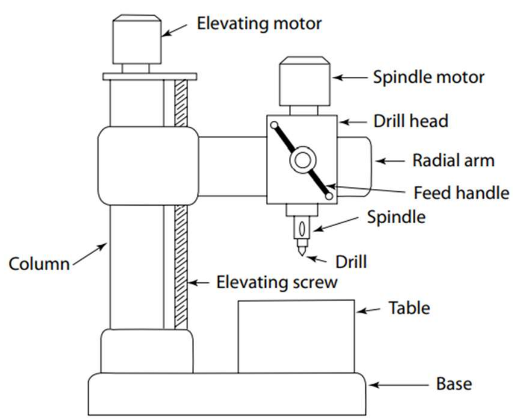


Fig.40

5. Gang Drilling Machine For a work piece which requires several related operations, such as drilling holes of different sizes, reaming, and boring a gang drilling machine can be used. A gang drilling machine has a number of independent columns and spindle heads mounted on a common base having a single common table. The spindles can be operated simultaneously and independently for different operations. Gang drilling machines are available with or without a power feed mechanism.

6. Multi Spindle Drilling Machine For a work piece which requires a number of parallel holes to be drilled, a multi-spindle machine can be used. Multi-spindle drilling machine has a

number of spindles driven by a single spindle head. Here, all the spindles are operated simultaneously and are used for drilling a number of holes on a work piece such as pipe flanges and pump housings.

Dial Gauge or Dial Indicator: Dial gauge is a mechanical device for sensing linear. The dial indicator measures the displacement of its plunger or on a circular dial by means of a rotating pointer. The dial indicator or the dial gauge is one of the simplest and the most widely used comparator. It is primarily used to compare workpieces against a master.

A dial gauge found its application: -

1. To check the flatness of a surface.
2. To check the roundness of a component.
3. For testing the machine tools.
4. To check the dimension of workpiece.

Advantages:

1. Accuracy can be as high as 0.01 mm.
2. Easy to read.
3. Quick and use if only comparison is required.

Limitations:

1. Easily damaged if mishandled.
2. Do not measure but will only indicate difference in size.
3. Must be rigidly supported in use.

Construction: Dial gauge consists of a body with a circular graduated dial, a contact point connected to a gear train, and an indicating hand (pointer) that directly indicates the linear displacement of plunger at the contact point. The plunger guide holds the plunger and provides the required length and rigidity for ease of measurement. The bezel clamp enables locking of the dial after setting the scale to zero. The scale of the dial indicator, usually referred to as dial, provides the required least count for measurement, which normally varies from 0.01 to 0.05mm.

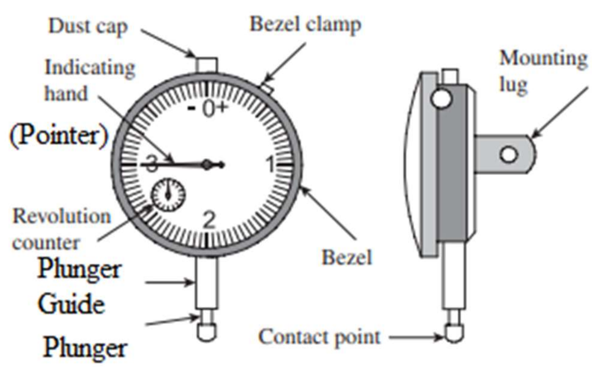


Fig.44

Working: To start with, the indicator is moved up and the standard is placed on the reference surface, while ensuring that the plunger of the indicator does not make contact with the standard. Next, the stand clamp is loosened and the plunger of the indicator is gently lowered onto the surface of the standard such that the plunger is under the required gauge pressure. Now, the indicator is held in position by tightening the stand clamp. The bezel clamp is loosened, the bezel is rotated, and the reading is set to zero. Once the zero setting is done, the standard is gently taken out by hand and the workpieces are gently inserted below the plunger, one by one. Now, the difference in height between the standard and the workpiece is read from the dial gauge scale A full revolution of the pointer about the scale corresponding to the 1mm travel of the plunger. Thus, a turn of the hand by one scale division represents the spindle travel of 0.01mm. Revolution counter to indicate the travel of the plunger through whole millimeter sometime incorporated in the gauge on the big dial.

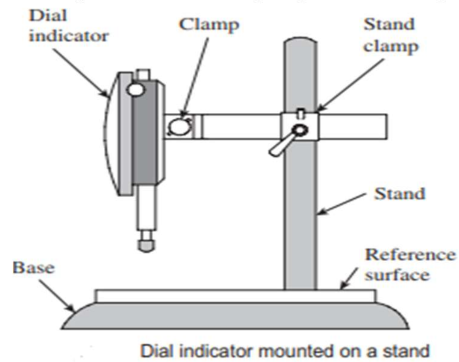


Fig.45

Mechanism of dial gauge: The plunger carries a rack, which meshes with a gear (marked gear A in the figure). A rack guide prevents the rotation of the plunger about its own axis. A small movement of the plunger causes the rack to turn gear A. A larger gear, B, mounted on the same spindle as gear A, rotates by the same amount and transfers motion to gear C. Attached to gear C is another gear, D, which meshes with gear E. Gear F is mounted on the same spindle as the indicator pointer.

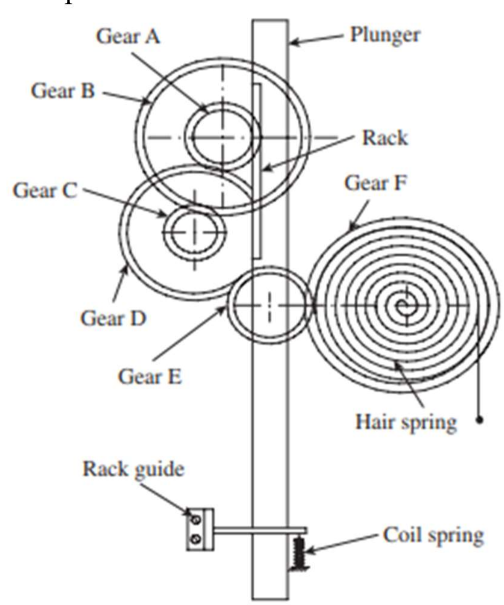


Fig.46

Slip Gauge: Slip gauges are blocks made of hardened alloy steel having a 30mm × 10mm cross section. These gauges are made in sets and consist of a number of hardened blocks made of high-grade steel. Measuring faces are finish to a high degree of accuracy, flatness, and surface finish. The height of a slip gauge is mentioned on one of the rectangular faces. Several slip gauges are combined together temporarily to provide the end standard of a specific length. They are used verifying and calibrating the measuring tool.

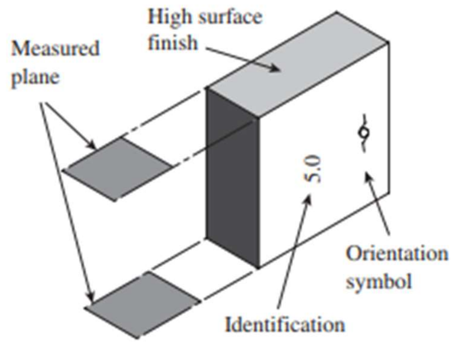


Fig.47

Slip gauges are designated into five grades, namely grade 2, grade 1, grade 0, grade 00, and inspection grade.

Grade 2 This is the workshop-grade slip gauge. Typical uses include setting up machine tools, milling cutters, etc., on the shop floor.

Grade 1 This grade is used for tool room applications for setting up sine bars, dial indicators, calibration of vernier, micrometer instruments, and so on.

Grade 0 This is an inspection-grade slip gauge. Limited people will have access to this slip gauge and extreme care is taken to guard it against rough usage.

Grade 00 This set is kept in the standards room and is used for inspection/calibration of high precision only. It is also used to check the accuracy of the workshop and grade 1 slip gauges.

Calibration grade This is a special grade, with the actual sizes of slip gauges stated on a special chart supplied with the set of slip gauges. This chart gives the exact dimension of the slip gauge, unlike the previous grades, which are presumed to have been manufactured to a set tolerance

While building slip gauges to the required height, the surfaces of slip gauges are pressed. into contact by imparting a small twisting motion while maintaining the contact pressure. The slip gauges are held together due to molecular adhesion between a liquid film and the mating surfaces. This phenomenon is known as 'wringing'
Technique of Wringing Slip Gauges:

The following are the preferred steps in the wringing of slip gauges:
1. Clean slip gauge surfaces with a fine hairbrush (camel hairbrushes are often recommended) and a dry pad.
2. Overlap gauging surfaces by about one-fourth of their length, as shown in Fig.(a).

3. Slide one block perpendicularly across the other by applying moderate pressure. The two blocks should now form the shape as shown in Fig. (b).
4. Now, gently rotate one of the blocks until it is in line with the other block Fig. (c).

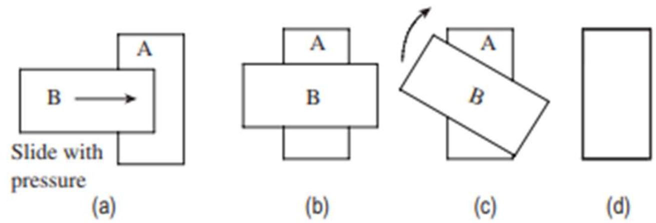


Fig.48

Sine Bar: A sine bar is used to measure angles based on the sine principle. The sine principle uses the ratio of the length of two sides of a right triangle in deriving a given angle.

$$Sin\ (\theta) = \frac{Perpendicular}{Hypotenuse}$$

Construction: The sine bar has a gauge body made of a rigid material such as steel. Its upper surface forms the hypotenuse of a triangle formed by a steel bar terminating in a cylinder (rollers) near each end. The rollers are of equal diameter, and the axes of these rollers are parallels to each other. The length of the sine bar equals the distance between the centres of the two rollers. The top of the steel bar parallels the line through the centres of the two rollers. Relief holes are sometimes provided to reduce the weight of the sine bar. This by itself is not a complete measuring instrument.

When one of the cylinders, called a roller, is resting on a flat surface, the bar can be set at any desired angle by simply raising the second cylinder. The required angle is obtained when the difference in height between the two rollers is equal to the sine of the angle multiplied by the distance between the centres of the rollers.

The sine of angle θ formed between the upper surface of a sine bar and the surface plate (datum) is given by: $Sin\ (\theta)\ = \frac{H}{L}$, where H is the height difference between the two rollers and L is the distance between the centres of the rollers.

Therefore, $h\ =\ L\,Sin\ (\theta)$

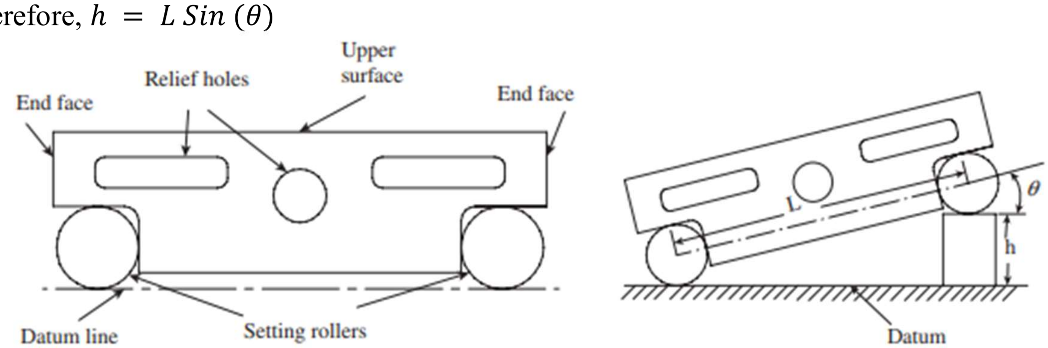


Fig.49

Uses of Sine Bar:

1. To calculate unknown angles of a small component with Sine Bar
2. To calculate the angle of a large component
3. To calculate the angle of taper plug gauge.

Unknown Angles with Sine Bar: Firstly, the component whose angle is to be measured, is mounted on sine bar. Then the one side of sine bar is raised by mean of slip gauge until the work surface is parallel to the datum surface.

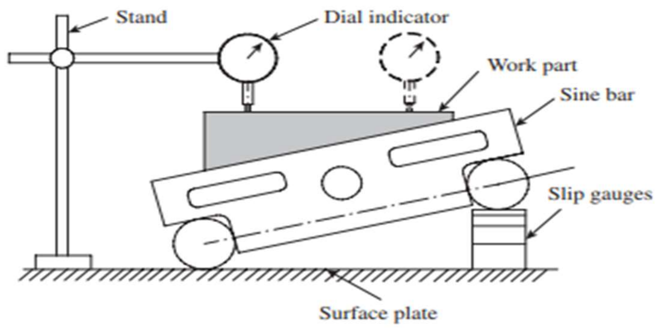


Fig.50

The sine of angle θ formed between the upper surface of a sine bar and the surface plate datum (**surface** plate) is given by: $Sin\ (\theta)\ =\frac{H}{L}$, where H is the height difference between the two rollers and L is the distance between the centres of the rollers.

To calculate the angle of a large component:

In the case of a large component, the sine bar is placed above the component because the component cannot be placed above the sine bar. When the sine bar is placed on a larger component, the lower surface of the larger component is parallel to the datum surfaces. The top surface of the component is bent, and its angle is to be measured.

The heights of the two rollers are measured using a Vernier height gauge, and the height of the two rollers is written as H_1 and H_2.

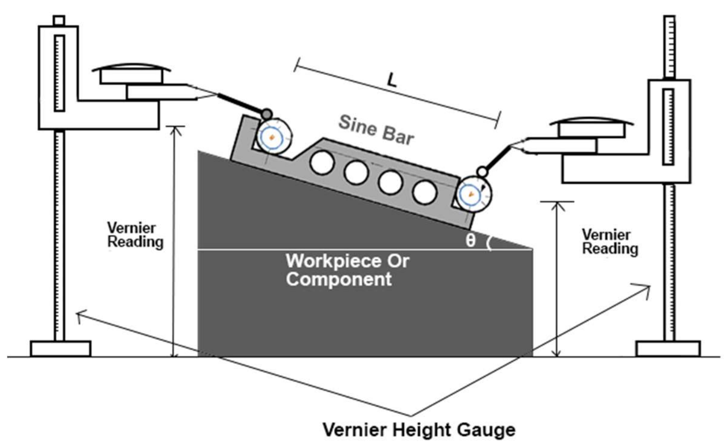


Fig.51

$$\text{Sin}(\theta) = \frac{H1 - H2}{L}$$

were,

- θ = angle of the component to be measured.
- H_1 = height of the upper roller.
- H_2 = height of a lower roller.
- L = length of the sine bar.

Setting Sine Bars to Desired Angles: The centre distance between the rollers (L) which is known will be the hypotenuse and the required perpendicular or height of slip gauge (h) can be determined using relationship. By building slip gauges to height h and placing the sine bar on a surface plate with one roller on top of the slip gauges, the upper surface can be set to a desired angle with respect to the surface plate.

$$h = L \text{ Sin}(\theta)$$

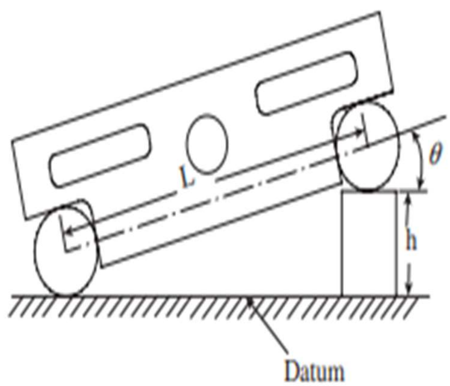


Fig.52

Precaution taken while using Sine bar:

1. The rollers must be of the same diameter.
2. The distance between rollers centres must be absolutely correct.
3. The centre line of roller centres must be absolutely parallel with the bottom and top edge of the bar.
4. The measuring faces of all the slip gauges should be cleaned and undamaged before wringing together it. If difficulty is experienced then the measuring faces should be closely examine for this small scratches.
5. In slip gauge pile the large size gauge is placed at the bottom and the small gauge at the top.

Combination Set: A combination set has three devices built into it: a combination square comprising a square head and a steel rule, a protractor head, and a centre head.The combination set is a useful extension of steel rule. This non-precision instrument is rarely used in any kind of production inspection. However, it is frequently used in tool rooms for tool and die making, pattern making, and fabrication of prototypes.

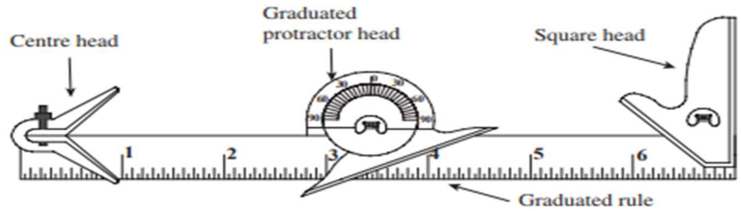
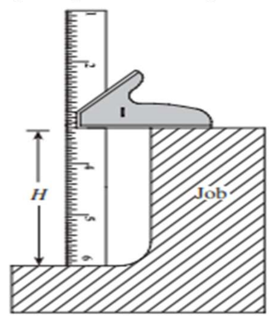
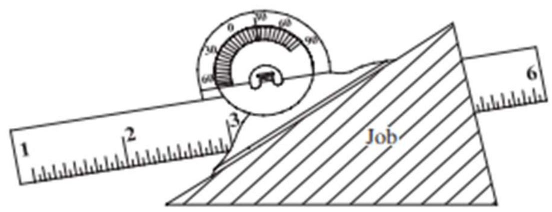


Fig. 4.14 Combination set

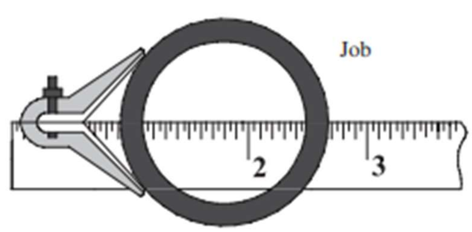
Square Head: The square head along with the graduated rule on the combination set provides an easy way of measuring heights and depths.



Protractor Head: This head comprises angular scale graduated in degrees The blade of the protractor is held firmly against the job and the angle can be directly read from the scale..



Centre Head: The centre head attachment is used along with the steel rule to locate the centre of a circular job. It can be seen that one edge of the steel rule bisects the V-angle of the centre head. Therefore, it lies on the centre line of any circular job held against the centre head. The diameter of the job can be directly read on the graduated scale, which is useful for marking the centre of the job by using a scriber

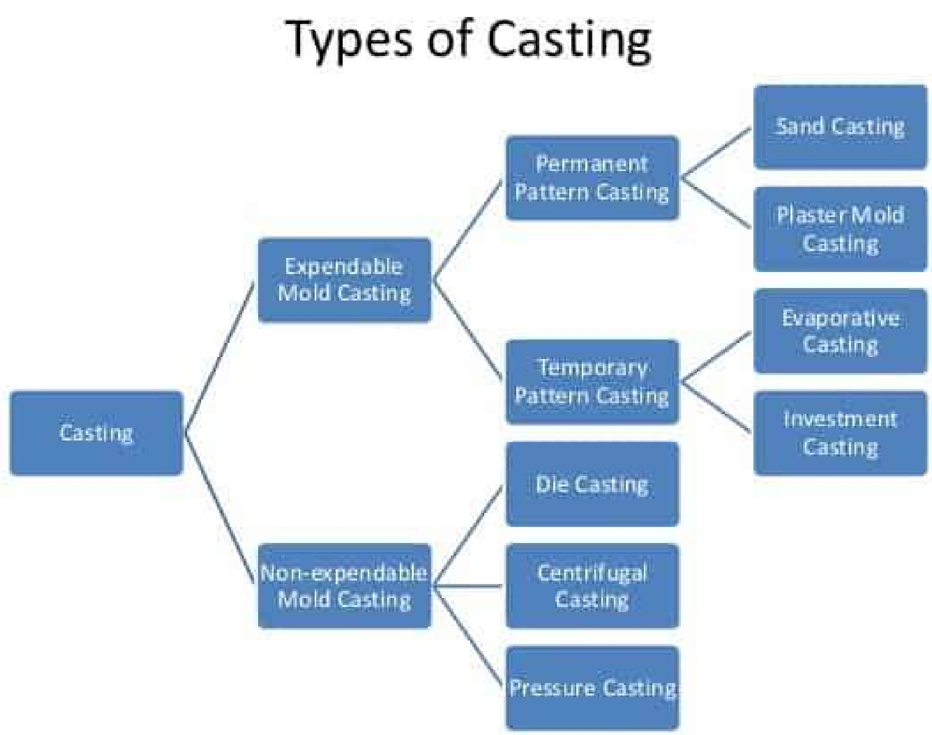


Casting

Casting process: Casting means pouring molten metal into a mold with a cavity of the shape to be made, and allowing it to solidify. When molten metal solidified, the desired metal object is taken out from the mold either by breaking the mold or taking the mold apart. The solidified object is called the casting.

Advantages of casting process:
1. The cost involved in the casting process is very low compared to the other manufacturing processes.
2. Very heavy and bulky parts which are difficult to fabricate can be manufactured by the casting process.
3. Casting can be employed for the mass production as well as for batch production.
4. A product can be cast as a single piece and hence the metal joining process is eliminated.
5. It is possible to cast practically any material that is ferrous or non-ferrous.

Disadvantages:
1. For many applications, the dimensional accuracy and surface finish may not be adequate.
2. Sand casting process is labour intensive
3. A complicated sequence of operations may be required for metal casting.
4. With some material it is often difficult to remove defects arising out due to moisture present in sand casting.



Process of casting:

1. Making pattern and mould cavity
2. Material is first liquefied by properly heating it in a suitable furnace.
3. Liquid is poured into a prepared mould cavity
4. Allowed to solidify liquid
5. product is taken out of the mould cavity, trimmed and made to shape

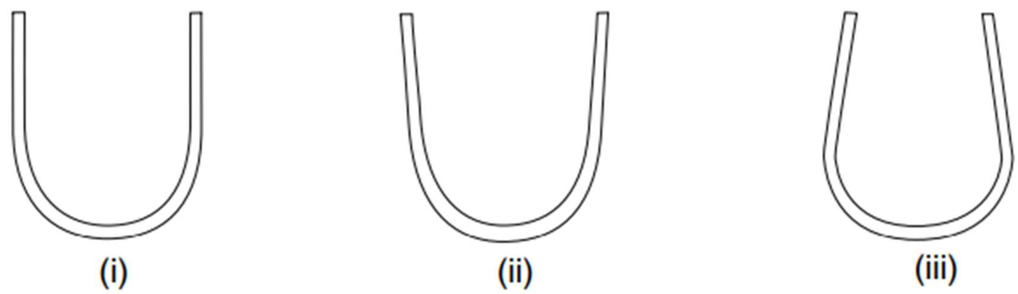
Pattern: It is the replica of the final object to be made. The mold cavity is made with the help of pattern

Pattern Allowances: The extra dimensions or extra materials provided for the pattern are known as allowances. The following allowances are provided for pattern making:
1. Shrinkage allowance.
2. Finishing allowance or machining allowance.
3. Draft allowance or taper allowance.
4. Distortion allowance or camber allowance.
5. Shaking allowance or rapping allowance

Shrinkage Allowance: Shrinkage allowance is the allowance given on the pattern size for avoiding any change in the dimensions of the casting because of the shrinkage of the metal during solidification.
Finishing Allowance or Machining Allowance: The finishing or machining allowance is the allowance given on size of the pattern for finishing or machining the rough surface of the casting
Draft Allowance or Taper Allowance: Draft allowance is the taper allowed on vertical faces of a pattern for easy removal of the pattern without damaging the mould cavity surface.

Fig. 7.1(a) *Pattern having no Draft Allowance* **Fig. 7.1(b)** *Pattern having Draft Allowance*

Distortion or Camber Allowance: Due to the internal stresses developed during cooling, the casting may be distorted. For example, if the casting has a U-shape, it will tend to cool faster at the ends, giving rise to internal stresses in the bent portion. As a result, on cooling, the legs of the casting would deflect outwards as shown below in Fig.



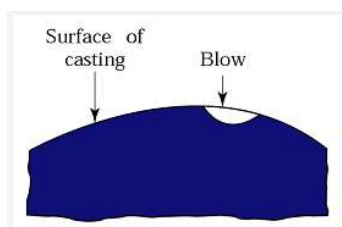
(a) U-shaped Casting

(i) Required shape of casting
(ii) Casting produced with distortion
(iii) Pattern provided with Camber allowance

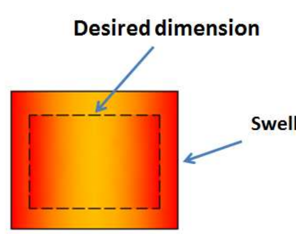
Shake Allowance or Rapping Allowance: For the easy withdrawal of the pattern from the moulding sand, the pattern is slightly rapped or shaked around the vertical faces which leads to a slight enlargement in the mould cavity. So, the final casting will be slightly over sized. The shake allowance is given to overcome this problem, by making the pattern slightly smaller in size.

Casting Defects: Casting defects are unwanted feature or irregularities in the casting which make it of poor quality. These defects occur due to several reasons such as the poor design of casting, excess moisture in the mold, improper ramming of molding sand, misalignment of cope and drag, etc.

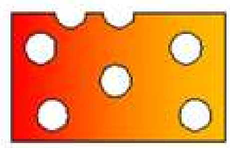
1. Blow: Blow is a small, round holes appearing at the surface of the casting covered with a thin layer of metal.



2. Swell: Swell is an enlargement of the mold cavity due to metal pressure. It caused due to defective ramming of the mold. To avoid swells, the sand should be rammed properly and evenly.



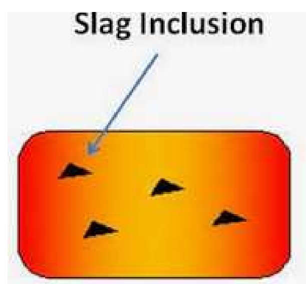
3. Blowholes: Blowholes are smooth, round holes appearing in the form of a cluster of a large number of small holes below the surface of a casting. Possible causes are excess moisture in the molding sand, moisture on chills, chaplets, and insufficiently baked and improperly vented core.



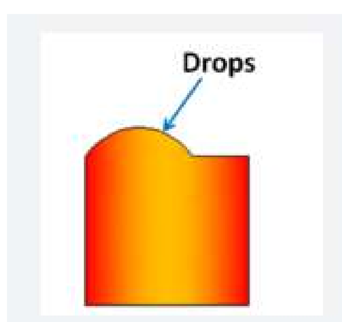
Blowholes

4. Mis-run: A mis-run is the incomplete filling of the mold that results when the metal lacks fluidity or temperature.

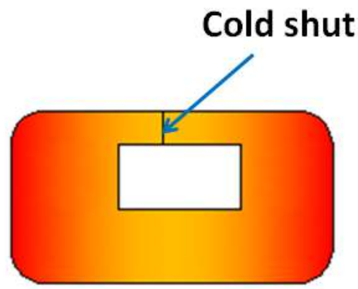
5. Inclusions: Inclusions is mixing of foreign particles such as sand and slag in the casting.



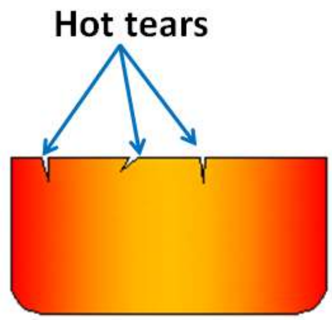
6. Drop: When the upper surface of the mold cracks and pieces of sand fall into the molten metal, this defect occurs. This is caused by low strength and soft ramming of sand, insufficient fluxing of molten metal and insufficient reinforcement of sand projections in the cope.



7. Cold shut: It is a casting defect when two metal streams freezes before meeting and fusing properly.



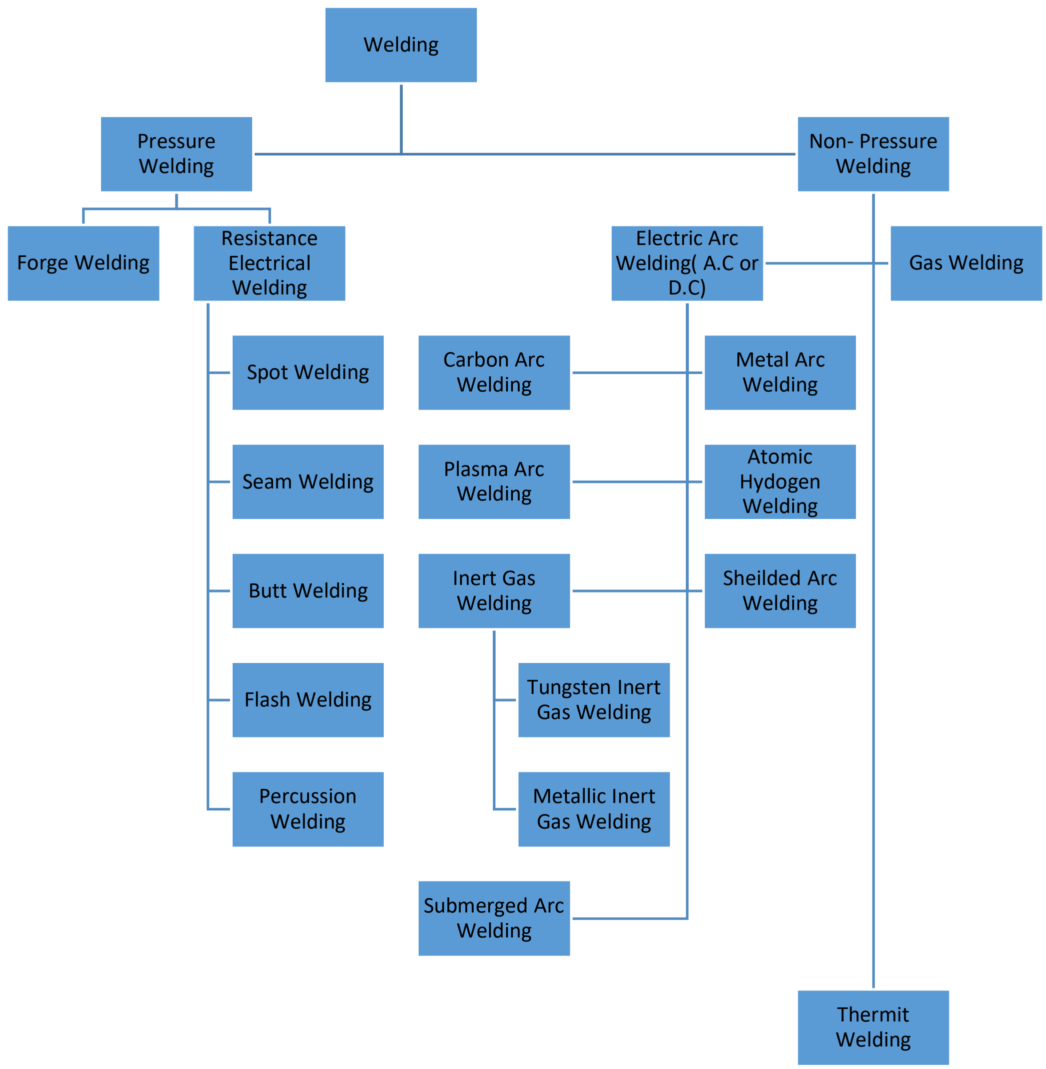
8. Hot Tears: They are internal and external cracks having a ragged edge occurring immediately after the metal has solidified.



Welding

Welding: Welding is a metal joining process in which the joining of metals is done by the application of heat with or without the application of pressure.
Applications: Fabrication of automobile, aircrafts, ships, electronic equipment's, home appliances etc.
.

Classification of welding process:



Welding Defects:

1. Cracks: Cracks may be formed due to various causes including unequal physical properties of the parent and weld metals, high stress conditions and faulty welding.

a. Hot cracks: The weld metal cracks are called hot cracks because these appear as a result of stress and lack of ductility of the deposited metal at the high temperature.

b. Cold cracks: These cracks are formed near the weld area and are due to excessive cooling rates and the absorbed hydrogen.

2. Inclusions: Inclusion are the slag or non-metallic particles and are derived from the environments around the weld metal. Inclusions are nonmetallic particles trapped in the weld-metal or at the weld interface.

3. Porosity: The formation of blow holes, gas pockets or roughness on the surface of the weld. This is due to the presence of gases in the metal.

4. Fish eyes: Fish eyes usually appear on the fractured surfaces of the welded sections in the form of white areas, circular in shape and varying in size. These are attributed to the presence of hydrogen in welds and the existence of stress conditions.

5. Incomplete Penetration: The Lack of thorough and complete union between the deposited and Parent metal. This is due to faulty welding conditions.